Boston University

OpenBU | **http://open.bu.edu**

Boston University Theses & Dissertations | Boston University Theses & Dissertations

2019

Whole body survey of arterial variants in anatomical donors

https://hdl.handle.net/2144/36591

Downloaded from DSpace Repository, DSpace Institution's institutional repository

BOSTON UNIVERSITY

SCHOOL OF MEDICINE

Thesis

WHOLE BODY SURVEY OF ARTERIAL VARIANTS IN ANATOMICAL DONORS

by

SOPHIE M. KONTUR

B.S., Tulane University, 2015

Submitted in partial fulfillment of the

requirements for the degree of

Master of Science

2019

© 2019 by
SOPHIE M. KONTUR
All rights reserved

Approved by

First Reader ____

Elizabeth R. Whitney, Ph.D.
Assistant Professor of Anatomy and Neurobiology

Second Reader ____

Maryann MacNeil, M.A.
Assistant Professor of Anatomy and Neurobiology

ACKNOWLEDGMENTS

I would like to thank the many people who helped me along my journey of completing my thesis:

To Dr. Elizabeth Whitney, Ph.D. who never gave up on me during this process. I will always appreciate the patience and kindness she showed me throughout this journey.

To Maryann MacNeil, M.A. who made embryology less intimidating. Her guidance in the development of my embryology section is much appreciated and helped me better understand the human body.

To Robert Bouchie who supported me in the anatomy lab and made sure that I always had everything I needed. He has always been there to encourage me and look out for me and his presence in the lab was always enjoyable.

To Lee Farris who ensured the logistics of my thesis were always in check. I would not have been able to my research without her.

And most importantly, to all the body donors. Without their generous gift of donation none of this would have been possible. They have given me the most precious gift of knowledge and for that I am truly thankful.

WHOLE BODY SURVEY OF ARTERIAL VARIANTS

IN ANATOMICAL DONORS

SOPHIE M. KONTUR

ABSTRACT

Arterial variants, defined as atypical presentations of anatomy including aberrant origin, course, and branching pattern, are important to be aware of because of their effects in the clinical setting as well as their possible link to pathology. Much research has already been done focusing on specific arterial variants in a specific region in the body. However, more research is needed to determine if there is a relationship between arterial variants in different regions of the body. The purpose of this study is to examine the whole-body arterial system of body donors in order to assess if there is a relationship between the presence of arterial variants in one region of the body to the other. The entire arterial system of twenty-five formalin fixed body donors was examined for the presence of arterial variants. The data was separated into two main categories, central variants (e.g. arch of the aorta, unpaired abdominal aortic branches) and peripheral variants (e.g. upper and lower extremities). The relationship between the central and peripheral variants was determined using quantitative observation, specifically, by examining the percent frequency of cases where arterial variants were co-occurring. Of the body donors examined, all were found to have at least one arterial variant, with an average of 8.7 variants per body. Arterial variants were most commonly found in the foregut with prevalence of 80%, the midgut (68%), left subclavian (60%), right upper extremity (52%), and the left upper extremity (48%). Of the central arterial variants, a percent

frequency of 20% was found for the arch of the aorta, 20% for the coronary artery, 12% for the hindgut, 28% for the right renal, and 28% for the left renal. For the peripheral variants, the percent frequencies were as follows: brain variants were 4%, right carotid 8%, left carotid 0%, right subclavian 28%, left upper extremity 40%, right suprarenal 24%, left suprarenal 12%, right phrenic 24%, left phrenic 12%, gonadal 4%, right iliac 40%, left iliac 32%, and right lower extremity 40%. Examination of the relationship between central variants and peripheral variants reveals that the most common arterial variants to occur in tandem in the sample were those of the variant foregut with variants of the left subclavian artery (52% of cases), the upper and lower extremities (36-44% and 40-44% of cases, respectively), and the right iliac artery (36% of cases). The most common central arterial variants to co-occur were the variants of the foregut and midgut observed in 64% of cases. The frequency of cases involving normal central anatomy and variant peripheral anatomy indicates that vascular variants in the periphery are likely unrelated to variants in the central body cavities. However, it does seem like there are "hot spots" for arterial variants to occur, including the foregut, midgut left subclavian artery, right and left upper extremities, the right iliac artery, and the right and left lower extremities. Although there was no discernable pattern found between vascular variants in the present study, that does not preclude the possibility that there is a significant relationship between certain vascular variants. Either way, the high prevalence of cases with multiple arterial variations suggests that they may be more likely to occur than previously thought.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AA .... Aortic arch

ABA.. Abdominal aorta

Acc.. Accessory

AccBr.. Accessory branch

AccDA.. Accessory duodenal artery

AccLHA.. Accessory left hepatic artery

AccRA .... Accessory renal artery

AccRHA .... Accessory right hepatic artery

ACE .... Angiotensin Cleaving Enzyme

ACHA.. Anterior circumflex humeral artery

AxA .... Axillary artery

BrA .... Brachial artery

BRCt .... Brachiocephalic trunk

C .... Cervical

CA .... Coronary artery

CCA .... Common carotid artery

CHA.. Common hepatic artery

CirSA .... Circumflex scapular artery

COD.. Cause of death

COPD.. Chronic obstructive pulmonary disease

CrA .... Coronary artery

CT .... Computed tomography

CTA .... Computed tomography angiography

CTr .... Celiac trunk

CYSA .... Cystic artery

DBrA .... Deep brachial artery

DFA .... Deep femoral artery

DiagB .... Diagonal branch

Dom .... Dominant

DPA .... Dorsal pancreatic artery

DSA .... Digital subtraction angiography

DScA .... Dorsal scapular artery

E .... Embryonic day

EsoA .... Esophageal artery

ExIA .... External iliac artery

F .... Female

FA .... Femoral artery

FacA .... Facial artery

GDA .... Gastroduodenal artery

HA .... Hepatic artery

IfPDA .... Inferior pancreaticoduodenal artery

IGA .... Inferior gluteal artery

IlCA .... Ileocolic artery

IMA .... Inferior mesenteric artery

IPA..Internal pudendal artery

IPHA..Inferior phrenic artery

ITA ....Internal thoracic artery

IThA .... Inferior thyroid artery

L .... Left

LAD .... Left anterior descending artery

LCA ....Left colic artery

LCFA .... Lateral circumflex femoral artery

LCxA ....Left circumflex artery

LE ....Lower extremity

LGA ....Left gastric artery

LHA .... Left hepatic artery

LMA ....Left marginal artery

LngA ....Lingual artery

M ....Male

MCA .... Middle colic artery

MCFA ....Medial circumflex humeral artery

MedSA .... Median sacral artery

Misc ....Miscellaneous

mm..millimeter

MPV .... Main portal vein

MSRA .... Middle suprarenal artery

ObA .... Obturator artery

OVA .... Ovarian artery

PA .... Boston University

PCHA .... International Standards Organization

PD .... Royal Canadian Mounted Police

PHA .... Boston University

PIVA .... Posterior interventricular artery

PSPDA .... Posterior superior pancreaticoduodenal artery

R .... Right

RA .... Renal artery

RAAS .... Renin-Angiotensin-Aldosterone System

RadA .... Radial artery

RCA .... Right colic artery

Rep .... Replaced

RGA .... Right gastric artery

RHA .... Right hepatic artery

SA .... Stomach artery

SCA .... Subclavian artery

SGA .... Superior gluteal artery

SMA .... Superior mesenteric artery

SMV .... Superior mesenteric vein

SPA .... Splenic artery

SubA .... Subscapular artery

SUCA .... Superior ulnar collateral artery

SupA .... Suprascapular artery

TCTr .... Thyrocervical trunk

TrCA .... Transverse cervical artery

UE .... Upper extremity

UlnA .... Ulnar artery

VA .... Vertebral artery

INTRODUCTION

The earliest documented knowledge of blood vessels is found in the Edwin Smith Papyrus dating to the ancient Egyptian empire in 1700 BC, in which the heart with the great vessels emanating from it was depicted (Loukas et al., 2011). Knowledge of the arterial system was advanced by the Ebers Papyrus, dating to 1500 BC, which included the number of vessels reaching the nostrils, extremities, testicles, liver, lungs, and bladder (Loukas et al., 2011). In accordance with the beliefs at the time, these papyruses stated that vessels carried elements of the organs they supplied such as mucus, air, or semen, rather than blood (Loukas et al., 2011). It was not until the second century, AD, that the true nature of these vessels was described by Galen of Pergamon – a prominent physician and anatomist of his time – who identified these vessels as arteries carrying blood (van Gulik and Schoots, 2005). Knowledge of the circulatory system increased throughout the 16th and 17th centuries as various anatomists discovered the flow of blood to the lungs, the separation of the right and left ventricles, and the function of valves in veins (Aird, 2011). However, it was William Harvey who, in 1628, laid the groundwork for the modern understanding of the cardiovascular system. In his book, *On the Motion of the Heart and Blood in Animals*, Harvey explained the direction of blood circulation and the functional importance of arteries and veins in the movement of blood from the lungs to the peripheral tissues and back to the heart (Aird, 2011). From there, numerous advances in the understanding of the circulatory system were made as technological advances have allowed anatomists to understand the histological, embryological, and microscopic elements of blood vessels. It is now understood that blood flow is dynamically regulated and that the structure and function of the vasculature is different for each organ (Aird, 2011).

The advancement of knowledge about the cardiovascular system in the 16th and 17th centuries was due, in large part, to an increase in public human body dissections (Aird, 2011). Andreas Vesalius, often referred to as the founder of modern human anatomy, changed the perspective on how public dissections should be done, emphasizing that anatomy should be learned using mindful dissection techniques of the human body, as opposed to animal corpses (Shotwell, 2016). Vesalius is well known for publishing, *On the Fabric of the Human Body*, an anatomical text that had a stronger focus on illustrations than text, but which also contained instructions for anatomical dissections (Harcourt, 1987). Notably, in the chapter entitled, “How to Undertake a Dissection,” Vesalius wrote that the best cadaver to use for a public dissection was an average specimen whereas any specimen would do for his own private dissections and, in fact, a variety of bodies was preferred, so the differences between bodies could be documented (Shotwell, 2016). The idea of differences between the bodies is one of the first times anatomical variants was brought up in classic anatomical texts. In the original version of his text, Vesalius wrote that when he encountered anything anomalous in his public dissections, he passed over it so as not to confuse the viewing audience. This was revised in later versions of his text, when Vesalius realized the importance of teaching and documenting anatomical variants (Shotwell, 2016). In the centuries following Vesalius’s work, more care was taken in documenting anatomical variants, especially variants found in the arterial tree because of their relevance in surgical procedures.

Albrecht von Haller, an 18th century physician and anatomist is responsible for the first known documentation of arterial variants in the upper limb and in the celiac trunk which he included in his book, *Anatomical Description of the Arteries of the Human Body* (Noussios et al., 2017, Rodríguez-Niedenführ et al., 2003). Further work on arterial variants was continued in the 19th century by Richard Quain, an anatomist and surgeon, who explored the role of variation in the arterial tree through the dissection of almost 1,000 subjects (Dungan and Heiserman, 1996). Thus, knowledge of the cardiovascular system and arterial variants has come a long way since the Egyptians and continues in the modern day as the study of anatomy has flourished and become recognized as its own branch of science.

The location and branching pattern of arteries depicted in textbooks and anatomical drawings is the arrangement seen in most cases and is hence termed "normal" anatomy. However, variation in arterial patterns has become a widely accepted occurrence with the advent of computed tomography (CT) imaging (Özbülbül, 2011). More arterial variants are being detected, even in asymptomatic patients, when CT imaging is used for preoperative mapping and vascular planning of procedures (Özbülbül, 2011). With an increase in detection, there is also an increase in documentation as seen through the inclusion of common arterial variants in anatomical atlases and websites devoted to documenting vascular variants that may be encountered during surgery. The variations documented include atypical presentations of anatomy such as aberrant origin, course, and branching pattern of the arteries.

Understanding normal biological variations is important in medicine because it serves as a comparison point between normal and abnormal states (Ellis, 2001). Commonly, however, arterial variations are considered benign and only found as incidental findings during patient imaging (Green 2015, Lale et al. 2014). This has led to a belief that arterial variants have little physiological consequence but increasing amounts of research about arterial variants indicate that this may not be the case (Malone et al., 2012). For example, variation of the great vessels off the aortic arch may alter hemodynamics, increasing the stress on the vessel walls and predisposing patients to the formation of aortic dilation (Malone et al., 2012). While the mechanism between variant arch morphology and the formation of aortic dilation is not fully illuminated, it shows that arterial variations may have more of a role in the development of disorders than previously thought. The presence of the variation does not mean causation of the pathology, but it remains important to consider that arterial variations can be considered risk factors for certain diseases. These ideas are necessary for clinicians as they see patients and diagnose how underlying variations may be related to pathological states.

It is clinically important to recognize arterial variants not only for their contribution to pathology, but also for their role in the planning and executing medical procedures. Without a sound knowledge of variant morphologies, aberrant anatomical features could be misinterpreted as pathologies or could be overlooked entirely. As the use of CT angiography (CTA) has increased in preoperative planning, so too has the pressure placed on radiologists to be able to correctly identify normal and aberrant anatomy (Arévalo Pérez et al., 2013). Preoperative knowledge of arterial variants is crucial to avoid making life threatening mistakes during procedures. The consequences of damaging or cutting an aberrant artery during surgery range from massive uncontrolled bleeding, ischemia of organs, loss of viability of transplant organs, fluid leaks into the abdominal cavity, and even death (Baranski et al., 2016, Darmanis et al., 2007, Huang et al., 2013, Rammohan et al., 2014). The best way to prevent injury to an aberrant artery is recognition and awareness of the normal and variant anatomies possible.

With the increased use of CTA, there has also been an increase in anatomical studies using that technology to find and classify various arterial variants. It is now possible to find many studies examining the prevalence rate of specific variants in different populations. These studies have been very important in raising awareness of variant morphologies possible and contribute greatly to the current understanding of the arterial variants. However, many of these studies focus on arterial variants in one specific region of the body. It is important to have that centralized focus, but regional studies do not capture the connections occurring between different regions of the body. Since the circulatory system is a closed loop, it is reasonable to believe that arterial variants in one part of the body could affect hemodynamics in another. Thus, a whole-body arterial survey assessing vascular variation is necessary to understand the frequency of arterial anomalies throughout the whole body. Using the entire body as the study system allows relationships between different variants to be illuminated and expands arterial studies from one site to a whole-body perspective.

Embryology of the Vascular System

The most common types of variants taught to future clinicians are arterial variants because of their relevance in surgical procedures (Raikos and Dade Smith, 2015).

However, in order to understand variant anatomy, one must understand the embryology and morphology of normal anatomy first.

Embryology of the heart, aortic arch, and coronary arteries

As the human embryo grows, its nutritional needs can no longer be met with diffusion, so a functional circulatory system becomes necessary to deliver oxygen and nutrients (Moore et al., 2016). It follows, that the heart is the first functional organ in the embryo and the circulatory system is the first functioning body system (Udan et al., 2014). The development of the vascular system begins with the development of the heart during the third week of gestation (Moore et al., 2016). The heart starts to form with the movement of cardiac progenitor cells through the primitive streak toward the cranial end of the embryonic disc (Moore et al., 2016). Here, they are positioned rostral to the oropharyngeal membrane and form a crescent shape, called the cardiac crescent or the primary heart field. The progenitor cells in the cardiac crescent are specified to form the left and right sides of the heart, the atria, left ventricle and part of the right ventricle (Moore et al., 2016). The other part of the right ventricle and the outflow track will be formed by the secondary heart field discussed later. The progenitor cells in the cardiac crescent induce hemangioblasts to congregate, forming blood islands that give rise to paired endocardial heart tubes (Moore et al., 2016). As the embryo continues to grow, body folding occurs, causing the cardiac crescent to swing ventrally and caudally, so that it becomes situated caudal to the oropharyngeal membrane. During this movement, the endocardial heart tubes are moved towards each other, into the midline of the body where the fuse forming the primordial heart tube (Moore et al., 2016).

The primordial heart tube acts as a passage for blood as it receives venous blood at the caudal pole and pumps blood to the first aortic arch through the outflow track at the cranial pole of the tube (Moore et al., 2016). The outflow track is populated by cells from the secondary heart field which become incorporated into the primary heart field, creating the conus cordis and truncus arteriosus. As the primordial heart tube grows and elongates a series of dilations becomes apparent along the length of the tube (Moore et al., 2016). The cranial dilations include the bulbus cordis – of which the conus cordis is a part of – and the truncus arteriosus. The caudal dilations include the primitive ventricle and the primitive atrium – separated by a single atrioventricular canal - and the sinus venosus (Moore et al., 2016). These dilations will give rise to the adult structures of the heart. Growth of the primitive ventricle and bulbus cordis causes the heart tube to bend upon itself and to the right, marking the beginning of a process known as cardiac looping (Moore et al., 2016). Once cardiac looping is completed the heart is in the correct anatomical position seen in the adult form with the caudal inflow track positioned dorsal to the outflow track and outflow track located towards the midline (Moore et al., 2016).

With the positioning of the inflow and outflow tracks in correct anatomical position, the rest of the cardiovascular system begins to develop. Originally, there are two primitive aortae with dorsal and ventral segments. The ventral aortae fuse to form the aortic sac and the dorsal aortae fuse to form the descending aorta (Moore et al., 2016). The outflow track, consisting of the truncus arteriosus and the bulbus cordis, connects to the aortic sac which gives off six, paired aortic arches (Moore et al., 2016). The truncus arteriosus becomes split by the aorticopulmonary septum, dividing the outflow channel of the heart into the proximal ascending aorta and the pulmonary trunk (Kloesel et al., 2016). The aorticopulmonary septum also causes the aortic sac to reposition allowing it to give rise to the brachiocephalic trunk and contribute to the proximal ascending aorta (Kloesel et al., 2016). The six, paired aortic arches that come off the aortic sac become modified and rearrange themselves, forming the great vessels, the early continuations of the great vessels, and the main vessels of the head and neck (Kau et al., 2007). The first aortic arch almost completely disappears but leaves a small portion that contributes the maxillary arteries. The second arch also almost disappears, leaving only a small portion that gives rise to the hyoid and stapedial arteries. The third aortic arch becomes very large and forms the right and left common carotid arteries, the first portion of the internal carotid arteries, and the external carotid arteries (Kau et al., 2007). The left arch of the fourth pair forms the arch of the aorta and the left subclavian artery whereas the right arch forms the proximal segment of the right subclavian artery. The fifth aortic arch disappears, leaving no remnants behind (Kau et al., 2007). The sixth arch, also known as the pulmonary arch gives rise to the pulmonary arteries. The proximal part of the right arch of the sixth pair, gives rise to the right pulmonary artery while the distal part regresses (Kau et al., 2007). On the left, the proximal part of the sixth arch gives rise to the left pulmonary artery and the distal part gives rise to the ductus arteriosus, a fetal vessel that shunts blood from the pulmonary trunk to the proximal descending aorta, bypassing the lungs that are not involved at gas exchange. The changes in the aortic sac and the six paired aortic arches represents the development of the main branches off the heart (Kau et al., 2007).

The blood supply to the heart via, the coronary arteries, develop separately from the great vessels (Bogers et al., 1984). During the third week of development, as the primitive heart tube is forming there is no need for coronary circulation because the blood flowing through the lumen of the heart tube is enough to nourish the heart tissue (Loukas et al., 2009). However, as the heart walls increase in thickness, diffusion is no longer sufficient to supply the heart with oxygen and nutrients; the heart needs its own dedicated supply of blood (Lluri and Aboulhosn, 2014). Previously, the coronary arteries were thought to develop via angiogenesis, the generation of arteries, capillaries, etc. off pre-existing vessels (Bernanke and Velkey, 2002). Specifically, it was thought that the coronary arteries were outgrowths of the aortic wall located at the aortic sinus (Bernanke and Velkey, 2002). However, more recent research suggests that the coronary arteries develop from a capillary plexus in the subepicardial spaces as opposed to a budding process off the aortic wall (Bernanke and Velkey, 2002). Evidence for this theory emerged as primitive vessels to the aorta were observed prior to the emergence of the openings in the aortic wall for the coronary arteries (Bernanke and Velkey, 2002). These primitive vessels are the precursors of the coronary arteries. They arise from a complex capillary ring around the bulbus cordis called the peritruncal ring. Thus, the roots of the coronary arteries are formed when vessels from the peritruncal ring grow towards and eventually penetrate the aorta (Silva Junior et al., 2009). This theory supports the idea of vasculogenesis in which de novo generation of the blood vessels is occurring, most likely induced by signals in the epicardium, followed by angiogenesis as more arteries form off the pre-existing vessels (Bernanke and Velkey, 2002).

Embryology of the abdominal aorta and its major branches

As stated previously, the abdominal aorta forms when the two dorsal aortas fuse and descend caudally. The branches of the abdominal aorta arise from numerus segmental arteries given off by the dorsal aorta. Two major groups of the segmental arteries include the ventral segmental branches and the lateral segmental branches. The ventral segmental arteries are originally paired, but fuse in the midline to form the major unpaired vessels of the abdomen, the celiac trunk, superior mesenteric artery, and inferior mesenteric artery (Lin and Chaikof, 2000). Most of the other ventral segmental arteries regress.

The lateral segmental arteries give rise to the renal, adrenal, and gonadal vascular systems. The predominant theory for how this occurs was proposed by Walter Felix in 1912 and is called the ladder theory (Isogai et al., 2010). The basic premise of this theory is that the mesonephric arteries, which are derived from the lateral segmental arteries, persist and form the definitive phrenic, adrenal, renal, accessory renal, gonadal, and accessory gonadal arteries. Felix developed the ladder theory by observing the mesonephric arteries in an 18-mm human embryo which he superimposed onto a contour drawing of the suprarenal gland, mesonephros, metanephros, and gonad of a 19.4-mm human embryo (Isogai et al., 2010). Using this drawing, he divided the many pairs of lateral segmental arteries coming off of the dorsal aorta into three groups: 1) a cranial group, consisting of the first two arteries on either side, 2) a middle group, consisting of the third and fourth arteries on the right side and the third through fifth on the left, 3) a caudal group, consisting of the fifth and sixth arteries on the right side and the sixth and ninth arteries on the left (Budhiraja et al., 2013). The fifth through ninth mesonephric arteries form the rete arteriosum urogenitale, an extensive arterial network that supply the mesonephros, metanephros, and reproductive gland (Özkan et al., 2006). The remaining ninth through eleventh mesonephric arteries supply the gonad. The ascending metanephros, which becomes the definitive kidney, uses the paired mesonephric arteries to climb from its original location near the bifurcation of the abdominal aorta to its final lumbar position. It does this by ascending through the peritoneal cavity, once blood supply is sufficient in the cranial pole, the caudal branches regress from the metanephros. This process is repeated until the kidney reaches its final position. However, because of this process, by the time the metanephros reaches its lumbar position, there are several renal arteries supplying it. One of these becomes enlarged to become the definitive renal artery and the others typically degenerate, but some persist as accessory renal arteries. The suprarenal arteries will develop from the middle group of mesonephric arteries. Felix's theory has been quoted in anatomical textbooks since its creation, but it is based on speculation and has not been verified *in vivo* (Isogai et al., 2010).

Isogai et al. (2010), wanted to re-examine the ladder theory because of its speculative nature. In their study, they micro-injected resin and dye into rat embryos on embryonic days (E) 10-20 to examine the development of the renal vascular network *in vivo* using scanning electron microscopy and immunohistochemistry. E10-14 were subdivided into nine intervals because development of the vascular networks occurs quickly during that time. They found that most of the mesonephric arteries had degraded before the metanephros began their ascent, contradicting the ladder theory. Specifically, by E14, most of the mesonephric arteries had already become disconnected from the mesonephric ridge and degenerated, except for a few that provided supply to the gonadal primordium and persisted as the gonadal arteries. The metanephros were still located in the pelvis at this time, meaning that there would be no mesonephric arteries for them to climb up as the ladder theory suggested. The metanephros were supplied by several arterial branches stemming from the common iliac artery, considered the primary renal arteries. The vascularization of the para-aortic ridges was also evident at this stage with the cranial half of the ridge (adrenal primordium) being supplied by new arterial branches emerging from the gonadal artery and/or the directly from the abdominal aorta and the caudal half of the ridge (gonadal rete blastema) being supplied by caudal branches of the gonadal artery and/or abdominal aorta. By E14.3, the caudal para-aortic ridges fused in the midline with one another and the metanephros ascended into its lumbar position. A few of the arterial branches supplying the cranial half of the para-aortic ridge thickened and became the definitive suprarenal arteries, with the most cranial of these branches reaching the diaphragm to become the inferior phrenic artery. Several of the caudal branches reached the metanephros and thickened to become the definitive renal arteries. At this stage, the metanephros were still connected to the primary renal arteries as well. The primary renal arteries disconnected from the common iliac artery as the metanephros ascended, shifting up to the abdominal aorta, meaning that the metanephros had a dual blood supply from the definitive renal arteries and the primary renal arteries. By E14.6, the metanephros was no longer connected to the primary renal arteries and the adrenal, renal, and gonadal arteries had acquired their definitive branching patterns. In summary, the definitive renal, adrenal, gonadal, ureteral, and inferior phrenic arteries appear as new branches of the gonadal artery and/or directly from the abdominal aorta to the para-aortic ridge as opposed to each branch being derived from a specific section of mesonephric arteries.

Contradictory results of the ladder theory were also found in human embryos in a study done by Hinata et al. (2015), who similarly found that the mesonephric arteries were degraded before the metanephros could theoretically climb them to reach their lumbar position. Hinata et al. (2015), looked at paraffin section of human embryos at weeks five through six and at week seven. In weeks five through six they found that the mesonephric arteries were unevenly distributed and that they were restricted to a small section between the 12th thoracic vertebra and the second lumbar vertebra, meaning that the mesonephric arteries had already regressed in the territory of the lower half of the mesonephros and the upper half of the adrenal gland. The adrenal arteries were seen coming off the abdominal aorta. By week seven, the mesonephric arteries had regressed, and the definitive renal arteries were seen as buds coming off the abdominal aorta. Taken together, these results indicate that it is unlikely that the metanephros used the mesonephric arteries during their ascent because most of the ladder had already regressed. Another contradiction to the ladder theory is that the mesonephric arteries were not observed giving off branches to the adrenal gland or metanephros, but rather these branches came off the abdominal aorta as the mesonephric arteries regressed. The results of the studies done by Isogai et al. (2010) and Hinata et al. (2015) demonstrate that the renal embryology is not as straightforward as the ladder theory proposed by

Felix, but rather is composed of an interplay between the regressing mesonephric arteries and the development of new arteries and arterial branches as the metanephros ascends.

Embryology of the iliac arteries and the lower extremity arteries

The development of the pelvic and lower limb vasculature begins with the umbilical arteries. The umbilical arteries are originally paired ventral branches of the dorsal aorta in the sacral region. During the fourth week of development, the left and right umbilical arteries make a connection with the fifth intersegmental lumbar arteries. The section of the umbilical arteries proximal to the connection with the intersegmental arteries regresses, creating a new origin of the umbilical arteries off the fifth intersegmental arteries. The fifth intersegmental arteries develop into the internal iliac arteries (Singh, 2013). The external iliac arteries develop from the internal iliac arteries secondarily and are much smaller in diameter at this stage (Sakthivelan et al., 2010). The branches of the internal iliac artery are derived from persistent channels of the primary capillary plexus in the pelvic region. The most appropriate channels enlarge to form the main arteries, while the other regress and disappear, resulting in the definitive arterial pattern (Pai et al., 2009).

The internal iliac artery gives off the axis artery of the lower limb, which is the primitive central artery of a limb. The axis artery of the lower extremity runs along the posterior aspect of the limb and forms the inferior gluteal artery, part of the popliteal artery, the distal part of the fibular artery and part of the plantar arch (Singh, 2013). There is also a sciatic artery off the common iliac artery that contributes blood supply to the lower limb bud, however, it regresses as the femoral arterial system continues to form.

The femoral arterial plexus develops as completely new vessels from the ventral aspect of the thigh and consists of multiple vascular channels that develop into the rete femorale, which then combines to form the superficial and deep femoral arteries (Hapugoda et al., 2016). The embryonic femoral artery continues to extend, forming connections with other vessels superiorly and inferiorly. Superiorly, the femoral artery develops a connection with the external iliac artery and inferiorly, with the rete pelvicum and the popliteal artery. Through the development of these arterial connections, the embryonic femoral artery becomes the main blood supply to the leg (Singh, 2013). The axis artery degrades as the femoral system develops, leaving behind the branches of the femoral artery (Brantley et al., 1993).

Embryology of the upper extremity arteries

The predominant theory of the development of the upper extremity comes from the work of Singer (1933) who stated that the entire arterial tree of the upper extremity occurs in five stages (Agarwal et al., 2016). In these stages a main axial artery, derived from the seventh intersegmental artery, extends from the axilla to the fingers with the proximal portion becoming the axillary and brachial arteries and the distal portion becoming the anterior interosseous artery (Agarwal et al., 2016, Rodríguez-Niedenführ et al., 2003). The other arteries of the arm develop via angiogenesis starting with the median artery, then the ulnar artery, then the superficial brachial artery, and finally, an anastomosis occurs between the brachial and superficial brachial arteries which becomes the radial artery (Agarwal et al., 2016, Rodríguez-Niedenführ et al., 2003). This theory, however, is based on adult variant patterns rather than embryological data and thus, does not explain all patterns of arterial variation that have been identified in the upper extremity (Rodríguez-Niedenführ et al., 2003). Thus, a new theory of development was proposed based on 112 serially section human embryos (Rodríguez-Niedenführ et al., 2001).

This theory proposes that the development of the upper extremity arterial system is a dual process in which an initial capillary network expands into the limb and, concurrently, the proximal parts of this network from the dorsal aorta, begin to grow and differentiate into the arterial wall (Rodríguez-Niedenführ et al., 2001). Specifically, the development of the arterial system begins at stage 12 when a capillary network arises from the dorsal aorta and reaches the limb bud. At stage 13, the proximal portion of the capillary network off the dorsal aorta begins to mature and enlarge and a more distinctive axial artery can be seen. By stage 15, well-differentiated tube-like structures can be seen which represent the differentiation of the axial artery into the subclavian and axillary arteries. They are seen entering the limb and branching into undifferentiated capillary networks. Throughout stages 16 and 17 the skeletal elements of the upper limb are forming starting from proximal to distal. As the humerus is forming, the brachial artery is becoming more distinctive in its morphology and by stage 17, can be followed to the level of the elbow. At the level of the elbow, the brachial artery gives off several capillaries that extend through the forearm, representing the primitive arterial branches of the forearm. By stage 18, the humerus, ulna, and radius are chondrified, and the carpals and metacarpals are represented by condensed mesenchymal tissue. Simultaneously, well-defined vessels representing the median, ulnar, and interosseous arteries can be followed to the level of the hand. The proximal portion of the radial artery is well-defined, but the distal portion is still a capillary network. By stage 21, the entire radial artery is well-defined as are the palmar arches. This means that the entire, definitive adult morphology is established by stage 21 (Rodríguez-Niedenführ et al., 2001).

This theory differs from the one proposed by Singer (1933) because it suggests that the arterial tree of the upper extremity develops from a capillary network that differentiates in a proximal to distal manner through the maintenance, growth, and development of specific capillary vessels simultaneously with the regression of others (Rodríguez-Niedenführ et al., 2001). This is contrast to the idea that the vessels of the arm form from angiogenesis off the axial artery of the limb bud as proposed by Singer (1933).

Embryology of the cerebral blood supply

The left and right common carotid arteries are derivatives of the third aortic arch. The internal carotid artery is formed from a combination of the third aortic arch, making up the proximal portion of the artery, and the cranial portion of the dorsal aorta, making up the distal part of the artery (Menshawi et al., 2015). The external carotid artery is formed from a branch of the aortic sac, the ventral pharyngeal artery, which supplies the first and second pharyngeal arches (Dungan and Heiserman, 1996). The ventral pharyngeal artery regresses from the dorsal aorta as the heart descends through the thorax and fuses with the common carotid artery (Dungan and Heiserman, 1996, Menshawi et al., 2015). The distal portion of the ventral pharyngeal artery becomes the external carotid artery (Menshawi et al., 2015). By day 29 of the embryologic period, the distal portion of the internal carotid artery divides into cranial and caudal branches (Dungan and Heiserman, 1996). The cranial branch initially supplies the optic and olfactory regions through primitive arteries, which later give rise to the anterior cerebral artery, the middle cerebral artery, the anterior communicating artery, and the anterior choroidal artery (Dungan and Heiserman, 1996, Menshawi et al., 2015). The caudal branch gives rise to the posterior cerebral artery and the posterior communicating artery (Dungan and Heiserman, 1996).

Early in development, the posterior circulation of the brain is reliant on blood coming from the anterior circulation through anastomoses between the carotid system and the vertebral-basilar system (Dungan and Heiserman, 1996, Menshawi et al., 2015). The development of the posterior circulation of the brain is induced by the growth of the occipital lobe and brain stem (Menshawi et al., 2015). At the four to five-mm stage, the rhombencephalon is supplied by bilateral longitudinal neural arteries, the precursors of the basilar artery (Dungan and Heiserman, 1996, Menshawi et al., 2015). Simultaneously, a branch from the dorsal aorta, the trigeminal artery, travels dorsally to reach the trigeminal ganglion in Meckel's cave, forming an anastomosis with the longitudinal neural arteries (Dungan and Heiserman, 1996). Other connections between the internal carotid artery and the longitudinal neural arteries include the otic artery, the hypoglossal artery, and the proatlantal artery (Dungan and Heiserman, 1996, Menshawi et al., 2015). At the five to eight-mm stage, the longitudinal neural arteries consolidate, and the basilar artery is formed (Menshawi et al., 2015). Once the posterior communicating artery is formed and connects with the basilar artery, the trigeminal artery and the other primitive branches, including the otic and hypoglossal arteries, recede (Dungan and Heiserman, 1996, Menshawi et al., 2015). The vertebral arteries form from anastomoses of the cervical segmental arteries (Dungan and Heiserman, 1996, Menshawi et al., 2015). These anastomoses extend to the sixth intersegmental artery, which forms the origin of the vertebral artery off the subclavian artery (Menshawi et al., 2015). The proatlantal artery persists until the vertebral arteries are formed and is incorporated into one of its segments (Menshawi et al., 2015).

Normal Anatomy

Aortic Arch and Coronary Arteries

Emerging from the heat is the ascending aorta, which is continuous with the aortic arch. The classical anatomical description of the proximal aorta includes the coronary arteries emerging from the ascending aorta and three main branches emerging from the aortic arch (Kini et al., 2007, Lale et al., 2014). The ascending aorta gives off the right and left coronary arteries at the aortic root, representing the first branches off the aorta (Kini et al., 2007). The arch of the aorta gives off three main branches; the brachiocephalic trunk, the left common carotid artery, and the left subclavian artery, from right to left (Lale et al., 2014). The brachiocephalic trunk then branches into the right subclavian artery and the right common carotid artery (Lale et al., 2014). This presentation is seen in about 70% of the population and thus, is considered the normal anatomy (Kau et al., 2007).

The first branches of the aorta, the right and left coronary arteries, are the primary source of blood supply to the heart. The right coronary artery emerges from the ascending aorta more anteriorly and somewhat inferiorly than the left coronary artery. It gives off the sinu-atrial nodal branch within millimeters of its origin. The right coronary artery travels in the right, anterior atrioventricular groove of the heart, coursing downwards and posteriorly towards the posterior interventricular septum. As it travels it gives off the right marginal (acute) artery that supplies the myocardium of the right ventricle. The right coronary artery wraps around to the diaphragmatic surface of the heart and gives off the posterior interventricular (posterior descending) artery which supplies the inferior myocardium of the left ventricle. The artery supplying the posterior interventricular artery establishes coronary dominance. In the normal anatomy, the right coronary artery supplies the posterior interventricular artery, and the system is said to be right dominant which occurs in approximately 80 to 85% of cases (Kini, 2007). If the posterior interventricular artery arises from the left coronary artery, then the system is left dominant.

The left coronary artery originates more posteriorly from the ascending aorta and is much shorter than the right. It bifurcates almost immediately into the left anterior descending (LAD), also known as the left anterior interventricular artery, and the left circumflex artery. The left circumflex artery gives off the left marginal artery, which supplies the lateral wall of the left ventricle, and then continues downward in the posterior atrioventricular groove. The left circumflex artery supplies most of the left atrium. The left anterior descending artery travels in the anterior interventricular sulcus and gives off diagonal branches – that supply the anterior wall of the left ventricle- and interventricular septal branches that supply the anterior ventricular septum (Kini, 2007).

Foregut: Celiac Trunk

The celiac trunk is the first major, unpaired vessel off the abdominal aorta and is responsible for the vascular supply to the foregut (White et al., 2015). In the typical anatomy of the celiac trunk it gives rise to three branches; the splenic artery, the left gastric artery, and the common hepatic artery (Michels, 1966). The splenic artery is known for being a very tortuous artery. It travels superior to the pancreas on its way to supply blood to the spleen. The splenic artery gives off branches to the stomach – including the short gastric artery, posterior gastric artery, and the left gastro-omental (gastroepiploic) artery – and multiple pancreatic branches before reaching the spleen. The splenic artery typically divides into multiple terminal branches before reaching the hilum of the spleen (Pandey et al., 2004).

The left gastric artery travels upwards from its point of origin off the celiac trunk, passing along the superior portion of the lesser curvature of the stomach. The left gastric artery gives off multiple small branches that supply the lower portion of the esophagus and the lesser curvature of the stomach. It forms an anastomosis with the right gastric artery (Yildirim et al., 1998).

The common hepatic artery originates from the celiac trunk and courses anteriorly and to the right, passing along the upper margin of the pancreas. Near the omental foramen (Foramen of Winslow), the common hepatic artery bifurcates into the gastroduodenal artery and proper hepatic artery (Favelier et al., 2015). The proper hepatic artery courses superiorly and to the right, traveling in the hepatoduodenal ligament. It gives off the right gastric artery, which passes from right to left along the lesser curvature of the stomach, anastomosing with the left gastric artery. The proper hepatic artery bifurcates into the right and left hepatic arteries typically just below the bifurcation point of the common hepatic duct (Özbülbül, 2011). The right hepatic artery goes on to give rise to the cystic artery.

The other branch of the common hepatic artery, the gastroduodenal artery, descends almost vertically, lodged in a shallow groove on the anterior surface of the pancreas (Bradley, 1973). It gives off the supraduodenal artery immediately after it reaches the superior border of the pancreas. The supraduodenal artery is responsible for supplying the retroperitoneal portion of the superior duodenum (Bradley, 1973). The gastroduodenal artery then gives off the posterior superior pancreaticoduodenal artery at the level of the superior border of the duodenum. The posterior superior pancreaticoduodenal artery travels inferiorly, along the posterior aspect of the duodenum, where it will anastomose with the posterior inferior pancreaticoduodenal artery, a branch of the superior mesenteric artery. Just below the inferior border of the superior part of the duodenum, the gastroduodenal artery gives off the right gastro-omental artery (right gastroepiploic artery), which travels along the greater curvature of the stomach from right to left before anastomosing with the left gastro-omental artery. Lastly, the gastroduodenal artery gives off the anterior superior pancreaticoduodenal artery which travels downwards before turning laterally to follow along the anterior, concave border of the duodenum, forming an anastomosis with the anterior inferior pancreaticoduodenal artery, a branch off the superior mesenteric artery (Bradley, 1973).

Midgut: Superior Mesenteric Artery (SMA)

The superior mesenteric artery supplies blood to the midgut, including the distal duodenum, the jejunum, the ileum, the right colon, and the proximal two thirds of the transverse colon. The superior mesenteric artery arises from the abdominal aorta usually less than one and a half centimeters inferior to the origin of the celiac trunk and just superior the origin of the renal arteries (Horton and Fishman, 2002).

The first branch off the superior mesenteric artery is the inferior pancreaticoduodenal artery which can arise from either the right or left side. It travels superiorly, bifurcating into an anterior and posterior branch which anastomose with the anterior and posterior superior pancreaticoduodenal arteries of the celiac trunk, forming a collateral pathway between the celiac trunk and the superior mesenteric artery (De Martino, 2015, Horton and Fishman, 2002).

The middle colic artery arises from the right side of the proximal superior mesenteric artery, after it passes the inferior border of the pancreas (De Martino, 2015). It passes to the transverse mesocolon, giving off a left and right branch. The right branch descends into the right lower quadrant, forming an anastomosis with the right colic artery and the ileocolic artery (Horton and Fishman, 2002).

Next, the superior mesenteric artery gives rise to the right colic artery distal to the inferior border of the duodenum (De Martino, 2015). The right colic artery gives off an ascending and descending branch. The ascending branch forms an anastomosis with the middle colic artery and supplies the ascending colon. The descending branch forms an anastomosis with the ileocolic artery, supplying the more proximal aspect of the ascending colon (De Martino, 2015).

The ileocolic artery, the last branch off the right side of the superior mesenteric artery, gives off multiple branches including the descending branch (supplies the distal ascending colon), the cecal branch (bifurcates into an anterior and posterior branch to supply the cecum), the ileal branch (supplies the terminal ileum), and the appendicular artery which supplies the appendix (De Martino, 2015).

The jejunal arteries originate from the left side of the superior mesenteric artery. The number of jejunal arteries varies but are typically four to six in number (Horton and Fishman, 2002). The ileocolic artery marks the transition point between the jejunal and ileal arteries (Horton and Fishman, 2002). The ileal arteries also originate from the left side of the superior mesenteric artery and are numerous. The multiple jejunal and ileal branches fan out, creating anastomotic loops that supply the small intestine (De Martino, 2015).

Hindgut: Inferior Mesenteric Artery (IMA)

The inferior mesenteric artery supplies blood to the hindgut including the distal third of the transverse colon, the descending colon, the sigmoid colon, and the superior rectum (De Martino, 2015). It emerges off the abdominal aorta, anterolaterally, approximately seven centimeters below the origination point of the superior mesenteric artery (Horton and Fishman, 2002). The inferior mesenteric artery gives off several branches all originating from the left side of the artery (Horton and Fishman, 2002).

The first branch is the left colic artery (LCA). The left colic artery bifurcates into an ascending branch and a descending branch. The ascending branch forms an anastomosis with the middle colic artery of the superior mesenteric artery via the marginal artery (Skinner and Van Fossen, 2018). This anastomosis point sets up collateral blood flow between the superior and inferior mesenteric arteries, creating arterial arcades along the length of the large intestine (De Martino, 2015). The descending branch of the left colic artery supplies the proximal descending colon and forms an anastomosis with the sigmoid arteries (De Martino, 2015).

The sigmoid artery is the next branch of the inferior mesenteric artery and supplies blood to the distal descending colon and the sigmoid colon (Horton and Fishman, 2002). The sigmoid artery typically gives off two to four branches called the sigmoid arteries which join the arterial arcades in the sigmoid mesocolon (Horton and Fishman, 2002).

Lastly the inferior mesenteric artery gives off the superior rectal artery which supplies the superior portion of the rectum. The superior rectal artery forms an anastomosis with the sigmoid arteries as well as with the middle rectal artery – a branch of the internal iliac artery – and the inferior rectal artery – a branch of the internal pudendal artery (De Martino, 2015).

Renal and Suprarenal Arteries

The right and left renal arteries originate from the abdominal aorta inferior to the origin of the superior mesenteric artery (Urban et al., 2001). The right renal artery courses in a slightly posterior direction and comes to pass posterior to the inferior vena cava and renal vein, as it courses to the more inferiorly located right kidney (Urban et al., 2001). The left renal artery has a shorter path that is oriented more horizontally and upwards, coursing posterior to the renal vein (Hazirolan et al., 2011). The renal arteries divide into multiple segmental arteries near the renal hilum (Urban et al., 2001).

The renal arteries also contribute blood supply to the suprarenal gland. The suprarenal gland are highly vascular structures and receive blood from three arteries; the superior, middle, and inferior suprarenal arteries (Dutta, 2010). The inferior suprarenal artery originates from the proximal renal artery and courses superiorly to supply the posterior and inferolateral regions of the suprarenal gland (Bergman et al., 2018, Hazirolan et al., 2011). The middle suprarenal artery arises from the abdominal aorta and supplies the anteromedial region of the suprarenal gland (Bergman et al., 2018). The superior suprarenal artery arises from the inferior phrenic artery and are multiple in origin ranging from three to 30 small branches that supply the superomedial region of the suprarenal gland (Bergman et al., 2018).

Internal and External Iliac Arteries

The right and left common iliac arteries arise from the bifurcation of the abdominal aorta at the level of the fourth lumbar vertebra. The common iliac arteries course inferiorly, into the pelvis. They bifurcate near the inferior border of the sacroiliac joint into the internal and external iliac arteries (Mamatha et al., 2015).

The internal iliac artery is the principle artery of the pelvis, supplying blood to the pelvic viscera, pelvic walls, perineum, and gluteal region (Yamaki et al., 1998). Variation in the branching pattern of the internal iliac artery is widely documented, with multiple classification systems used to categorize the branching patterns (Bilhim et al., 2014). For the current study, the normal anatomy of the internal iliac artery is the Group A anatomy proposed by Yamaki et al. (1998). In the classification system of Yamaki et al. the internal iliac artery is categorized based on the branching patterns of the superior gluteal artery, the inferior gluteal artery, and the internal pudendal artery (1998). This system excludes the umbilical artery as a main branch because embryologically it is derived from ventral segmental branches of the dorsal aorta whereas the internal iliac is derived from the dorsal segmental branches of the dorsal aorta and because the umbilical artery is much less important after birth (Bilhim et al., 2014, Yamaki et al., 1998). In the Group A description of the internal iliac artery, it descends posteromedially into the lesser pelvis, bifurcating into the anterior and posterior divisions at the superior edge of the greater sciatic foramen (Bilhim et al., 2014).

The anterior division of the internal iliac artery consist of a long, common trunk for the internal pudendal artery and the inferior gluteal artery (Yamaki et al., 1998). The other smaller branches of the internal iliac artery come off that common trunk. These include the umbilical artery, the obturator artery, the inferior vesicle artery (males only), the uterine artery (females only), the vaginal artery (females only), and the middle rectal artery. Prenatally, the umbilical arteries are very important and carry deoxygenated blood back to the placenta for replenishment, passing superiorly along the anterior abdominal wall to the umbilical cord (Moore et al., 2014). After birth, the patent part of the umbilical arteries remains antero-inferiorly between the bladder and the lateral wall of the pelvis, giving rise to multiple superior vesicle arteries that supply the superior aspect of the bladder (Moore et al., 2014). The obturator artery usually arises close to the origin point of the umbilical artery and descends along the rim of the pelvis, passing anteriorly to exit the pelvis through the obturator canal (Bilhim et al., 2014). The inferior vesical artery is found only in males; it supplies the lower aspect of the bladder, the prostate gland, and the seminal vesicles. The vaginal artery, found only in females, is the equivalent of the inferior vesicle artery. It supplies numerous branches to the anterior and posterior aspects of the vagina (Moore et al., 2014). The uterine artery, also found only in females, descends along the lateral wall of the pelvis moving anteromedially within the cardinal ligament to reach the uterus. Along its path it passes superior to the ureter (Moore et al., 2014). The middle rectal artery moves inferiorly, along the lateral wall of the pelvis to reach the inferior part of the rectum (Moore et al., 2014). It forms an anastomosis with the superior rectal artery (a branch of the inferior mesenteric artery) and the inferior rectal artery (a branch of the internal pudendal artery). The internal pudendal artery and the inferior gluteal artery are the terminal branches of the anterior division. They travel inferiorly and posteriorly, exiting the pelvis through the inferior aspect of the greater sciatic foramen, inferior to the piriformis muscle (Bilhim et al., 2014). The internal pudendal artery exits the foramen anterior to the inferior gluteal artery and then crosses the spine of ischium and reenters the pelvis in the ischio-anal fossa via the lesser sciatic foramen. It is the main artery of the perineum, supplying the muscles and skin of the anal and urogenital triangles and the erectile bodies of the penis or clitoris (Moore et al., 2014). The inferior gluteal artery continues to travel inferiorly after exiting the pelvis to supply the muscles and skin of the inferior aspect of the gluteal region and the posterior surface of the thigh (Bilhim et al., 2014).

The posterior division of the internal iliac artery includes the superior gluteal artery (Yamaki et al., 1998). The superior gluteal artery travels superiorly, along the posterior wall of the pelvis before curving concavely down to exit the pelvis via the greater sciatic foramen superior to the piriformis muscle (Bilhim et al., 2014). Along its path, it gives off the iliolumbar artery and the lateral sacral arteries. The superior gluteal artery supplies the piriformis, the gluteal muscles, and the tensor fasciae latae (Moore et al., 2014).

The other branch of the common iliac artery, the external iliac artery provides the main supply of blood to the lower extremities. The external iliac artery travels anteriorly and inferiorly, along the medial border of the psoas major muscle (Nayak, 2008). It exits the pelvic girdle by passing deep to the inguinal ligament, becoming the femoral artery at the midinguinal point (Nayak, 2008). Along its path, the external iliac artery gives off the inferior epigastric artery and the deep circumflex iliac arteries, which contribute blood supply to the inferior portion of the anterior abdominal wall (Nayak. 2008).

Lower Extremity Arteries

The femoral artery is the main artery of the lower extremity and a continuation of the external iliac artery. The femoral artery gives off the deep femoral artery (profunda femoris artery) from its posterolateral aspect in the femoral triangle, approximately four to five centimeters inferior to the inguinal ligament (Dixit et al., 2011).

The deep femoral artery is the principle supply of blood to the thigh. It travels posteriorly and distally, giving off three to four perforating branches that supply muscles of the thigh (Dixit et al., 2011). The other branches of the deep femoral artery include the medial and lateral circumflex femoral arteries which wrap around the proximal end of the femur to supply it as well as the thigh muscles. The medial circumflex femoral artery originates from the medial aspect of the deep femoral artery slightly superior than the origin point of the lateral circumflex femoral artery (Dixit et al., 2011). It supplies blood to the head and neck of the femur (Nasr et al., 2014). The lateral circumflex femoral artery originates from the lateral aspect of the deep femoral artery and passes laterally dividing into ascending, transverse, and descending branches (Dixit et al., 2011). It contributes blood supply to the lateral thigh.

The femoral artery continues distally and enters the adductor canal. The canal terminates at the adductor hiatus, through which the femoral artery passes, entering the posterior compartment of the thigh, proximal to the knee (Kim et al., 1989). Here, there is a name change from femoral to popliteal artery. Within the popliteal fossa, the popliteal artery gives off five genicular branches that supply the capsule and ligaments of the knee joint. These branches are the superior lateral, superior medial, middle, inferior lateral, and inferior medial genicular arteries (Moore et al., 2014). The popliteal artery continues inferolaterally, terminating at the inferior border of the popliteus muscle by bifurcating into the anterior and posterior tibial arteries (Kim et al., 1989). The anterior tibial artery passes anteriorly through a gap in the interosseous membrane and courses laterally alongside the fibula before changing names to the dorsalis pedis artery at the level of the ankle joint (Kim et al., 1989, Moore et al., 2014). The anterior tibial artery is the primary blood supply to the anterior compartment of the leg and gives off perforating arteries that supply the proximal lateral compartment of the leg. The posterior tibial artery supplies blood to the posterior compartment of the leg and the foot. It descends through the leg, giving off the fibular (peroneal) artery. It continues moving posterior to the medial malleolus and terminates at the level of the calcaneus by bifurcating into the medial and lateral plantar arteries (Kim et al., 1989). The fibular artery descends along the interosseous membrane, passing along the medial aspect of the fibula. It gives off muscular branches to the popliteus and to muscles in the lateral and posterior compartments of the leg (Kim et al., 1989, Moore et al., 2014).

Subclavian Artery and Upper Extremity Arteries

The subclavian arteries and their branches supply blood to the upper extremity, thorax, head, neck, and brain (Poonam et al., 2013). The subclavian arteries are asymmetric in origin, with the left subclavian artery arising from the arch of the aorta and the right subclavian artery arising from the brachiocephalic trunk (Mehrdad and Sadeghi, 2007). The course of both the left and right subclavian arteries is divided into three parts based on its relationship with the anterior scalene muscle: the first part extends from its point of origin to the medial border of the anterior scalene muscle, the second part lies posterior to the anterior scalene, and the third spans from the lateral border of the anterior scalene to the lateral border of the first rib where the artery changes name to the axillary artery (Farmery et al., 2003).

The course of the first part of the left subclavian artery ascends from the arch of the aorta to a point about 20 millimeters above the sternoclavicular joint (Farmery et al., 2003). The first part of the subclavian artery gives off the vertebral artery, the internal thoracic artery, and the thyrocervical trunk (Mehrdad and Sadeghi, 2007). The vertebral artery travels superiorly through the neck to reach the transverse foramen of the sixth cervical vertebra (Takafuji and Sato, 1991). The internal thoracic artery branches off the subclavian artery inferiorly and takes a descending course along the internal surface of the sternum and rib cage (Takafuji and Sato, 1991). It gives off anterior intercostal branches and perforating branches to each of the anterior intercostal spaces (Takafuji and Sato, 1991). The internal thoracic artery terminates at the inferior edge of the sternum by bifurcating into the superior epigastric artery and the musculophrenic artery (Takafuji and Sato, 1991). The third branch, the thyrocervical trunk branches from the subclavian artery superiorly, immediately proximal to the medial border of the anterior scalene muscle (Takafuji and Sato, 1991). The thyrocervical trunk gives rise to the suprascapular artery and the transverse cervical artery (cervicodorsal trunk) from its lateral aspect and then continues to ascend, terminating with a bifurcation into the ascending cervical and inferior thyroid arteries (Moore et al., 2014). The suprascapular artery travels inferolaterally across the anterior aspect of the anterior scalene muscle, before turning slightly more posterior to pass superiorly to the brachial plexus (Takafuji and Sato, 1991). It passes superior to the superior scapular transverse ligament to supply the muscles of the posterior scapula (Takafuji and Sato, 1991). The transverse cervical artery branches off the subclavian artery more distally and travels laterally over the anterior surface of the anterior scalene muscle. It passes superior to the brachial plexus to reach the lateral border of the levator scapulae muscle where it bifurcates into a superficial branch and a deep branch (Takafuji and Sato, 1991). The ascending cervical artery ascends on the anterior surface of the anterior scalene muscle before entering the intervertebral foramen along the fourth or fifth cervical nerve (Takafuji and Sato, 1991).

The last branch of the thyrocervical trunk, the inferior thyroid artery makes a loop posterior to the common carotid artery, moving posteromedially to reach the inferior aspect of the thyroid gland to which it supplies blood (Takafuji and Sato, 1991).

The second part of the subclavian artery travels posterior to the anterior scalene muscle, giving off the costocervical trunk (Mehrdad and Sadeghi, 2007). The costocervical trunk bifurcates into the supreme intercostal artery and the deep cervical artery. The supreme intercostal artery descends from its point of origin supplying the first and second intercostal spaces (Takafuji and Sato, 1991). The deep cervical artery arises between the first rib and the seventh cervical vertebra and helps supply the deep neck musculature (Takafuji and Sato, 1991).

The third part of the subclavian artery begins to descend into the axilla, curving concavely inferiorly. It gives off the dorsal scapular artery which travels laterally through the trunks of the brachial plexus. It passes deep to the levator scapulae and rhomboid muscles supplying both and traveling to the scapula where it forms an anastomosis with the other arteries supplying the scapula (Moore et al., 2014).

The subclavian artery ends at the lateral border of the first rib, becoming the axillary artery (Farmery et al., 2003). The axillary artery, like the subclavian artery, is divided into three segments based on its relationship to the pectoralis minor muscle. The first part of the axillary artery begins at the lateral border of the first rib and extends to the medial border of pectoralis minor. The second part of the artery lies posterior to the pectoralis minor and the third part spans from the lateral border of pectoralis minor to the inferior border of the teres major muscle where the artery changes name to the brachial artery (Agarwal et al., 2016).

The first part of the axillary artery gives off one branch, the superior thoracic artery. It runs posteromedially and supplies the subclavius, muscles of the first and second intercostal spaces, and the overlying pectoral muscles (Moore et al., 2014).

The second part of the axillary artery gives off two branches; the thoracoacromial trunk and the lateral thoracic artery (Agarwal et al., 2016). The thoracoacromial trunk curves around the superomedial border of pectoralis minor and pierces the clavipectoral fascia to supply the regions of the upper limb via four branches (Moore et al., 2014). The four branches are the acromial, deltoid, pectoral, and clavicular branches and are named for the area they supply (Moore et al., 2014). The lateral thoracic artery travels inferomedially along the axillary border of pectoralis minor to the thoracic body wall. It supplies blood to the serratus anterior, pectoral, and intercostal muscles as well as to the lateral aspect of the breast (Moore et al., 2014).

The third part of the axillary artery gives off three branches; the subscapular artery and the anterior and posterior circumflex humeral arteries (Agarwal et al., 2016). The subscapular artery courses inferiorly along the posterior axillary wall, bifurcating into the circumflex scapular artery and the thoracodorsal artery. The circumflex scapular artery curves around the lateral border of the scapula, entering the infraspinatus fossa via the triangular space (Moore et al., 2014). It supplies blood to the posterior scapula and forms an anastomosis with the other vessels supplying the scapula. The thoracodorsal artery courses inferiorly alongside the thoracodorsal nerve to supply the latissimus dorsi muscle (Moore et al., 2014). The circumflex humeral arteries travel around the anterior and posterior faces of the surgical neck of the humerus, encircling it and creating an anastomosis with each other (Moore et al., 2014). The anterior circumflex humeral artery is the smaller of the two and travels horizontally, deep to the biceps brachii and coracobrachialis to reach the humerus (Moore et al., 2014). The posterior circumflex humeral artery travels posteriorly alongside the axillary nerve, passing through the quadrangular space to supply the glenohumeral joint and its surrounding muscles (Moore et al., 2014).

The brachial artery begins at the inferior border of the teres major muscle as a continuation of the axillary artery and terminates in the cubital fossa by bifurcating into the radial and ulnar arteries deep to the bicipital aponeurosis (Al Talalwah et al., 2015, Satyanarayana et al., 2010). It is the principle blood supply to the arm. The brachial artery courses inferiorly through the arm, travelling medially to the humerus and anterior to the brachialis muscle (Al Talalwah et al., 2015). It gives off several branches along its path including the deep brachial artery (profunda brachii artery), the humeral nutrient artery, the superior and inferior ulnar collateral arteries, and many muscular branches (Moore et al., 2014). The deep brachial artery is the largest branch and is responsible for supplying the posterior compartment of the arm (Al Talalwah et al., 2015). The deep brachial artery travels with the radial nerve, they pass posteriorly along the radial groove of the humerus to reach the posterior arm (Al Talalwah et al., 2015). The deep brachial artery terminates by bifurcating into the middle and radial collateral arteries at the level of the elbow. The middle and radial collateral arteries participate in the creation of a collateral blood supply around the elbow by anastomosing with the recurrent interosseous artery and the radial recurrent artery, respectively (Al Talalwah et al., 2015). The humeral nutrient artery is given off around the middle of the arm and enters the nutrient canal of the humerus (Moore et al., 2014). The superior ulnar collateral artery is given off near the middle of the arm and descends alongside the ulnar nerve, posterior to the medial epicondyle of the humerus. It anastomoses with the posterior ulnar recurrent artery and the inferior ulnar collateral artery around the elbow (Moore et al., 2014). The inferior ulnar collateral artery branches off the brachial artery more distally, just superior to the elbow joint. It passes anterior to the medial epicondyle of the humerus and forms an anastomosis with the superior ulnar collateral artery (Moore et al., 2014).

The ulnar and radial arteries are the main arteries of the forearm, originating from the brachial artery in the inferior part of the cubital fossa (Ghosh et al., 2016). The ulnar artery travels infero-medially through the forearm, passing superior to the flexor retinaculum of the wrist in the ulnar (Guyon) canal to terminate in the hand as the superficial palmar arch (Al Talalwah and Getachew, 2015). Along its path it gives off the anterior and posterior ulnar recurrent arteries, the common interosseous artery, and muscular branches that supply muscles on the medial side of the forearm (Moore et al., 2014). The anterior and posterior ulnar recurrent arteries anastomose with the ulnar collateral arteries, mentioned previously, to supply collateral circulation to the elbow (Moore et al., 2014). The common interosseous artery is a short branch, bifurcating almost immediately into the anterior and posterior interosseous arteries. The anterior interosseous artery travels on the anterior surface of the interosseous membrane alongside the anterior interosseous nerve. It pierces the interosseous membrane and travels posteriorly to supply the dorsal carpal arch (Moore et al. 2014). The posterior interosseous artery passes on the posterior surface of the interosseous membrane and courses inferiorly through the forearm between the superficial and deep layers of the extensor muscles. It is replaced at the wrist by the anterior interosseous artery when the latter passes through the interosseous membrane (Moore et al., 2014).

The radial artery is the smaller of the two terminal branches and courses infero-laterally in the forearm deep to the brachioradialis muscle (Nasr, 2012). It curves around the lateral surface of the radius in the distal forearm and passes through the anatomical snuffbox and into the hand (Nasr, 2012). It gives off the radial recurrent artery, the palmar and dorsal carpal branches, and muscular branches that supply muscles in the anterolateral side of the flexor and extensor compartments of the forearm (Moore et al., 2014). The radial recurrent artery ascends back to the elbow forming an anastomosis with the radial collateral artery (branch of the deep brachial artery) (Moore et al., 2014). The palmar and dorsal branches are given off at the wrist and travel to the hand to anastomose with similar branches from the ulnar artery creating the palmar and dorsal carpal arches (Moore et al., 2014).

Carotid Arteries

The common carotid arteries and their branches supply blood to the head, neck, and brain. The common carotid arteries are asymmetric in origin with the right common carotid artery originating from the brachiocephalic trunk and the left from the arch of the aorta. The common carotid arteries course superiorly through the neck in the carotid sheath, bifurcating at the level of the superior border of the thyroid cartilage into the internal and external carotid arteries (Moore et al., 2014). The internal carotid artery has no branches in the neck whereas the external carotid artery has several branches within the neck.

The external carotid artery supplies blood to most structures of the head and neck external to the cranium (Moore et al., 2014). It courses superiorly through the neck, posterior to the neck of the mandible, but anterior to the lobule of the ear (Moore et al., 2014). The external carotid artery terminates within the substance of the parotid gland by bifurcating into the maxillary artery and the superficial temporal artery. Along its path it gives off the superior thyroid artery, ascending pharyngeal artery, lingual artery, facial artery, occipital artery, and posterior auricular artery. The superior thyroid artery descends obliquely to reach the superior lobe of the thyroid gland (Michalinos et al., 2016). It supplies the thyroid gland and gives off branches to the infrahyoid muscles, the sternocleidomastoid muscle, and supplies the larynx via the superior laryngeal artery (Moore et al., 2014). The ascending pharyngeal artery originates from the posteromedial aspect of the external carotid artery and courses superiorly on the pharynx, sending branches to the pharynx, prevertebral muscles, middle ear, and cranial meninges (Michalinos et al., 2016, Moore et al., 2014). The next branch, the lingual artery, originates from the anterior aspect of the external carotid artery at the level of the middle pharyngeal constrictor. It travels antero-superiorly, passing deep to the posterior belly of the digastric. It continues to course deep to the hyoglossus muscle, supplying branches to the posterior tongue before turning superiorly and bifurcating into the deep lingual and sublingual arteries (Moore et al., 2014). The facial artery arises just superior to the lingual artery. It gives rise to the ascending palatine artery and the tonsillar artery close to its point of origin and then courses superiorly along the angle of the mandible. It curves anteriorly, passing deep into the substance of the submandibular gland which it supplies. It continues ascending through the gland, giving off the submental artery, and then arches around the inferior border of the mandible to pass onto the face which it supplies. The facial artery ascends superficially on the face, giving off the superior and inferior labial arteries at the angle of the mouth, and continues to the medial canthus of the eye where it changes name to the angular artery (Moore et al., 2014). The last two branches, the occipital artery and the posterior auricular artery, arise from the posterior aspect of the external carotid artery. The occipital artery arises superior to the origin of the facial artery and passes posteriorly, traveling in the occipital groove of the temporal bone. It terminates by dividing into multiple branches on the posterior part of the scalp (Moore et al., 2014). The posterior auricular artery ascends posteriorly between the external acoustic meatus and the mastoid process. It supplies the muscles in that area, the parotid gland, facial nerve, and structures in the temporal bone (Moore et al., 2014).

The terminal branches, the superficial temporal artery and the maxillary artery, help supply the superficial and deep structures of the face, respectively. The superficial temporal artery travels superiorly, passing anteriorly to the ear region to reach the scalp (Moore et al., 2014). The maxillary artery is the larger of the two terminal branches and divided into three parts based on its relation to the lateral pterygoid muscle (Moore et al., 2014). The first part is the mandibular part, which travels posterior to the lateral pterygoid muscle. The second part is the pterygoid part, which runs adjacent to the lateral pterygoid muscle. The third part, the pterygoid-palatine part, runs distal to the lateral pterygoid muscle, passing through the pterygomaxillary fissure into the pterygopalatine fossa (Moore et al., 2014). Each part of the maxillary artery gives off branches that help supply the deeper structures of the face.

The other branch of the common carotid artery, the internal carotid artery, continues to ascend within the carotid sheath until it reaches the base of the skull. There, it enters the middle cranial fossa through the carotid canal in the petrous part of the temporal bone. The internal carotid artery and its branches supply the eye, orbit, forehead, pituitary gland, and provides the anterior circulation of the brain (Moore et al., 2014). It is divided into four segments based on its course, these are the cervical, petrous, cavernous, and cerebral segments (Menshawi et al., 2015). The cervical segment begins at the carotid bifurcation and ascends through the neck to the skull base giving off no branches as it travels (Menshawi et al., 2015). The petrous segment ascends through the carotid canal, curving anteromedially within the petrous part of the temporal bone. It gives off two caroticotympanic arteries to the tympanic cavity and the petrous artery which travels with the nerve of the pterygoid canal (Menshawi et al., 2015). The cavernous part of the artery bends sharply as it travels through the cavernous sinus. It travels anteriorly towards the superior orbital fissure then bends sharply back on itself and finally, turns vertically to enter the roof of the cavernous sinus (Moore et al., 2014). Small branches to the dura and pituitary gland are given off from this segment. The cerebral part extends from the roof of the cavernous sinus to the terminal branching of the internal carotid artery (Moore et al., 2014). The ophthalmic artery is also given off by the cerebral part. The ophthalmic artery gives off many branches that follow the branches of the trigeminal nerve to supply the retina, lacrimal gland, dura, extraocular muscles, paranasal sinuses, nasal cavity, upper and lower eyelids, and the forehead and superior structures of the face (Moore et al., 2014).

The terminal branches of the internal carotid artery make up the anterior circulation of the brain. The terminal branches include the anterior and middle cerebral arteries (Iqbal, 2013). The anterior cerebral arteries participate in a central anastomosis, called The Circle of Willis, with the vertebral arteries to supply blood to the entire brain (Iqbal, 2013). The anterior cerebral arteries supply the medial and superior surfaces of the brain and are connected by the anterior communicating artery (Moore et al., 2014). The middle cerebral arteries supply the lateral surface of the brain including the temporal lobes, anterolateral frontal lobe, and the parietal lobe (Moore et al., 2014). The internal carotid arteries are connected to the posterior cerebral arteries via the posterior communicating arteries (Iqbal, 2013). The posterior cerebral arteries are the terminal branches of the basilar artery, which is formed by the union of the vertebral arteries (Iqbal, 2013). The posterior cerebral arteries supply the inferior surface of the brain and the occipital lobe (Moore et al., 2014). Other branches of the basilar artery include the superior cerebellar artery and the anterior inferior cerebellar artery. The posterior inferior cerebellar artery is given off by the vertebral artery. Together, these branches form the posterior circulation of the brain, supplying the upper cervical spinal cord, medulla, pons, cerebellum, and the posterior cerebrum (Moore et al., 2014).

Common Arterial Variants

Variants of the Aortic Arch

Aortic arch variants have been identified and classified, with upwards of 25 arch variants described (Nizankowski et al., 1975). A more recent classification system proposed by Natsis et al. (2009), breaks down aortic arch variants into eight categories based on the anatomy seen in 633 digital subtraction angiographies (DSA). In this system, the categories are labeled as Type I through Type VIII with Type I being the most frequent anatomy observed and Type VIII being the least frequent (Natsis et al., 2009). Type I is the normal anatomy of the aortic arch as described previously. The normal anatomy was found in 527 cases (83%) in the study done by Natsis et al. (2009). This result is similar to the frequency of the normal anatomy reported in the literature (Table 1). In another imaging study using CT angiography 853 of 1050 cases (81.23%) in a Chinese population had the normal aortic arch anatomy (Tapia et al., 2015). This frequency is seen across multiple populations as well. In a CT angiography study done in a Peruvian population the normal arch anatomy was seen in 78.12% (282 out of 361) cases and in a Turkish population the frequency was 87.4 % (770 out of 881 cases), indicating that the frequency of aortic arch variations is conserved across multiple races (Huapaya et al., 2015, Lale et al., 2014). Similar frequencies of normal versus variant anatomy are also seen in cadaveric studies. Variants of the aortic arch were being discovered and categorized as early as 1893, in which the results of 500 cadaveric dissections were compiled and categorized into a similar system used by Natsis et al. (2009), (Thomson, 1893). In that study, 410 out of 500 (82%) cases displayed the normal anatomy (Thomson, 1893). In a more recent cadaveric study in an Indian population, the frequency of the normal branching pattern was found at a slightly higher frequency with 56 of 62 (90.3%) of cases displaying it (Nayak et al., 2006). This represents the upper limits of the range in frequency at which the normal anatomy is found. The lowest frequency was also found in a cadaveric study and performed in the Colombian population (Rojas et al., 2017) In this study, only 26 of 35 cases (74.29%) displayed the normal arch anatomy (Rojas et al., 2017). The wider range in the frequency distribution in cadaveric studies could be due to the smaller sample size in comparison to the imaging studies or it could also reflect differences between populations. Either way, the normal anatomy was still the most common morphology seen across all the studies with a range of 74.29% to 90.3% (Table 1).

Type II has two branches coming off the aortic arch (1) a common stem for the brachiocephalic trunk and the left common carotid artery and (2) the left subclavian artery (Natsis et al., 2009). This configuration is described as a bovine aortic arch, which is misleading, as the actual branching pattern of the aortic arch in cattle does not resemble this orientation (Malone et al., 2012). Nonetheless, this variant is the second most commonly encountered configuration of the aortic arch with a frequency of 15% (96 of 633 cases) in the imaging study by Natsis et al. (2009). The incidence of the bovine aortic arch in the imaging studies ranged from 7.2% to 18.28% with different racial groups showing similar frequencies of this variation (Huapaya et al., 2015, Lale et al., 2014, Natsis et al., 2009, Tapia et al., 2015). The greatest frequency of the bovine aortic arch was seen in Huapaya et al. (2015) with 66 of 361 cases (18.28%) displaying this morphology. The incidence of the bovine aortic arch in the cadaveric study done by Thomson (1893) falls into the same range as the imaging studies with a frequency of 10% (51 of 500 cases) as does the frequency found in Rojas et al. (2017) study with a frequency of 11.43% (4 of 35 cases). However, the frequency is lower in Nayak et al. (2006) study with only 3 of 62 (4.8%) cases displaying this variant morphology indicating that the Indian population may have a different frequency distribution of aortic arch variants.

Type III depicts an aortic arch with four branches: (1) the brachiocephalic trunk, (2) the left common carotid artery, (3) the left vertebral artery arising from the aortic arch, not from the left subclavian artery, and (4) the left subclavian artery (Natsis et al., 2009). This morphology was found with an incidence of 0.79% in Natsis et al. (2009), 2.22% in Huapaya et al. (2015), 2.8% in Lale et al. (2014), and 4.85% in Tapia et al. (2015). In the cadaveric studies it was found with an incidence of 10% in Thomson (1893), 1.6% in Nayak et al. (2006), and 8.57% in Rojas et al. (2017). The greater range in frequency of this variant may indicate that it occurs with different incidences across different ethnic groups. However, even with the differing frequencies of this variant morphology it is still the third most commonly seen pattern of the aortic arch across most of the studies presented (Table I).

Type IV has a common origin of the common carotid arteries, creating an arch with three branches: (1) the right subclavian artery, (2) a common stem for the left and right common carotid arteries (bicarotid trunk) located between the subclavian arteries, and (3) the left subclavian artery (Natsis et al., 2009). This variant is much rarer and that is reflected in its lack of occurrence in any other studies aside from Natsis et al. (2009), who found this morphology in one case (0.16%). This pattern has been previously recognized as a possible morphology for the aortic arch in the work of Nizankowski et al. (1975) who made a classification system with 25 arch categories based on dissections of 453 cadavers. However, Nizankowski et al. (1975) did not find this variant in their specimens, indicating how rare it truly is.

Type V has three branches off the aortic arch: (1) a common stem for the left and right carotid arteries (bicarotid trunk), (2) the left subclavian artery and, (3) an aberrant right subclavian artery as the last branch of the arch (Natsis et al., 2009). The aberrant right subclavian artery typically originates on the left side of the aorta and travels retroesophagealy to reach the right arm (Natsis et al., 2009). The incidence of this variant is also very low with a reported frequency of only 0.16% in Natsis et al. (2009), 0.83% in Huapaya et al. (2015), and 0.09% in Tapia et al. (2015) (Table 1). In the cadaveric studies it was found with a frequency of 3% (1 of 35 cases) on Rojas et al. (2017).

Type VI has two branches arising from the aortic arch: (1) a common stem for the left and right common carotid arteries and, (2) a common stem for the left and right subclavian arteries (Natsis et al., 2009). This morphology of the aortic arch is known as an avian form aortic arch because of its resemblance to the aortic arch of birds (Natsis et al., 2009). The incidence of this variant is very rare, and it was only found in one case of all the studies listed (Table 1), (Natsis et al., 2009).

Type VII is characterized by an absence of the brachiocephalic trunk and four branches coming off the aortic arch: (1) the right subclavian, (2) the right common carotid artery, (3) the left common carotid artery and, (4) the left subclavian artery (Natsis et al., 2009). This morphology had the lowest incidence in Natsis et al. (2009), with only 1 out of 633 cases (0.16%) displaying it. However, it was more common in the other studies with a frequency of 1.9% (17 of 881 cases) in Lale et al. (2014), 0.28% (3 of 1050 cases) in Tapia et al. (2015), 0.8% (4 of 500 cases) in Thomson (1893), and 1.6 % (1 of 62 cases) in Nayak et al. (2006). The higher frequency of incidence of this variant indicates that it may be more common than would otherwise be indicated by its lower position in the Natsis et al. (2009) classification system. Most ethnicities had at least several cases with this variant anatomy except for the South American populations indicating that it may not be equally distributed across ethnic groups. The difference in distribution could also account for the variation in the incidence of this morphology across different studies. Either way, this is not a common variant as seen through the low frequency of cases with it (Table 1).

Type VIII has an aortic arch with four branches: (1) the brachiocephalic trunk, (2) the thyroidea ima artery, (3) the left common carotid artery and, (4) the left subclavian artery (Natsis et al., 2009). The thyroidea ima artery itself, is an arterial variant that supplies the inferior thyroid gland when present (Moore et al., 2014). It occurs in approximately 10% of the population and most commonly originates from the brachiocephalic trunk, but can also arise from the aortic arch, the right common carotid artery, the subclavian artery, or the internal thoracic artery (Moore et al., 2014). The thyroidea ima artery ascends on the anterior aspect of the trachea to reach the isthmus of the thyroid gland (Moore et al., 2014). The incidence of the thyroidea ima artery originating from the arch of the aorta is low with a frequency of 0.16% (1 of 633 cases) in Natsis et al. (2009) and 0.4% (2 of 500 cases) in Thomson (1893). The frequency is slightly higher in Rojas et al. (2017) with 3% of cases displaying this morphology, but because of their smaller sample size 3% equates to 1 case out of 35 cadavers meaning that this variant morphology is still rather rare.

Types I through VIII as proposed by Natsis et al. (2009) do not cover all the variants of the aortic arch that have been found. There are many more variants possible including anomalous branching patterns of a left-sided aortic arch – Types I through VIII fall into this category, right-sided aortic arches with or without anomalous branching patterns, and double aortic arches (Hanneman et al., 2016). There are many possible combinations of the origin and position of the arteries off the aortic arch. Nizankowski et al. (1975) created the classification system with 25 possible morphologies to capture many of such combinations. Most of the studies presented found one to a few cases with a unique branching pattern off the left-sided aorta that fits into the 25 possible morphologies. However, the incidence of such morphologies is so low that the exact details of each need not be described, but awareness that more morphologies can exist is important.

The right-sided aortic arch is a rare variant of the aortic arch in which the aortic arch faces to the right and passes over the right main stem bronchus to the right of the trachea and esophagus (Ciná et al., 2000). It arises from the persistence of the right fourth aortic arch and regression of the left fourth arch (Ciná et al., 2000). The right-sided aortic arch has a prevalence of approximately 0.1% in the general population (Ciná et al., 2000). Almost half of those cases are accompanied by an aberrant left subclavian artery (Mubarak et al., 2011). The second most common right-sided arch variant is one with mirror imaging (Hanneman et al., 2016). In this morphology the aortic arch is a mirror image of the left-sided aortic arch (Hanneman et al., 2016). It occurs when the left dorsal aorta regresses distal to the origin of the seventh intersegmental artery, meaning that the left fourth aortic arch becomes the proximal subclavian artery instead of the aortic arch (Hanneman et al., 2016). The frequency of a right-sided aortic arch with mirror image branching is 0.05 to 0.1% in the general population (Singh et al., 2015). Lale et al. (2014) had an incidence of three right-sided aortic arches (0.34%) with 2 of them (0.22%) co-occurring with an aberrant left subclavian artery and one with mirror image branching (0.12%). Tapia et al. (2015) also had one case (0.09%) of a right-sided aortic arch with an aberrant left subclavian artery. The frequency of the right-sided aortic arch variants in Lale et al. (2014) is slightly higher than the population frequency, but that could be attributed to ethnic differences in distribution frequencies.

Double aortic arches form from the persistence of both the right and left fourth aortic arches (Hanneman et al., 2016). The order of the vessels branching from the aortae from right to left is, (1) the right subclavian artery, (2) the right common carotid artery, (3) the left common carotid artery and, (4) the left subclavian artery (Hanneman et al., 2016). The two arches travel distally, encircling the esophagus and trachea, before they reunite to form the descending aorta (Lale et al., 2014, Hanneman et al., 2016). Only one case of double aortic arch was found across the literature reviewed and that was in Lale et al (2014), giving it an incidence of 0.12%. The low frequency of this morphology in the literature indicated how rare of a variant this is.

Table 1. Percent frequency of aortic arch variants in the literature.

Type	Natsis et al., (2009) % (n)	Huapaya et al., (2015) % (n)	Lale et al., (2014) % (n)	Tapia et al., (2015) % (n)	Thomson, (1893) % (n)	Nayak et al., (2006) % (n)	Rojas et al., (2017) % (n)
I	83 (527)	78.12 (282)	87.4 (770)	81.23 (853)	82 (410)	90.3 (56)	74.29 (26)
II	15 (96)	18.28 (66)	7.2 (63)	13.23 (51)	10 (50)	4.8 (3)	11.43 (4)
III	0.79 (5)	2.22 (8)	2.8 (25)	4.85 (51)	5 (25)	1.6 (1)	8.57 (3)
IV	0.16 (1)	---	---	---	---	---	---
V	0.16 (1)	0.83 (3)	---	0.09 (1)	---	---	3 (1)
VI	0.16 (1)	---	---	---	---	---	---
VII	0.16 (1)	---	1.9 (17)	0.28 (3)	0.8 (4)	1.6 (1)	---
VIII	0.16 (1)	---	---	---	0.4 (2)	---	3 (1)
Other	---	0.56 (2)	0.7 (6)	0.28 (3)	0.8 (4)	1.6 (1)	---
Examination Method	633 DSA	361 CT angio-graphies	881 CT angio-graphies	1050 CT angio-graphies	500 cadavers	62 cadavers	35 cadavers
Population	Greek	Peruvian	Turkish	Chinese	English	Indian	Columbian

Variants of the Coronary Arteries

The normal anatomy of the coronary arteries has been well described, but more attention is being paid to variations in coronary artery anatomy as they can be related to disorders of the heart (Loukas et al., 2009). Historically, many anomalies of the coronary arteries went unnoticed because they were clinically benign or too subtle to be noticed in post-mortem examination (Loukas et al., 2009). However, with the advent of CT angiography, large scale studies on patient populations were possible; these allowed researchers to determine the frequency of anomalous coronary artery anatomy (Loukas et al., 2009). In one such study, 126,595 coronary angiographies from the Cleveland Clinic

Foundation were examined over a 28-year period to investigate the anatomy of the coronary arteries (Yamanaka and Hobbs, 1990). They identified 1,686 patients with anomalies of the coronary arteries, equating to an incidence of 1.3% (Yamanaka and Hobbs, 1990). Of the patients with anomalies, there were two main categories of variations seen; variations in the origin and distribution of the arteries (1,461 patients, 87%) and coronary artery fistulas (225 patients, 13%) (Yamanaka and Hobbs, 1990).

Anomalous origins of the coronary arteries include an origin from the posterior sinus of Valsalva, the ascending aorta, and the pulmonary artery (Yamanaka and Hobbs, 1990). The sinus of Valsalva is another name for the coronary sinuses, the right coronary artery typically originates from the right sinus of Valsalva, the left coronary artery originates from the left sinus of Valsalva, and no arteries originate from the posterior sinus of Valsalva (Yamanaka and Hobbs, 1990). A relatively rare anomaly is the right or left coronary arteries taking origin from the posterior sinus of Valsalva. Of the 1,461 patients with coronary artery variation, only 5 patients (0.3%) presented with this anomaly, giving it an incidence of 0.0038% (5 of 126,595 cases) in the general population (Yamanaka and Hobbs, 1990). The course of the coronary arteries is still normal despite the altered origin and no symptoms or complications are associated with this variant (Yamanaka and Hobbs, 1990). More frequently, the left and right coronary arteries can arise from the opposite coronary sinus, e.g. the left coronary artery arises from the right sinus of Valsalva (Loukas et al., 2009, Yamanaka and Hobbs, 1990). When the left coronary artery arises from the right sinus of Valsalva, the entirety of the artery is coming off from this ectopic origin. The right coronary artery may arise independently from the left coronary artery or they may share an ostium, in which case they are considered a single coronary artery (Yamanaka and Hobbs, 1990). The left coronary artery must loop around to descend along its normal path and the location of this loop determine if this variant is clinically significant. If it loops in between the aorta and the pulmonary artery, the left coronary artery can potentially become occluded if the aorta expands, such as with exercise (Yamanaka and Hobbs, 1990). However, this variant is very rare with only 22 cases seen in the 126,595 patients (0.017%) (Yamanaka and Hobbs, 1990). More frequent, is the right coronary artery originating from the left sinus of Valsalva with 136 of 126,595 (0.107%) cases displaying this morphology (Yamanaka and Hobbs, 1990). The right coronary artery originates anterior to the left coronary artery in this variation and travels in between the aorta and pulmonary artery to reach the atrioventricular groove (Yamanaka and Hobbs, 1990). As with the left coronary artery traveling in between the aorta and pulmonary artery, the right coronary artery is at risk for occlusion in this location which can lead to myocardial ischemia (Yamanaka and Hobbs, 1990).

A clinically significant variant is an ectopic origin of the left coronary artery from the pulmonary artery, also known as Bland-White-Garland syndrome (Yamanaka and Hobbs, 1990). In this syndrome, blood will flow from the right coronary artery into the left coronary artery via collateral branches and then from the left coronary artery into the pulmonary artery in a retrograde flow (Yamanaka and Hobbs, 1990). Most patients with this syndrome die in infancy and the 10% that do survive into adulthood often suffer from symptoms of myocardial ischemia, mitral regurgitation, and progressive heart failure

(Parizek et al., 2010). Often the first major clinical manifestation of Bland-White-Garland syndrome is sudden cardiac death (Parizek et al., 2010). The incidence of Bland-White-Garland syndrome is very low with Yamanaka and Hobbs (1990) finding only 10 of 126,595 (0.008%) patients displaying this morphology. Even more rare is an ectopic origin of the right coronary artery off the pulmonary artery with only 2 of 126,595 (0.002%) cases of this found (Yamanaka and Hobbs, 1990). Like the flow of blood in Bland-White-Garland syndrome, blood will flow from the left coronary artery into the right coronary artery and then into the pulmonary artery via retrograde flow. The low incidence of this morphology is thought to be because of high mortality rate of this syndrome (Yamanaka and Hobbs, 1990).

An origin of the coronary arteries from the ascending aorta is more common than an origin from the pulmonary arteries and much less dangerous. Origination of the right coronary artery from the ascending aorta is more common than one for the left coronary artery, with 188 out of 126,595 cases (0.15%) for the right coronary artery, versus 16 of 126,595 cases (0.013%) for the left (Yamanaka and Hobbs, 1990). When the right and left coronary arteries arise from the ascending aorta, they are typically found originating within the proximal two centimeters of the ascending aorta and follow their typical paths along the heart (Yamanaka and Hobbs, 1990). This morphology is asymptomatic, but important in preoperative planning for cardiac surgery (Yamanaka and Hobbs, 1990).

The other major category of coronary artery variants, fistulas, are less common, but can be clinically significant. A coronary fistula is an abnormal connection between a coronary artery or its branches, and a chamber of the heart or any of the great vessels

(Lluri and Aboulhosn, 2014). They can be broken down into two categories based on their clinical significance; small fistulas and large fistulas (Yamanaka and Hobbs, 1990). Small fistulas usually arise from one branch of either of the coronary arteries and empty into a single chamber of the heart and are asymptomatic (Yamanaka and Hobbs, 1990). They are more common than large fistulas, with 163 cases of 126,595 (0.12%) found versus 62 cases of 126,595 (0.05%) of large fistulas found (Yamanaka and Hobbs, 1990). Of the cases of small fistulas, the majority originated from the left anterior descending artery and drained into the pulmonary artery (Yamanaka and Hobbs, 1990).

The large coronary fistulas are more serious because they can be symptomatic. In the large coronary fistulas, arteries draining into the right chambers of the heart act as left to right shunts, putting more blood into the right ventricle and possible overloading it (Yamanaka and Hobbs, 1990). Symptoms of large fistulas include continuous murmur, angina, shortness of breath, and eventual congestive heart failure (Lluri and Aboulhosn, 2014, Yamanaka and Hobbs, 1990). The incidence of large fistulas is relatively lower in adults because most are detected and repaired during adolescents (Yamanaka and Hobbs, 1990).

Another anatomical difference that could be considered a variant is coronary dominance. Coronary dominance is determined by which coronary artery supplies the posterior interventricular artery. If the right coronary artery supplies it, then the heart is right-dominant. If the left coronary artery supplies it, then the heart is left-dominant, and if both the right and left coronary arteries supply it, then the system is said to be co-dominant (Kini et al., 2007). In one study 1,453 postmortem, cardiac angiograms were performed to see the frequencies of coronary dominance (Knaapen et al., 2013). They found that 81.2% (1,180 0f 1,453 cases) were right-dominant, 9.1% (132 of 1,453 cases) were left-dominant, and 9.7% (141 cases of 1,453) were co-dominant (Knaapen et al., 2013). Thus, the right-dominant morphology is typically considered the normal anatomy, while the left-dominant and co-dominate morphologies are considered anomalous.

Variants of the Celiac Trunk and Foregut

Knowledge of celiac trunk variants is well established, with the first description of its normal and aberrant anatomy published in 1756 by von Haller (Noussios et al., 2017). Since then, multiple classification systems have been proposed to categorize the most common morphologies of the celiac trunk. Much attention has been paid to the hepatic arterial supply because of the role it plays in abdominal surgery, including liver transplants, cholecystectomies, and pancreatic and biliary disease. The most commonly used classification scheme for the hepatic arterial supply was created by Michel's based on the results of 200 cadaveric dissections (De Cecco et al., 2009, Michels, 1966). He identified ten types of hepatic arterial anatomy describing the origin of the arteries supplying the liver (Michels, 1966).

Type I is the normal anatomy of the celiac trunk as described previously (Michels, 1966). The prevalence of the normal anatomy varies greatly, but in a review of literature looking at hepatic artery variants, 81% (15,342 of 19,013 cases) displayed the normal morphology (Noussios et al., 2017). The review included studies that used imaging and cadavers as the data source and spanned over multiple ethnic groups, creating an incidence rate for the general population (Noussios et al., 2017). When the individual studies used in the review are inspected, they generally have a lower incidence of the normal anatomy with a prevalence between 61.3% and 70% (Table 2), (Covey et al., 2002, Lopez-Andujar et al., 2007). The discrepancy between the incidence rates could be because of sample size or it could reflect local population differences in the frequency distribution of the variants. Either way, the range of frequencies demonstrates that variations in the hepatic arterial system are not uncommon.

Type II describes a replaced left hepatic artery from the left gastric artery (Michels, 1966). A replaced vessel is a substitute for the normal artery, meaning that the normal artery is missing and an aberrant artery, originating from a different vessel, is present to supply blood to the territory that the original artery otherwise would have (Michels, 1966). This is different from accessory vessel which is a vessel that is present, in addition to the normal artery (Michels, 1966). When the left hepatic artery originates from the left gastric artery it travels from the left to the right within the hepatogastric ligament, superior to the common hepatic artery to reach the liver (Favelier et al., 2015). Type II anatomy was found in 3% (556 of 19,013 cases) of the population according to the review paper (Noussios et al., 2017). This is lower relative to the individual studies who report a prevalence of 5.2 % (13 of 250 cases) in De Cecco et al. (2009), 7.48% (128 of 1,629 cases) in Saba and Mallarini (2011), 9.7% (105 of 1,081 cases) in Lopez-Andujar et al. (2007), and 3.8% (23 cases of 600) in Covey et al. (2002), (Table 2). This discrepancy could, once again, be due to the differences in sample size or populational differences. Despite the discrepancy, the literature agrees that this is one of the more common variants seen in the hepatic arterial system.

Type III anatomy consists of a replaced right hepatic artery from the superior mesenteric artery (Michels, 1966). The replaced right hepatic artery ascends through the lesser omentum, moving from left to right, dorsal to the pancreas and portal vein to reach the right lobe of the liver (Mugunthan et al., 2016). The prevalence of this variation in Noussios et al. (2017) was 3.7% (710 of 19, 013 cases). Like the Type II anatomy, the incidence of Type III was higher in the individual studies with frequencies of 9.2% (23 of 250 cases) in De Cecco et al. (2009), 10.56% (172 of 1,629 cases) in Saba and Mallarini (2011), 7.8% (84 of 1,081 cases) in Lopez-Andujar et al. (2007), and 8.7% (52 of 600 cases) in Covey et al. (2002), (Table 2).

Type IV describes a replaced left hepatic artery from the left gastric artery and a replaced hepatic artery from the SMA (Michels, 1966). This is the first category in Michels' classification scheme that combines variations, i.e. there are two variations seen at once. The incidence of Type IV anatomy in Noussios et al. (2017) was 0.8% (163 of 19,013 cases). This value is similar to the prevalence of Type IV anatomy seen in the individual studies who had a range of 0.5% to 3.1% (Table 2), (Covey et al., 2002, Lopez-Andujar et al., 2007). The similarities in the frequency of Type IV anatomy indicates that this is a more consistently rare variation among multiple populations and ethnicities.

Type V anatomy consists of an accessory left hepatic artery from the left gastric artery (Michels, 1966). The accessory hepatic artery travels from left to right, superior to the common hepatic artery to supply the left lobe of the liver (Favelier et al., 2015). The accessory arteries to the liver are still true end arteries, they make no anastomoses inside of the liver and supply their own distinct territory within the liver (Michels, 1966). The incidence of Type V anatomy was 3.2% (592 of 19,013 cases) in Noussios et al. (2017) which is slightly lower than that reported in the individual studies, but still comparable (Table 2). In the studies using cadavers and CTA imaging, the frequencies were similar to each other with a prevalence of 5.2% (13 of 250 cases) in De Cecco et al. (2009), 6.69% (109 of 1,629 cases) in Saba and Mallarini (2011), and 3.9% (42 of 1,081 cases) in Lopez-Andujar et al. (2007). The incidence of Type V anatomy was higher though in Covey et al. (2002) with 10.7% (64 of 600) of the cases displaying it. It is possible that the different imaging techniques used could be responsible for the discrepancies or that there is a populational difference in the distribution of this variation. In general, accessory branches are smaller in size than the normal arteries and that could lead to an underestimation of their prevalence in imaging studies if they cannot be properly visualized (De Cecco et al., 2009).

Type VI describes an accessory right hepatic artery from the SMA (Michels, 1966). The accessory right hepatic artery ascends through the lesser omentum dorsal to the pancreas and the bile duct to reach the right lobe of the liver, where it will supply its own distinct territory (Favelier et al., 2015). There is a greater range in the prevalence of Type VI anatomy seen, ranging from 0.6% in Lopez-Andujar et al. (2007) to 6.99% in Saba and Mallarini (2011), (Table 2). The higher incidence rates are seen in the studies using CTA protocol, with De Cecco et al. (2009) reporting a frequency of 4.0% and Saba and Mallarini (2011) at 6.99%, which could indicate a higher sensitivity of CTA to capture the smaller accessory right hepatic artery when compared to DSA protocol. The discrepancy in the frequencies could also be due to population variability as De Cecco et al. (2009) and Saba and Mallarini (2011) both examined Italian populations.

Type VII describes an accessory left hepatic artery from the left gastric artery and an accessory right hepatic artery from the SMA (Michels, 1966). This morphology is rarer with a frequency of 0.2% (38 of 19,013 cases) reported in Noussios et al. (2017). That frequency is comparable to the incidence reported in the individual studies with a frequency of 0.73% (12 of 1,629) seen in Saba and Mallarini (2011), 0.6% (7 of 1,081 cases), and 1.0% (6 of 600 cases) in Covey et al. (2002). The highest reported frequency was found in De Cecco et al. (2009) with 2.0% (5 of 250 cases), but that is still comparable to the other reported frequencies and may seem higher because of their smaller sample size.

Type VIII anatomy consists of a combination pattern of a replaced right hepatic artery from the SMA and an accessory left hepatic artery from the left gastric artery or the reverse of this, an accessory right hepatic artery from the SMA with a replaced left hepatic artery from the left gastric artery (Michels, 1966). The frequency distribution is similar to Type VII, with a range of 0.3% to 3.0% reported in the literature (Lopez-Andujar et al., 2007, Covey et al., 2002). Although there is a range of prevalence across the individual studies, this variant is still one of the least commonly found in each of the studies (Table 2).

Type IX describes the common hepatic artery arising from the SMA (Michels, 1966). When the common hepatic artery arises from the SMA it is given off as the first branch and can take multiple routes to reach the liver (Ha et al., 2016). In a study by Ha et al. (2016), they classified the different paths the common hepatic artery can take using 34 cases of Type IX anatomy shown with CTA. In Type A the common hepatic artery travels through the parenchyma of the pancreas and posterior to the superior mesenteric vein (SMV). This was the most common morphology and found in 17 of the 34 cases (50%). Type B is defined as the common hepatic artery passing posterior to the pancreas with no penetration into the parenchyma and continuing posterior to the SMV or the main portal vein (MPV). There were 10 cases (29%) of the Type B path. In Type C the common hepatic artery travels posterior to the pancreas and passes anteriorly to the MPV or the SMV. This was found in 7 cases (21%), (Ha et al., 2016). The variety of paths that the common hepatic artery can take adds another dimension to the variation as described by Michels and demonstrates that even variant morphologies may have additional. Type IX anatomy has a relatively stable incidence across the studies listed, with a prevalence of 1.2% to 2.5% (Noussios et al., 2017, Lopez-Andujar et al., 2007). The similarity of the frequency rates indicates that this variant morphology is present at a stable rate across the general population.

Type X anatomy describes the common hepatic artery arising from the left gastric artery (Michels, 1966). This is one of the rarest variants of the hepatic arterial system with only a few cases reported in the literature. Of the 19,013 cases included in the review by Noussios et al. (2017), they only found five cases (0.04%) with this variation (Table 3). The five cases that they describe were identified by Saba and Mallarini (2011), which is one of the studies included in the Noussios et al. (2017) review, indicating how uncommon this morphology really is. The five cases found in Saba and Mallarini (2011) could represent a high incidence of these frequency in their local population, as they were the only study to report this variation. Although uncommon, it is still important to be aware that this variant morphology can exist.

An important thing to note, is that the variants that do not fit into Michels' classification scheme are among the most prevalent variations found indicating that the hepatic arterial axis can take on more morphologies then the ones previously described (Table 2). Noussios et al. (2017) reports a frequency of 4.1% (784 of 19,013 cases) of morphologies that do not fit into Michels' classification scheme but does not specify what those variations are. However, the individual studies include more details about the other morphologies seen. The other most common variants found were classified as Type XI and Type XII in Lopez-Andujar et al. (2007). Type XI describes the common hepatic artery originating from the SMA and an accessory left hepatic artery arising from the left gastric artery (Lopez-Andujar et al., 2007). This morphology was found in 3 of 1,081 cases (0.3%) in Lopez-Andujar et al. (2007) and 3 of 1,629 cases (0.18%) in Saba and Mallarini (2011). Type XII consists of the common hepatic artery originating directly from the aorta (Lopez-Andujar et al., 2007). There was an incidence of 0.7% (8 of 1,081 cases) in Andujar et al. (2007), 0.91% (15 of 1,629 cases) in Saba and Mallarini (2011), and 2.0% (12 of 600 cases) in Covey et al. (2002). Type XII anatomy was also found in De Cecco et al. (2009), but the number of cases was unspecified. The inclusion of this morphology in each of the individual studies shows that it is present in multiple ethnic groups and that it is common enough that clinicians should be aware of it, even if it is not in Michels' classification scheme.

Another variant found in Covey et al. (2002) was a double hepatic artery, in which one or both hepatic arteries originate from either the celiac trunk or the abdominal aorta. The gastroduodenal artery can branch off either of the hepatic arteries (Covey et al., 2002). The prevalence of this morphology in Covey et al. (2002) was 3.7% (22 of 600 cases). The other variations mentioned in the individual studies that do not fit into Michels' classification scheme are all various combinations of accessory or replaced vessels arising from different places. The spectrum of morphologies included in these studies demonstrates how variable the arterial supply to the liver can be.

Michels classification system provides a useful mechanism to categorize the variants seen in the hepatic arterial system, however, the common hepatic artery is only one branch of the celiac trunk. Variants of the left gastric artery can also occur. One of the most common left gastric artery variants is the origin of a replaced or accessory left hepatic artery from it, which was covered under Michels' classification scheme (Michels, 1966). Another variant of the left gastric artery is an ectopic origin from the abdominal aorta or from a gastro-splenic trunk (Covey et al., 2002, Lezzi et al., 2008). A gastro-splenic trunk consists of the celiac trunk bifurcating into the common hepatic artery and the splenic artery with the left gastric artery coming off the splenic artery (Lezzi et al., 2008). In Covey et al. (2002), they not only looked at the hepatic arterial system in the 600 patient angiographies, but also at the origin of the left gastric artery. They were able to visualize the left gastric artery in 583 patients, and of those patients, the left gastric artery originated from the celiac trunk in 550 cases (94.5%), from the abdominal aorta in 21 cases (3.5%), and from a gastro-splenic trunk in 12 cases (2.0%), (Table 3), (Covey et al., 2002). These results are like those reported in Lezzie et al. (2008), who reviewed 524 CTA images of the abdominal aorta to assess the vascular anatomy of the celiac trunk. They found that the left gastric artery originated from the celiac trunk in 497 cases (94.8%), from the abdominal aorta in 15 cases (2.9%), and from a gastro-splenic trunk in 12 cases (2.3%), (Table 3), (Lezzi et al., 2008). A similar prevalence for the origin of the left gastric artery off the abdominal aorta was also found in a cadaveric study with 1 of 52 cadavers (1.9%) displaying this variant morphology (Yildirim et al., 1998). The similar incidences demonstrate that this variation is relatively stable across multiple populations even if it is not the most prevalent variation found.

The final main branch of the celiac trunk, the splenic artery, is known for being the largest and most tortuous branch (Pandey et al., 2004). The most common variants of the splenic artery are seen in its origination (Pandey et al., 2004). In terms of origin, the splenic artery has been observed to have an ectopic origin from the abdominal aorta and from the SMA. Pandey et al. (2004) observed the origin and course of the splenic artery in 320 cadavers and found the splenic artery originating from the abdominal aorta in 26 cases (8.1%) and from the SMA in 4 cases (1.3%), (Table 4). This is similar to the frequencies observed in Lezzi et al. (2008) who found an incidence of the splenic artery originating from the abdominal aorta in 26 of 524 cases (5%) and from the SMA in 2 cases (0.4%), (Table 4). The prevalence of the splenic artery originating from the abdominal aorta indicates that this is a fairly common variation and something clinicians should be aware of in the planning of abdominal surgeries. However, in a review of 36 studies looking at celiac trunk variants, the prevalence of splenic artery anomalies was much lower, with a frequency of 0.08% (8 of 9,829 cases) for an origin off the abdominal aorta and 0.03% (3 of 9,829 cases) for an origin off the SMA (Panagouli et al., 2013). The discrepancy in the reported frequencies between the review and the individual studies could be because of the large difference in sample size. It could also be due to an under-reporting of splenic artery variants in the papers used in the reviews. Most of the studies included in the review were not focusing on the splenic artery and thus, may have missed variants of its morphology (Panagouli et al., 2013). Nevertheless, knowledge of splenic artery variants is important for planning and conducting surgical procedures no matter what the prevalence rate is (Pandey et al., 2004).

Table 2. Percent frequency of foregut morphologies as classified by the Michel's classification system in the literature.

Type	**Noussios et al. (2017) % (n)**	**De Cecco et al. (2009) % (n)**	**Saba and Mallarini (2011) % (n)**	**Lopez-Andujar et al. (2007) % (n)**	**Covey et al. (2002) % (n)**
I	81 (15,342)	66 (165)	61.37 (992)	70 (761)	61.3 (368)
II	3 (556)	5.2 (13)	7.48 (128)	9.7 (105)	3.8 (23)
III	3.7 (710)	9.2 (23)	10.56 (172)	7.8 (84)	8.7 (52)
IV	0.8 (163)	2.0 (5)	1.35 (22)	3.1 (34)	0.5 (3)
V	3.2 (592)	5.2 (13)	6.69 (109)	3.9 (42)	10.7 (64)
VI	1.6 (309)	4.0 (10)	6.99 (114)	0.6 (7)	1.5 (9)
VII	0.2 (38)	2.0 (5)	0.73 (12)	0.6 (7)	1.0 (6)
VIII	0.35 (66)	0.6 (2)	1.4 (31)	0.3 (3)	3.0 (18)
IX	1.2 (245)	2.0 (5)	1.59 (26)	2.5 (27)	2.0 (12)
X	0.04 (5)	---	0.31 (5)	---	---
Misc.	4.1 (784)	3.6 (9)	1.09 (18)	1 (11)	7.5 (45)
Exam Method	19,013 Review including imaging and cadavers	250 CTA	1,629 CTA	1,081 cadavers	600 DSA
Population	N/A	Italian	Italian	Spanish	American

Table 3. Percent frequency of origins of the left gastric artery in the literature.

Variant Origin	Yildirim et al. (1998) % (n)	Covey et al. (2002) % (n)	Lezzi et al. (2008) % (n)
Abdominal aorta	1.9 (1)	3.5 (21)	2.9 (15)
Gastro-splenic trunk	---	2.0 (12)	2.3 (12)
Exam Method	52 cadavers	583 DSA	524 CTA
Population	Turkish	American	Italian

Table 4. Percent frequency of origins of the splenic artery in the literature.

Variant Origin	Panagouli et al. (2013) % (n)	Pandey et al. (2004) % (n)	Lezzie et al. (2008) % (n)
Abdominal aorta	0.08 (8)	8.1 (26)	5 (26)
SMA	0.03 (3)	1.3 (4)	0.4 (2)
Exam Method	9.829 cases: review including imaging and cadaveric studies	320 Cadavers	524 CTA
Population	Mixed	Indian	Italian

Variants of the SMA and Midgut

As discussed previously, the SMA can participate in any number of variants relating to branches of the celiac axis including the hepatic arteries and the pancreatic arteries. Other variants of the SMA include absent arterial branches, supernumerary branches, and branches originating from a common trunk (Gamo et al., 2016). In a review paper examining the incidence of the colic branches of the SMA across cadaveric, radiological, and intraoperative studies, the ileocolic artery was found to be the most consistent branch of the SMA with nine out of ten studies reporting the presence of the ileocolic artery 100% of the time (Alsabilah et al., 2017). The lowest reported frequency of the ileocolic artery was found in a radiological study in which 48 of 50 (98%) patient images included the ileocolic artery Alsabilah et al., 2017, Spasojevic et al., 2011). These results agree with the frequency of the ileocolic artery reported by Michels et al. (1965), who found the artery to be consistently present across 200 cadaveric dissections. A similar frequency was also reported in a meta-analysis of 45 cadaveric, radiological, and surgical dissection studies with a total of 6,090 specimens, in which the pooled prevalence of the ileocolic artery was 99.8% (Negoi et al., 2018).

The middle colic artery displays a similar prevalence to the ileocolic artery. It was present in 100% of cases in five of the six studies reviewed by Alsabilah et al. (2017); the lowest reported frequency in the final study was 98% (55 of 56 cases). The pooled prevalence of the middle colic artery was slightly lower in Negoi et al. (2018), where it was present in 94.6% of the cases.

In contrast, the reported frequencies of the right colic artery are more variable. The highest frequency was found by Michels et al. (1965) in which 176 of 180 cases (98%) had the right colic artery. This is much higher than the frequency range reported in Alsabilah et al. (2017), in which the right colic artery was found in as few 10.7% (6 of 56) of cases and as many as 63.3% (19 of 30) of cases. Across the ten studies included in Alsabilah et al. (2017), the average prevalence of the right colic artery was 41.09% (204 of 669 cases). This is lower than the pooled prevalence found in Negoi et al. (2018) in which the right colic artery was present in 60.1% of cases.

The variability in the presence of the right colic artery may be due to its variability in origin. The right colic artery is known to arise from the SMA, from a common trunk with the middle colic artery, from a common trunk with the ileocolic artery, and from a common trunk for all three arteries (Michels et al., 1965). While it is known that the right colic artery can have variable origins, it is unclear which point or origin is most commonly found (Gamo et al., 2016). However, there is a consensus across the literature that the most common origination points are from the SMA or from a common stem with the middle colic artery (Table 5). In a retrospective study of 50 cadavers and 560 CT images, Gamo et al. (2016) found that the right colic artery most commonly arose from the SMA in 40% (20) of the cadavers and in 73.69% (437) of the CT images. The frequency found from the CT images is similar to the frequency found in the Negoi et al (2018) meta-analysis in which the right colic artery arose from the SMA in 70.8% (4,312) cases. The reported frequency based on the morphology displayed in the cadavers, is also similar to the frequency reported in Michels et al. (1965) - 38% (68 0f 180 cadavers) of cases displaying an origination of the right colic artery from the SMA - and the frequency reported in Haywood et al. (2016) – 32% (8 of 25 cadavers). However, both Michels et al. (1965) and Haywood et al. (2016), more commonly found that the right colic artery arose from a common stem with the middle colic artery, with 93 of 180 cadavers (52%) displaying this morphology. A similar result was found in Haywood et al. (2016), in which the origin of the right colic artery was examined in 25 cadavers. Of the 25 cadavers, 12 (48%) were found to have the right colic artery arising from a common stem with the middle colic artery (Haywood et al., 2016). A much lower frequency was found in Negoi et al. (2018) with only 15.4% (938) of specimens displaying this morphology. Although this frequency is much lower, a common stem for the middle and right colic arteries was still the second most observed morphology in Negoi et al. (2018).

Gamo et al. (2016) observed a frequency for a common stem of the middle and right colic arteries at a similar rate to that seen in Negoi et al. (2018), with 20% (10 cadavers) displaying this morphology. However, the frequency observed amongst the CT images was much lower with only 4.28% (24) displaying it. The common stem of the middle and right colic arteries was also the third most commonly seen morphology in Gamo et al. (2016) as opposed to the first or second most commonly seen in the other studies.

The prevalence of a common stem of the ileocolic and right colic arteries is similar across the studies with a range from 8% to 15% (Gamo et al., 2016, Haywood et al., 2016, Michels et al., 1965, Negoi et al., 2018). The highest reported incidence was found in Gamo et al. (2016) with 32% (16) of cadavers displaying this morphology, although, this increased incidence rate could be due to populational variation. The prevalence of a common stem for all three colic arteries is also similar across the literature with most studies finding no cases with this morphology, displaying how rare it is (Gamo et al., 2016, Haywood et al., 2016, Michels et al., 1965, Negoi et al., 2018). The frequency rate across these studies reflects the considerable variability of the right colic artery, assuming it is even present.

Another variant regarding the right colic artery is the presence of supernumerary right colic arteries. Haywood et al. (2016) found 4 cases (16%) with multiple right colic arteries and each case had a unique origination point for the supernumerary arteries. Two of the cadavers displayed a common stem of the ileocolic and right colic arteries with an additional right colic artery arising from the SMA in one case and from the middle colic artery in the other. Another cadaver had two right colic arteries originating from the middle colic artery and the last case of supernumerary arteries displayed one right colic artery arising from the middle colic artery and the other arising from the ileocolic artery (Haywood et al., 2016). Michels et al. (1965) also found supernumerary right colic arteries in 14 cases (8%), but exact details of their location were not provided. The uniqueness of each case in Haywood et al. (2016), along with all the possible origination points for the right colic artery, demonstrates the vast array of morphologies possible in the abdomen. Indeed, across a total of 400 cadaveric dissections of the mesenteric vasculature, Michels et al. (1965) found no two bodies with identical vasculature branching patterns demonstrating how widely variable the arterial system can be.

Yet, another variant of the SMA is the presence of an anastomosis between the proximal SMA or one of its branches with the proximal IMA or one of its branches (Gourley and Gering, 2005). This anastomosis has been given many names throughout history including the marginal artery, anastomotic maxima of Haller, and the meandering mesenteric artery, but it is perhaps most well known as the arc of Riolan, named after Jean Riolan who was credited with describing this anastomosis in the sixteenth century (Gourley and Gering, 2005, Toh et al., 2018). The prevalence of the arc of Riolan is difficult to find amongst the literature. Indeed, Michels et al. (1965) noted the existence of the arc of Riolan originating from the middle colic artery in his cadaveric dissections but did not specify the frequency at which this morphology was observed. There is a similar lack of reporting in imaging studies; this may be attributed to the small diameter of the vessel. Fisher and Fry (1987) asserted that the arc of Riolan only becomes identifiable on angiograms when there is an occlusion of the SMA or IMA, leading to a greater volume of blood flowing through the arc of Riolan and increasing its diameter. Thus, it would be very difficult to identify this variation in a retrospective analysis of routine abdominal images. Gourley and Gering (2005) found a way to determine the frequency of the arc of Riolan by retrospectively analyzing recorded footage of laparoscopic and robotically assisted anterior resections. They observed the arc of Riolan in 17.8% (102 of 576) of cases (Gourley and Gering, 2005). However, because of the lack of frequency data from other studies and across different populations, it is difficult to ascertain if this is a value that can be applied to the general population or if this is a rate found in the local population that the study was drawn from. Either way, the work of Gourley and Gering (2005) contributes to the body of literature regarding the arc of Riolan and demonstrates that this is a variation that surgeons may come across during abdominal procedures.

Table 5. Percent frequency of the origin of the right colic artery in the literature.

Variant Origin	**Gamo et al. (2016) % (n)**	**Haywood et al. (2016) % (n)**	**Michels et al. (1965) % (n)**	**Negoi et al. (2018) % (n)**
SMA	40 (20 cadavers) 73.69 (437 CTs)	32 (8)	38 (68)	70.8 (4,312)
Common stem of middle and right colic arteries	20 (10 cadavers) 4.28 (24 CTs)	48 (12)	52 (93)	15.4 (938)
Common stem of ileocolic and right colic arteries	32 (16 cadavers) 15 (83 CTs)	12 (3)	8 (14)	13.8 (840)
Common stem of middle, right, and ileocolic arteries	0 (0 cadavers) 0.35 (2 CTs)	---	---	---
Absent right colic artery	8 (4 cadavers) 2.32 (13 CTs)	4 (1)	2 (3)	39.9 (2,430)
Supernumerary right colic artery	---	16 (4)	8 (14)	---
Exam Method	50 Cadavers 560 CTA	25 Cadavers	180 Cadavers	Meta-analysis including 6,090 specimens
Population	Spanish	British	---	---

Variants of the IMA and Hindgut

The inferior mesenteric artery has traditionally been considered the most consistent of the three main arteries supplying the gut, but variations in its branching pattern have been encountered (Dimitriou and Griniatsos, 2015, Michels et al., 1965). As mentioned previously, one such variant is the presence of an arc of Riolan, which is a collateral channel between the SMA and the IMA. Another variant of the IMA that is frequently encountered is variant branching patterns off the IMA for its three major branches (Wang et at., 2018). Normally, the three branches of the IMA – the left colic artery, the sigmoid arteries, and the superior rectal artery – would arise independently from the IMA. Known variations of this pattern include a common stem of the left colic artery and the sigmoid arteries and a common stem for the three branches (Wang et al., 2018).

The observed frequencies of these morphologies vary greatly (Table 6) demonstrating that the IMA may not be as consistent as previously thought. The normal anatomy of the IMA was only observed in 46.4% of cases (51 of 110) based on 3D reconstructions of vascular anatomy of patients undergoing laparoscopic radical resections for rectal cancer that spared the IMA (Wang et al., 2018). Even lower frequencies were observed in cadaveric-based studies. In a study of 7 cadaveric cases from India, Singh (2016) identified normal anatomy in 29% (2 of 7) of cases. Similarly, Sinkeet et al. (2013) examined 57 cadaveric cases from Africa and found normal anatomy in only 12% (7 of 57) cases (Table 6). The disparity in ranges could be due to populational variability, but more likely represents a greater variable nature of the IMA.

Indeed, the most common morphology found in Sinkeet et al. (2013) was a variant morphology, in which 39.6% of the cases had a common stem of the left colic artery and the sigmoid artery (Table 6). A lower frequency was found in Wang et al. (2018) with only 23.6% of cases displaying this morphology. This is more similar to the prevalence reported in Singh (2016) of 29%. Either way, there seems to be a consensus that this variant morphology may be encountered in at least a quarter of all patients, which is something clinicians need to be aware of.

A similar frequency was reported for a common stem of the left colic artery, sigmoid artery, and superior rectal artery with Wang et al. (2018) observing this morphology in 30% of cases and Singh (2016) observing it in 29% of cases. Although this specific variant was not reported by Sinkeet et al. (2013), it was the second most common morphology seen in Wang et al. (2018), after the normal anatomy. The wide range of frequencies reported for IMA variants makes it difficult to determine a definitive prevalence rate, however, these findings demonstrate that the IMA exhibits variant morphology. More imaging and cadaveric studies with larger sample sizes are needed to get a better sense of the incidence rates of IMA variations and to determine if the frequency of variations is stable across multiple populations.

Table 6. Percent frequency of normal and variant IMA morphology in the literature.

Morphology	Wang et al. (2018) % (n)	Sinkeet et al. (2013) % (n)	Singh, (2016) % (n)
Independent origin of 3 branches	46.4 (51)	12 (7)	29 (2)
Common stem of LCA and sigmoid artery	23.6 (26)	39.6 (23)	29 (2)
Common stem of LCA, sigmoid artery, and superior rectal artery	30.0 (33)	---	29 (2)
Miscellaneous	---	---	14 (1)
Exam Method	110 3D reconstructions of vascular anatomy	57 cadavers	7 cadavers
Population	Chinese	African	Indian

Renal Artery Variants

In most individuals, each kidney is supplied by a single renal artery originating from the abdominal aorta (Urban et al., 2001). The renal artery divides into segmental arteries near the renal hilum which are true end arteries to specific renal segments (Rani et al., 2014, Urban et al., 2001). However, variations of this pattern are commonly seen, including supernumerary renal arteries that can originate from different locations, and enter and supply different parts of the kidney (Talović et al., 2007). These variations are important as they can alter the number and location of the renal segments (Talović et al., 2007). Supernumerary renal arteries include multiple renal arteries and accessory renal arteries (Urban et al., 2001). Multiple renal arteries are unilateral or bilateral arteries originating, most commonly, from the aorta. They are similar to the renal artery in caliber and length and typically travel parallel to the renal artery, entering the renal hilum to supply a renal segment (Urban et al., 2001). Accessory renal arteries typically originate from the aorta and are much smaller in caliber than the renal artery. They can be unilateral or bilateral and often supply a segment of the upper or lower renal poles (Urban et al., 2001). It is important to note that the terminology and classification of supernumerary renal arteries is variable across the literature with different terms being used to describe the same variants. For example, multiple renal arteries can be termed accessory hilar arteries and accessory renal arteries can be called polar aberrant arteries (Özkan et al., 2006). The lack of unified terminology makes it difficult to determine the frequency of renal artery variants. However, even with the discrepancies in terminology, it is still important to remember that while these arteries may be termed supernumerary, accessory, or aberrant they are not just extra arteries, but essential arteries that supply a specific renal segment (Kumar, 2011).

While it is difficult to determine the frequency of renal artery variants in a comprehensive manner across the literature, there are still many studies examining the various morphologies of the renal arteries. In a retrospective study of 1,572 DSAs, variants of the renal artery were found in 411 (26.2%) patients (Kuczera et al., 2009). Of the variants found, 174 (11.2%) patients had multiple renal arteries and 237 (15.3%) patients had accessory renal arteries (Kuczera et al., 2009). Kuczera et al. (2009) defined the renal artery variants they were looking as multiple and accessory. However, they did not report the origin of the variants or the prevalence of unilateral versus bilateral variants. Thus, while they do report a clear incidence rate it is not a complete picture of the variants found.

A thorough investigation of renal artery variants was conducted by Özkan et al. (2006), in which 855 renal artery angiographs were examined retrospectively to determine the origin and frequency of renal artery variants in their local population. The normal renal artery morphology, with a single renal artery going to each kidney, was found in 76% of patients, whereas, variant morphology, defined by multiple renal arteries, was found in 24% of patients (202 cases) (Table 7) (Özkan et al., 2006). Multiple renal arteries were present in 11.6% (99 cases) of patients and accessory renal arteries were present in 12.4% of patients (103 cases) (Özkan et al., 2006). The origin of the supernumerary renal arteries was from the abdominal aorta. Of the 855 patients, 16% (135 cases) had multiple renal arteries on the right, 13% (113 cases) had multiple renal arteries on the left, and 5% (46 cases), (Table 7) had multiple renal arteries on both sides (Özkan et al., 2006). It is important to note, that the terminology used in Özkan et al. (2006) defined multiple renal arteries and accessory renal arteries as accessory and aberrant, respectively, highlighting the disparity in terminology across studies. However, the frequency of renal artery variants (24%) is still similar to that found in Kuczera et al. (2009) of 26.2% (Table 7), indicating that incidence rates for variant morphologies may be similar across populations. Likewise, the frequency of multiple renal arteries and accessory renal arteries are similar across the different studies.

While the frequency of variant morphologies is similar in the imaging studies, a higher frequency was found in cadaveric dissection-based study. Talović et al. (2007) examined the kidneys of 39 cadavers to determine the origin and frequency of supernumerary renal arteries. Multiple renal arteries were found in 46.15% (18 cases) of the cadavers, with 17.95% (7 cases) displaying multiple renal arteries and 28.2% (11 cases) displaying accessory renal arteries (Talović et al., 2007). Three cases (7.69%),

(Table 7) had bilateral supernumerary renal arteries. The origin of all but one of the supernumerary renal arteries was from the abdominal aorta; in one case an accessory renal artery descended from the thoracic aorta and traveled posterior the diaphragm to reach the superior pole of the kidney (Talović et al., 2007). The greater frequency of supernumerary renal arteries found in the cadaveric study compared to the imaging studies may be attributed to the difficulty in imaging supernumerary renal arteries. Often, the accessory renal arteries can be missed in angiography because of their thin caliber or they are mistaken for capsular or adrenal arteries (Özkan et al., 2006). Accessory renal arteries can also be missed during angiography if they are occluded or their lumen is significantly narrowed by arteriosclerosis possibly leading to an underestimation of their frequency in imaging studies (Kuczera et al., 2009).

Overall, the frequency of renal artery variants based on the imaging and cadaveric-based studies is 24%-46.15% (Table 7), (Kuczera et al., 2009, Özkan et al., 2006, Talović et al., 2007). Accessory renal arteries are more commonly observed than multiple renal arteries with a frequency of 12.4%-28.2% compared to 11.2%-17.95%, respectively (Table 7), (Kuczera et al., 2009, Özkan et al., 2006, Talović et al., 2007).

Table 7. Percent frequency of supernumerary renal arteries in the literature.

Morphology	**Kuczera et al. (2009) % (n)**	**Özkan et al. (2006) % (n)**	**Talović et al. (2007) % (n)**
Supernumerary renal arteries	26.2 (411)	24 (202)	46.15 (18)
Multiple renal arteries	11.2 (174)	11.6 (99)	17.95 (7)
Accessory renal arteries	15.3 (237)	12.4 (103)	28.2 (11)
Exam Method	1,572 DSA	855 renal angiograms	39 cadavers
Population	Polish	Turkish	Bosnian

STUDY RATIONALE

The purpose of this study is to examine the whole-body arterial system of body donors in order to assess if there is a relationship between the presence of arterial variants in one region of the body to the other.

METHODS

Twenty-six formalin-fixed body donors, obtained through generous donation to the Anatomical Gift Program at Boston University School of Medicine, were examined. There were 10 male and 16 female body donors with a mean age of 85 years (range 64-97). The body donors were dissected according to the instructions provided in *Grant's Dissector* 15th edition, (Tank, 2012) by the first-year medical students and graduate students of the Department of Anatomy & Neurobiology during the human gross anatomy course. Dissections began with the back and limbs; this was followed by dissection of the thorax, abdomen, and pelvis, and concluded with the dissection of the head and neck.

Data collection began in September 2017 and continued through January 2018. At the start of the course, the medical and graduate students were informed that an anatomical vascular study was being conducted during their time in the anatomy laboratory. Students were provided with data collection forms at the beginning of each lab (see Appendix I); these forms were used to aid in the documentation of arterial variants present in the anatomical donors. The data collection forms were designed to follow the dissection order laid out in *Grant's Dissector* (Tank, 2012), and included the arteries the students were expected to encounter during the laboratory dissection. The form was organized as a checklist; for bilateral structures, students were asked to check if a variant was identified of the right and/or left of the body donor. For midline or unilateral structures, students marked the presence of a variant in the single check box provided. The form also included an optional comment box. Students were instructed to check-off any variant arterial anatomy they identified, defined as, atypical presentations of anatomy including aberrant origin, course, and branching pattern. Following each laboratory session, and, again at the end of each unit, the data collection forms were reviewed by the graduate student researcher conducting this study. The information from each data collection form was compiled onto a master form, which included every variant identified throughout the course.

At the conclusion of each unit, the information on the data collection forms was used as a guide for additional inspection of the body donors' vasculature; this was conducted by the graduate student researcher. Every artery included in *Grant's Dissector* (Tank, 2012) was examined and its anatomy recorded. Normal anatomy was recorded as well as variant anatomy. When a variant was identified, the type, location, and detailed description was documented. Arterial variants caused by pathology were also documented, but not included in statistical analysis because they were not congenital in nature. Examples of pathologically caused variants included changes in the course of arteries in the presence of tumors and the absence of arteries because of their participation in arterial grafts elsewhere in the body. This qualitative documentation of the vasculature was used throughout the body; the entire arterial system of each body donor was examined.

The data was separated into two main categories, central variants and peripheral variants. The central variants included any arterial variants found for the arch of the aorta, coronary arteries, foregut, midgut, hindgut, and the right and left renal arteries. Peripheral variants included arterial variants found in the brain, right and left carotid arteries, right and left subclavian arteries, right and left upper extremities, right and left suprarenal and phrenic arteries, right and left gonadal arteries, right and left iliac arteries, and the right and left lower extremities. The presence or absence of each of these variants was checked-off for each body donor and the total number of variants for each body donor was calculated. The percent frequency of each of the variations was also obtained.

The central variant category was further broken defined by the specific types of variations seen in those regions. For example, the foregut category was categorized according to Michel's classification system with the miscellaneous category being expanded to describe the variants not previously seen under this classification system (Michels, 1960). The percent frequency of each of the specific central variants was obtained.

The relationship between the central and peripheral variants was determined by looking at the percent frequency of cases where the variants were co-occurring. The relationship between different groupings of central variants to other central and peripheral variants was also determined using percent frequency tables.

RESULTS

One of the body donors was excluded from the study due to preservation issues, thus 25 body donors were included in this study. Of the body donors examined, all were found to have at least one arterial variant with a range of 3-16 variations per specimen (Table 8). The average number of variants found per body was 8.7 with the most frequent number of variants per case were 7, 9, and 12 variants.

Arterial variants were most commonly found in the foregut, with 80% of the cases presenting with a variant. The next most common areas where arterial variants were identified were the midgut (68%), left subclavian (60%), right upper extremity (52%), and the left upper extremity (48%), (Figure 1, Table 8). Of the central arterial variants, a percent frequency of 20% was found for the arch of the aorta, 20% for the coronary artery, 12% for the hindgut, 28% for the right renal, and 28% for the left renal. For the peripheral variants, the percent frequencies were as follows: brain variants were 4%, right carotid 8%, left carotid 0%, right subclavian 28%, left upper extremity 40%, right suprarenal 24%, left suprarenal 12%, right phrenic 24%, left phrenic 12%, gonadal 4%, right iliac 40%, left iliac 32%, and right lower extremity 40% (Figure 1, Table 8).

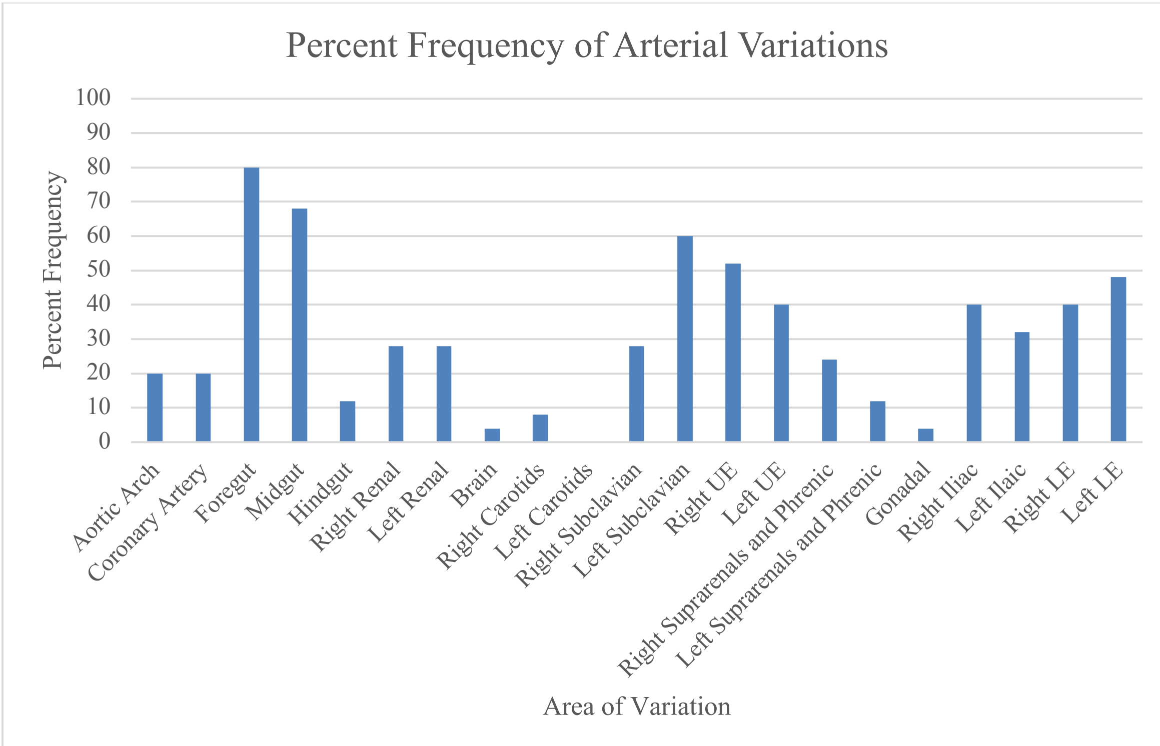

Figure 1: Percent frequency of the arterial variants found in the 25 body donors.
UE = upper extremity, LE = lower extremity

Table 8. Presence of arterial variants in each body donor.

Donor	Aortic Arch	Coronary Artery	Foregut	Midgut	Hindgut	Right Renal	Left Renal	Brain	Right Carotids	Left Carotids	Right Subclavian	Left Subclavian	Right UE	Left UE	Right Supra	Left Supra	Gonadal	Right Iliac	Left Iliac	Right LE	Left LE	
NZFST (F)			X		X	X	X						X	X				X		X	X	9
DIBNCFSMJO (F)	X											X							X			3
CVDLMFZ (F)	X		X^1	X							X	X	X					X	X	X	X	10
KFOLJOT (F)						X					X	X										3
GJUZQBUSJDL (M)			X^1 X^2	X																	X	4
NBDLOJHIU (F)			X	X								X						X	X		X	6
NDMBVHIMJO (M)		X	X	X								X	X	X							X	7
IBVHIUPO (F)		X	X	X								X		X							X	6
NDEBEF (M)			X	X		X	X					X		X	X				X	X		9
IPEHETPO (F)			X	X							X	X	X					X		X	X	7
EBSTU (M)		X																X	X		X	4
LFGBVWFS (F)			X												X	X			X		X	5
NBJO (M)			X	X	X	X	X				X		X	X								8
NBSUJO (F)											X		X				X					3
DBTUSP (M)			X	X^3		X							X	X	X	X		X		X		9
DMPVHI (F)			X				X				X	X						X				5
CFSOTUFJO (F)	X	X^1										X	X					X		X	X	7
NBJMMPVY (M)			X	X^3									X	X	X	X					X	7
TJMWB (F)			X	X^3			X	X			X	X			X				X			8
HSFFO.N (M)		X	X^1	X		X	X		X			X								X		8
UJOLIBN (F)				X	X		X						X	X					X			6
TVMMJMBO (F)	X		X	X^3								X	X		X			X		X		8
TQFBLNBO (F)			X	X					X			X	X					X		X	X	8
CFSOJOHFS (M)	X	X	X	X^3		X						X		X						X		8
TVMMJWBO.S.J (F)			X^2	X									X	X								4
	20%	20%	80%	68%	12%	28%	28%	4%	8%	0%	28%	60%	52%	40%	24%	12%	4%	40%	32%	40%	48%	

The X represents the presence of each variant in the body donors. X^1 indicates that the celiac trunk gives off the inferior phrenic artery (foregut + suprarenal and phrenic variant), X^2 indicates that there is a foregut + midgut variant, X^3 indicates that there is a midgut + hindgut variant. The bottom row represents the present frequency of each variant type and the last column represents the number of variants in each case (before they are further categorized).

Arch of the Aorta and Coronary Artery Variants

Following the classification system proposed by Natsis et al. (2009), 20 of 25 cases (12 females, 8 males, 80%) displayed Type I anatomy, 1 of 25 cases (1 female, 4%) displayed Type II anatomy, and 4 of 25 cases (3 Female, 1 male, 16%) displayed type III anatomy (Figure 2). There were no cases displaying Type IV through Type VIII morphology. There were also no cases that displayed a variant anatomy outside of the classification system of Natsis et al. (2009).

For the coronary arteries, there were a total of 5 of 25 (1 female, 4 males, 20%) body donors displaying anomalous morphology (Figure 3). There were two cases of a left-dominant heart (2 males, 8%), one of which occurred with an anomalous branching pattern consisting of the left marginal artery branching from the LAD. One case (1 male, 4%) involved a triplication of the posterior interventricular artery. Two cases (1 male, 1 female, 8%) had the left coronary artery trifurcate into its branches.

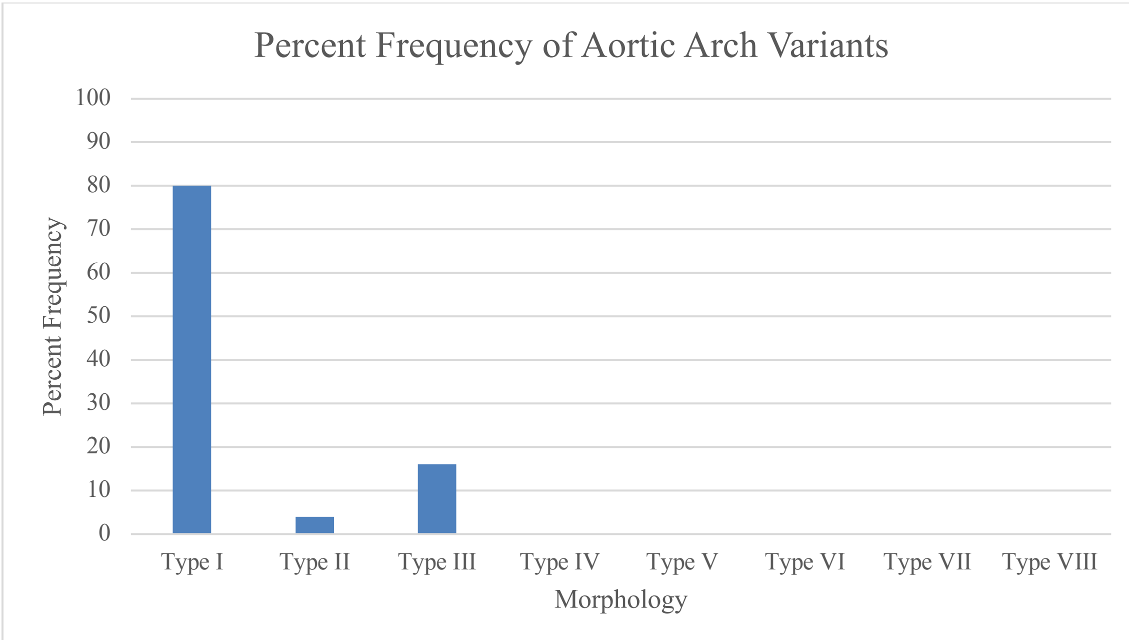

Figure 2: Percent frequency of aortic arch variants following the classification system proposed by Natsis et al. (2009).

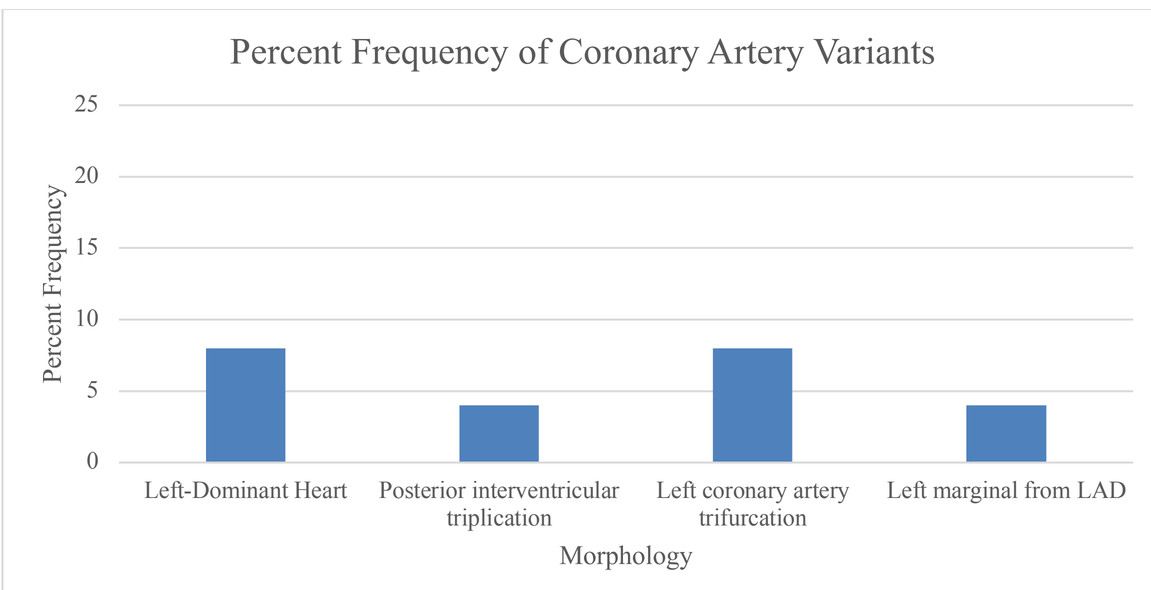

Figure 3: Percent frequency of coronary artery variants.
LAD = left anterior descending artery

Foregut Variants

Twenty of 25 body donors (80%) displayed variants of foregut arterial anatomy (Figure 4). Following Michels' (1966) classification system there were two cases (2 females, 8%) with Type I anatomy. There was one case (1 female, 4%) of Type II anatomy (Figure 4). However, in that case there was also an additional branch off the celiac trunk, but it was grouped into Type II because of the replaced left hepatic artery. There were no cases with Type III anatomy. Type IV was observed in one case (1 female, 4%). Type V was observed in one case (1 female, 4%). In that case the left gastric artery also gave rise to two branches that went to the stomach in addition to the accessory left hepatic artery. There was one case (1 male, 4%) of Type VI anatomy. Type VII anatomy was observed in one case (1 female, 4%). There were no cases with Type VIII or Type X anatomy. Type IX anatomy was seen in one case (1 male, 4%), but this case also had other variants including additional branches off the celiac trunk and aberrant branching of the gastroduodenal artery. The most common anatomy were morphologies that did not fit into Michels' classification scheme with 14 cases (8 females, 6 males, 56%). The anomalous morphologies included:

- Accessory hepatic arteries from the common hepatic artery along with the proper hepatic artery giving off the cystic artery (1 Female, 4%)
- Four branches off the celiac trunk, the three typical branches as well as the left inferior phrenic artery (2 cases, 1 female, 1 male, 8%). In addition, one of those cases (female) had the gastroduodenal artery giving off the right gastric artery and the cystic artery

- Double common hepatic artery (2 cases, 1 male, 1 female, 8%). In one case (male) both the common hepatic arteries travelled to the liver and in the other case (female) the two common hepatic arteries came back together to form the proper hepatic artery
- Proper hepatic artery bifurcated into the cystic artery and a common trunk for the right gastric artery and the left/right hepatic arteries (1 female, 4%)
- Hepato-splenic trunk with left gastric artery arising from the aorta (1 male, 4%)
- Aberrant origin of the dorsal pancreatic artery from the celiac trunk (3 cases, 1 female, 2 males, 12%)
- Aberrant origin of the right gastric artery from the left hepatic artery (1 female, 4%)
- Celiac trunk with 7 branches, the three typical branches as well as the following four variant branches: (1) the dorsal pancreatic artery, (2) left inferior phrenic, (3) right inferior phrenic, (4) common stem for middle suprarenal and esophageal branch. Additionally, the proper hepatic artery bifurcated into the cystic and left hepatic arteries with the cystic artery giving off the right hepatic artery (1 female, 4%)
- Gastro-hepatic trunk with an origin of the splenic artery from the common hepatic artery. An accessory left hepatic artery originates from the left gastric artery. Proper hepatic artery terminated by branching into the right and left hepatic arteries, an accessory hepatic artery, and a branch that went to the pancreas and gave off the cystic artery (1 female, 4%)

- Common hepatic artery trifurcated into the gastroduodenal, cystic and proper hepatic arteries (1 female, 4%)

There were also three cases (2 females, 1 male, 12%) that could not be classified because the abdominal arterial supply was altered by pathology. In all three of the cases the effecting pathology involved metastasis of abdominal tumors that prevented the identification of the vessels.

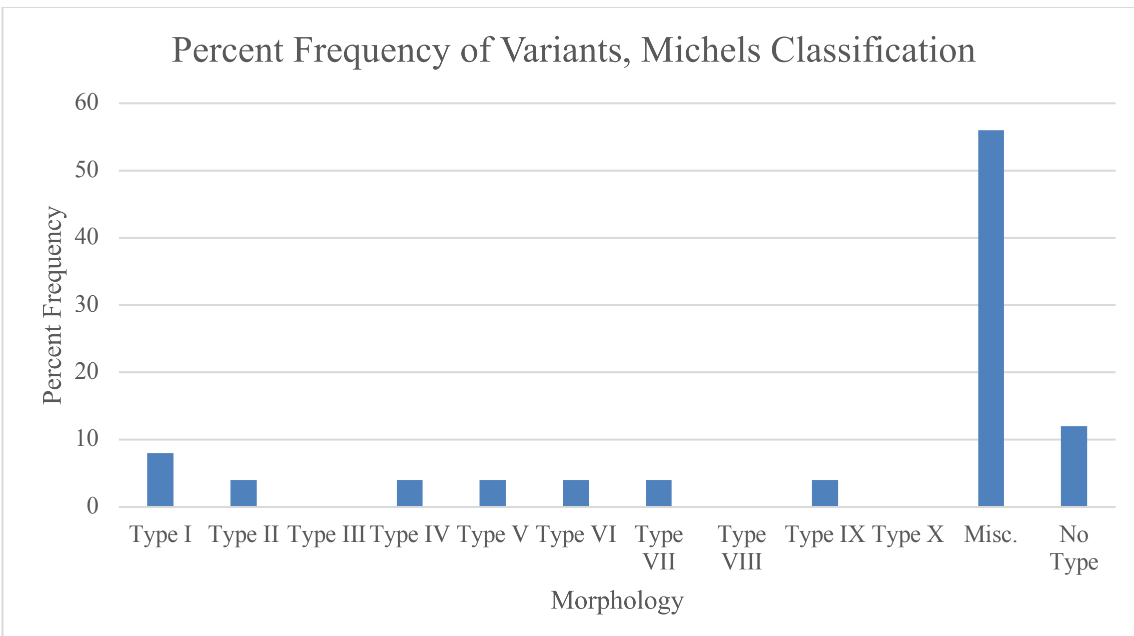

Figure 4: Percent frequency of celiac trunk variants classified according to Michels' (1966) classification system.
Misc. = miscellaneous.

Midgut Variants

There were 17 of 25 cases (68%) displaying variant morphology of the midgut. Variants of the midgut frequently involved vessels that are considered part of the foregut and the hindgut – e.g. the right hepatic artery or the left colic artery, respectively. Cases involving variants of the midgut along with vessels of the foregut and hindgut were still classified as midgut variants.

Of the 17 cases with variant morphology, 9 cases (53%) had only 1 variant, 7 of 17 cases (41%) had 2 variants, and 1 of 17 cases (6%) had 3 variants. There were 2 cases (8%) displaying an accessory right hepatic artery from the SMA, 1 case (4%) of a replaced right hepatic artery from the SMA, and 1 case (4%) of an ectopic origin of the common hepatic artery from the SMA.

Normal anatomy of the SMA was seen in five of 25 cases (20%), (Figure 5). A common stem for the middle colic artery and the right colic artery was seen in 12 cases (48%). A common stem for the right colic and ileocolic arteries was seen in two cases (8%). There were no observations of a common stem for the middle, right, and ileocolic arteries. The right colic artery was absent in two cases (8%), (Figure 5). There was ambiguous anatomy in one case, in which the middle colic artery was missing, and the right colic artery supplied the ascending and transverse colons and made an anastomosis with the left colic artery of the IMA, forming an Arc of Riolan. An Arc of Riolan was seen in five cases (20%), (Figure 5). Three cases (12%) could not be determined because pathology altered the abdominal arteries.

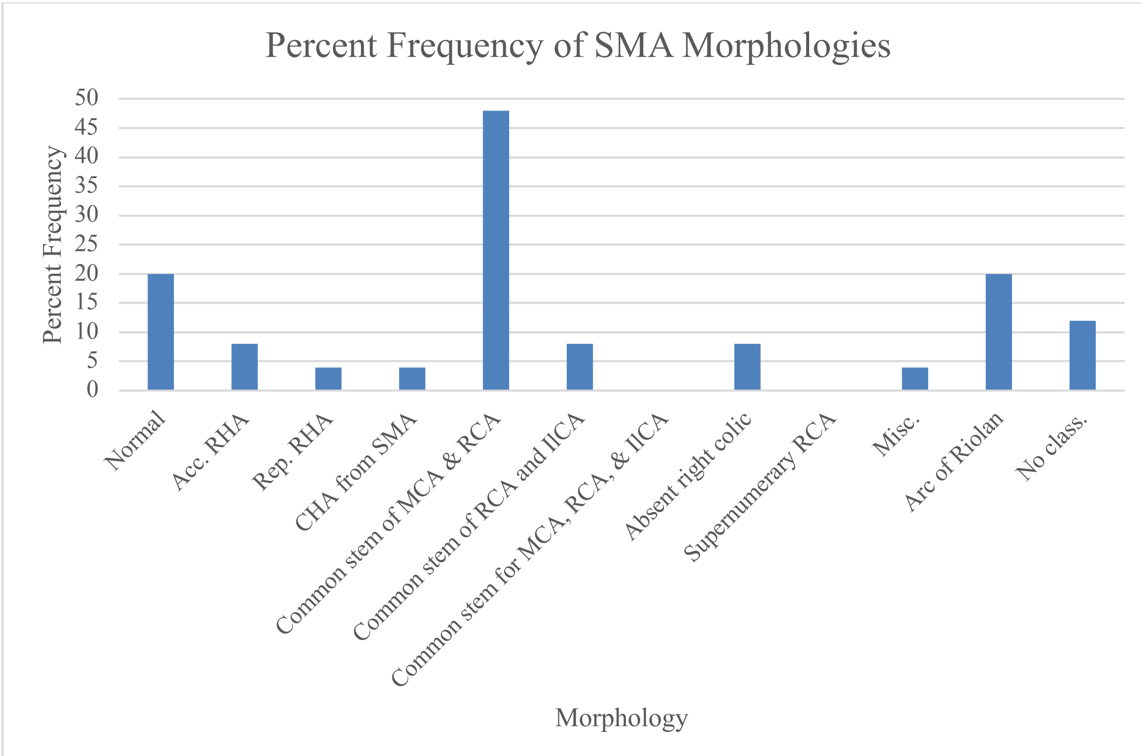

Figure 5: Percent frequency of SMA morphologies.
Acc. = accessory, RHA = right hepatic artery, Rep. = replaced, CHA = common hepatic artery, MCA = middle colic artery, RCA = right colic artery, IlCA = ileocolic artery, class. = classification

Hindgut Variants

There were eight cases (32%) of variant anatomy of the IMA, if cases with an arc of Riolan are included. If the arc of Riolan is excluded, then there were three cases (12%) of variant IMA morphology. In one case (4%), the descending branch of the left colic artery bifurcated into its own set of ascending and descending branches, creating a total of two ascending branches and one descending branch. A similar variant was seen in a second case with both the ascending and descending branches of the left colic artery bifurcating into their own sets of ascending and descending branches. In a third case, there was a common stem for the left colic artery and the sigmoid artery.

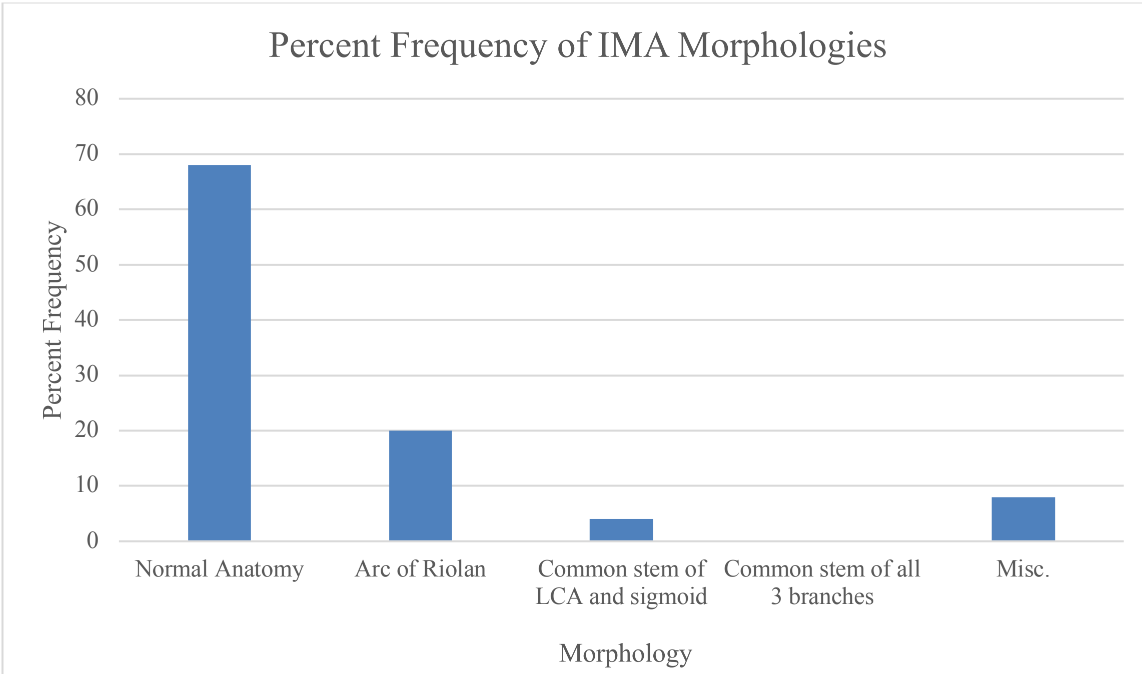

Figure 6: Percent frequency of IMA morphologies.
LCA = left colic artery

Renal Variants

Normal renal artery morphology, in which a single renal artery supplies each kidney was found in 14 of 24 cases (58.3%), (Table 9). One body donor was excluded because pathology altered the renal vasculature. Supernumerary renal arteries were observed in 10 of 24 cases (41.7%), (Table 9). There were three cases (12.5%) of accessory renal arteries, five cases (20.8%) of multiple renal arteries, and two (8.3%) cases with both accessory renal arteries and multiple renal arteries (Table 9). Of the 10 cases with renal artery variants, five cases had one variant (50%), three cases had two variants (30%), and two cases had three variants (20%). Bilateral variation of the renal artery was observed in four of the ten cases (40%). All renal artery variants originated from the abdominal aorta.

On the right, multiple renal arteries were observed in three of 24 cases (12.5%) and accessory renal arteries were observed in four cases (16.7%), (Figure 7). On the left, there were five cases (20.8%) of multiple renal arteries and four cases (16.7%) of left accessory renal arteries (Figure 7).

Table 9. Percent frequency of renal artery morphologies broken down by side and total.

Renal artery morphology	Right kidney % (n)	Left kidney % (n)	Total % (n)
Single renal artery	70.8 (17)	70.8 (17)	70.8 (48)
Multiple renal arteries	29.2 (7)	29.2 (7)	29.2 (14)
2 renal arteries	12.5 (3)	12.5 (3)	12.5 (6)
2 renal arteries and an accessory renal artery	---	8.3 (2)	4.2 (2)
1 accessory renal artery	12.5 (3)	8.3 (2)	10.4 (5)
2 accessory renal arteries	4.2 (1)	---	2.1 (1)

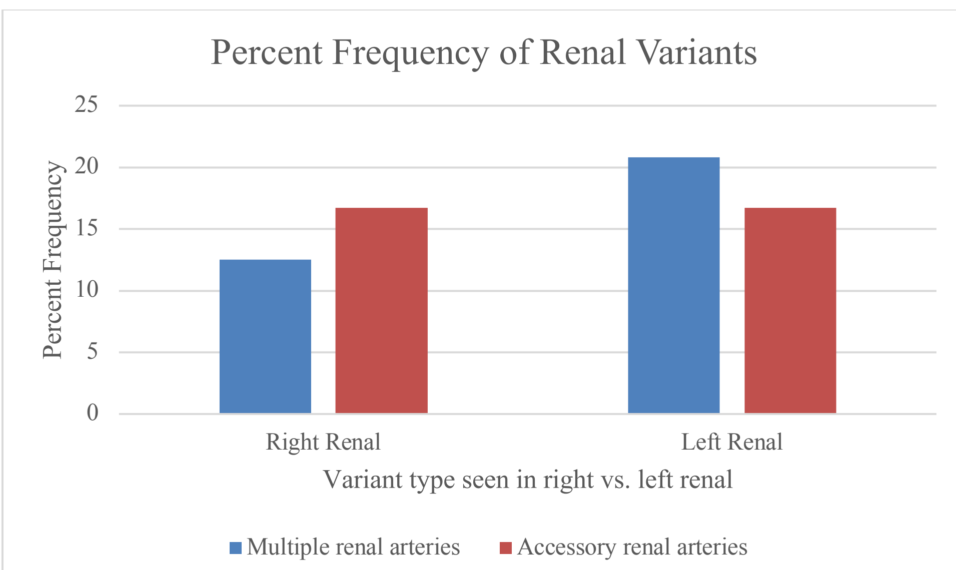

Figure 7: Percent frequency of renal artery variants on the right and left.

Subclavian Artery Variants

Normal anatomy of the subclavian artery and its branches was found in 32% (8 cases) of the body donors (Figure 8). Variant anatomy was found in 68% (17 cases) of the body donors and included a common origin of the thyrocervical trunk and the internal thoracic artery, anomalous origins of the dorsal scapular artery, and anomalous branching patterns (Figure 8).

The most common variant was a common origin of the thyrocervical trunk and the internal thoracic artery with 14 of 25 cases (56%) displaying this morphology (Figure 8). Of the 14 cases, 1 (7.1%) had the variant on the right side, 10 (71.4%) had the variant on the left side, and 3 (21.5%) had the variant on both sides (Figure 9). When looking at the frequencies compared to the total sample, 21 of 25 cases (84%) had a normal origin of the internal thoracic artery from the subclavian artery on the right side and 4 of 25 cases (16%) had an anomalous origin. On the left side, 12 of 25 cases (48%) displayed the normal anatomy of the internal thoracic artery and 13 of 25 cases (52%) displayed an anomalous origin of the internal thoracic artery.

The next most common variant was an anomalous origin of the dorsal scapular artery with 2 specimens (8%) displaying the dorsal scapular artery originating from the thyrocervical trunk via the suprascapular artery (Figure 8). In one of the cases, the variant anatomy was seen coming off the right subclavian artery and involved a trifurcation of a branch off the thyrocervical trunk into the suprascapular artery, the dorsal scapular artery, and a third branch that was cut before reaching its target. In the other case, there was an anomalous origin of the dorsal scapular artery off both sides of the subclavian artery. In this case, the right dorsal scapular artery was a branch of the thyrocervical trunk, and the left dorsal scapular artery emerged from the thyrocervical trunk with a common stem for the dorsal scapular and suprascapular arteries.

Another subclavian artery variant encountered in this study involved the anomalous origin of branches off the subclavian artery (Figure 8). In one case, the branches of the right subclavian artery originated very close to one another with the transverse cervical artery being an independent branch. This variant was found in a specimen that also had a subclavian variant on the left side involving a common stem for the internal thoracic artery and the thyrocervical trunk. In another case, the suprascapular artery originated from the internal thoracic artery on the left. There were no other variants of the subclavian branches on the left side or the right side of that body donor.

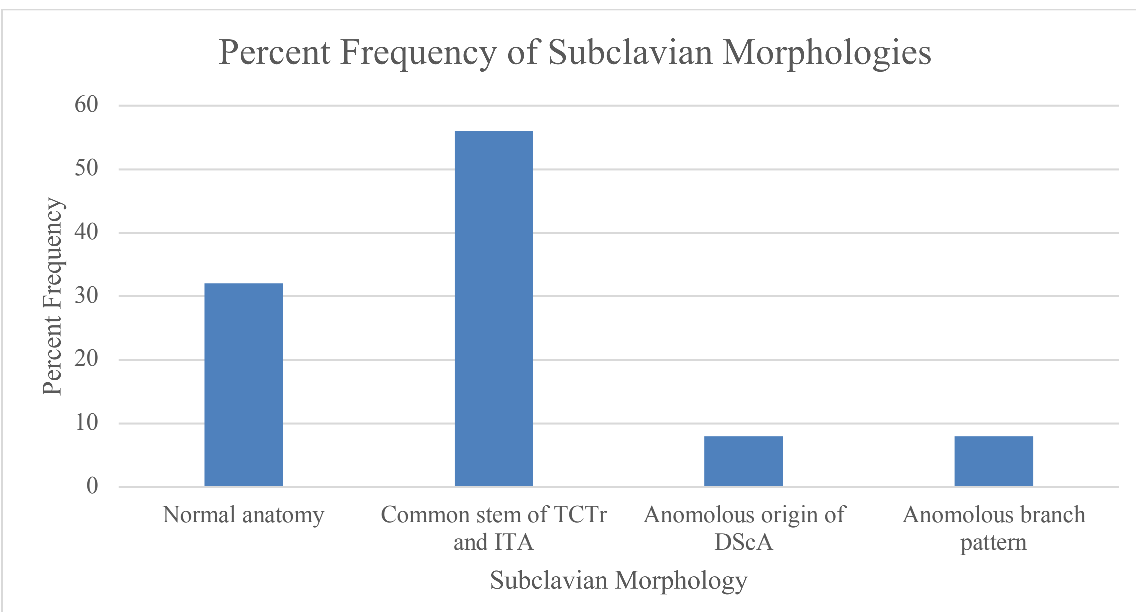

Figure 8: Percent frequency of subclavian morphologies.
TCTr = thyrocervical trunk, ITA = internal thoracic artery, DScA = dorsal scapular artery

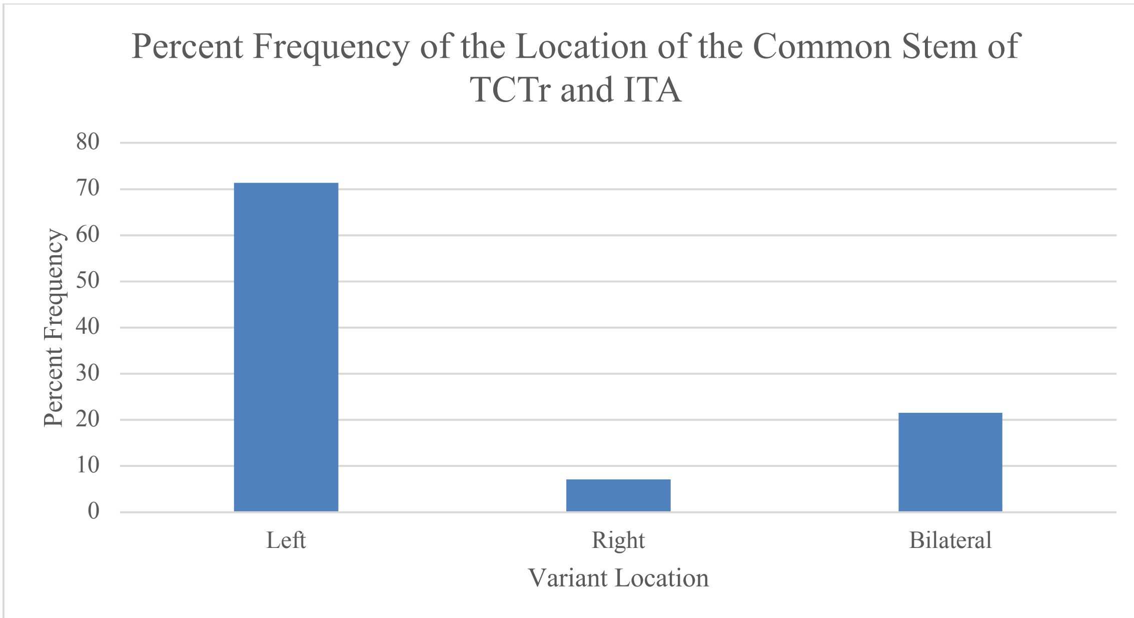

Figure 9: Percent frequency of the origin point of the common stem of the thyrocervical trunk and the internal thoracic artery.

Upper Extremity Variants

Normal anatomy of the upper extremity, including the axillary artery and the brachial artery, was found in 36% (9 cases) of the body donors (Figure 10). Variant anatomy was found in 64% (16 cases) of the body donors (Figure 10). There were 13 cases (52%) with variants on the right side of the body and 10 cases (40%) with variants on the left side of the body. Of the 16 cases with upper extremity arterial variants, 6 (37.5%) had variants on the right side only, 3 (18.8%) has variants on the left side only, and 7 (43.8%) had bilateral variants. Multiple variants in each case were also common, with 6 of 16 cases (37.5%) having only 1 variant, 3 cases (18.8%) having 2 variants, 3 cases (18.8%) having 3 variants, 3 cases (18.8%) having 4 variants, and 1 (6.3%) case having 5 variants.

When upper extremity variants are divided into an axillary artery variant group and a brachial artery variant group, then there are 7 of 16 cases (43.8%) with axillary artery variants, 5 cases (31.3%) with brachial artery variants, and 4 cases (25%) with both axillary and brachial artery variants (Figure 10). If the upper extremities of each specimen are counted individually, creating a total of 50 upper extremities, then there are 5 cases of axillary artery variants on both the right and left and 4 cases of brachial artery variants on the right and 5 cases on the left (Table 10). Interestingly, the 4 cases with both axillary and brachial artery variants were only seen on the right side (Table 10).

Looking at the frequency of axillary artery morphology in the 50 upper extremities, there were 36 cases (72%) with normal anatomy of the axillary artery and 14 cases (28%) with variant axillary artery anatomy (Table 11). Of the cases with a variant, a single variant was seen in 10 cases (71.4%), 2 variants were seen in 3 cases (21.4%), and 3 variants were seen in 1 case (7.1%). Variants were also more commonly seen on the right than the left with 9 cases (64.3%) and 5 cases (35.7%), respectively (Table 11).

The most common variants of the axillary artery included an anomalous origin of the lateral thoracic artery from the subscapular artery, multiple circumflex scapular arteries, and common stems for multiple branches (Table 12). The lateral thoracic artery originating from the subscapular artery was seen in 6 of 50 (12%) axillary arteries. Four of the cases occurred on the right side and 2 of the cases occurred on the left side. There were 4 cases (8%) of multiple circumflex scapular arteries, with 3 of them occurring on the right side and 1 on the left. A common stem of the anterior and posterior circumflex humeral arteries was observed in 3 cases (6%, 1 on the right, 2 on the left). Other variants of the axillary artery observed included multiple anterior circumflex humeral arteries (2 cases, 4%), a common stem for posterior circumflex humeral artery, subscapular artery, and deep brachial artery (1 case, 2%), and an anomalous origin of the circumflex scapular artery from the brachial artery on both sides in 1 body donor (4%). There was also 1 case with an extra branch observed off the axillary artery, but it was cut before reaching its target, so identification of that branch could not be made.

Of the 50 upper extremities, normal anatomy of the brachial artery was seen in 37 cases (74%) and variant anatomy was seen in 13 cases (26%). Variants of the brachial artery were more commonly seen on the right side with 8 of 13 cases (61.5%) having a variant, in comparison, 5 cases (38.5%) revealed a variant on the left. A single variant of the brachial artery was seen in 6 cases on the right and 2 cases on the left, 2 variants were seen in 1 case on the right and 3 cases on the left, and 3 variants were only seen on 1 case on the right side (Table 13).

The most common variants of the brachial artery included an anomalous bifurcation point of the brachial artery into the radial and ulnar arteries and an anomalous origin of the interosseous arteries from the radial artery. The anomalous bifurcation points of the brachial artery most often occurred superior to the cubital fossa, but there were some case where the bifurcation occurred inferior to the cubital fossa as well. A superior bifurcation of the brachial artery was seen in 8 of 50 cases (16%), with 5 occurring on the right and 3 on the left (Table 14). An inferior bifurcation of the brachial artery was seen in 3 cases (6%), with 2 occurring on the right and 1 occurring on the left (Table 14). The next most common variant was an anomalous origin of the interosseous arteries from the radial artery, which was observed in 4 of 50 cases (8%, 2 on the right, 2 on the left), (Table 14). There were also several cases with more than one variant. For example, in 1 case, the right brachial artery bifurcated superiorly to the cubital fossa with both of its branches subsequently bifurcating in the cubital fossa. The more medial branch bifurcated into the anterior and posterior interosseous arteries and the more lateral branch bifurcated into the radial and ulnar arteries. In another case, the left ulnar artery branched from the brachial artery between the thoracoacromial and subscapular arteries. The brachial artery continued normally to the cubital fossa where it bifurcated into the radial artery and the common interosseus artery.

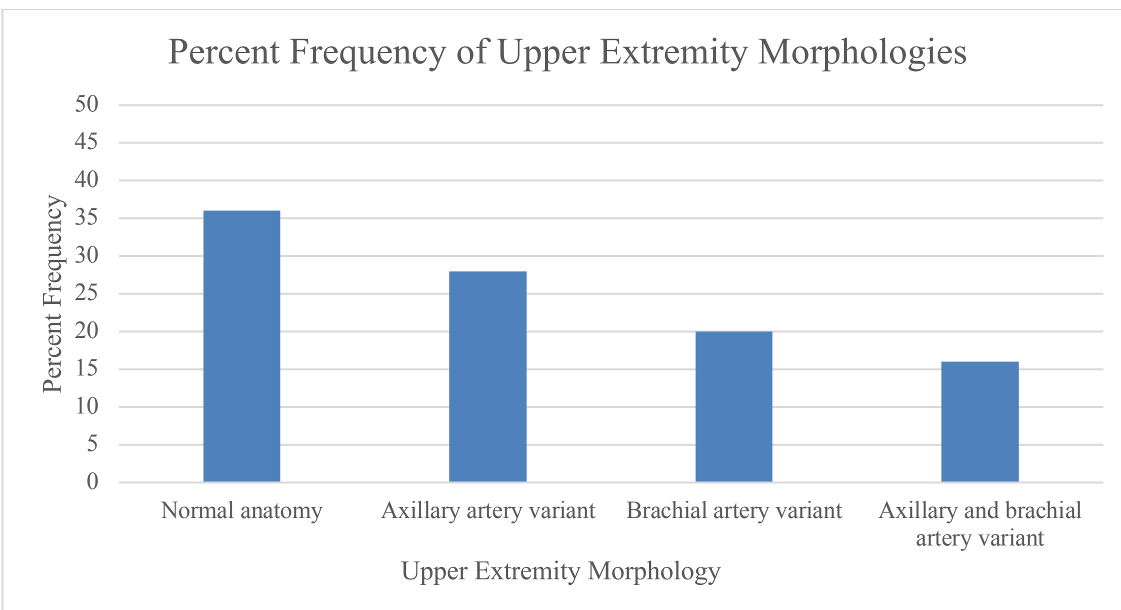

Figure 10: Percent frequency of upper extremity morphologies.

Table 10. Percent frequency of upper extremity arterial variants considered individually on the right and left.

	Right (n = 25) % (n)	Left (n = 25) % (n)	Total (n = 50) % (n)
Axillary artery variant	20 (5)	20 (5)	20 (10)
Brachial artery variant	16 (4)	20 (5)	18 (9)
Axillary and brachial artery variant	16 (4)	0	8 (4)

Table 11. Percent frequency of the number of axillary artery variants on the right and left.

Axillary artery morphology	Right (n = 25) % (n)	Left (n = 25) % (n)	Total (n = 50) % (n)
Normal anatomy (no variant)	64 (16)	80 (20)	72 (36)
1 variant	24 (6)	16 (4)	20 (10)
2 variants	8 (2)	4 (1)	6 (3)
3 variants	4 (1)	0	2 (1)

Table 12. Percent frequency of axillary artery variants on the right and left.

Axillary Artery Variants	Right (n = 25) % (n)	Left (n = 25) % (n)	Total (n = 50) % (n)
Anomalous origin of the lateral thoracic artery from the subscapular artery	16 (4)	8 (2)	12 (6)
Multiple circumflex scapular arteries	12 (3)	4 (1)	8 (4)
Common stem for anterior and posterior circumflex humeral arteries	4 (1)	8 (2)	6 (3)
Multiple anterior circumflex humeral arteries	8 (2)	0	4 (2)
Common stem for posterior circumflex humeral artery, subscapular artery, and deep brachial artery	4 (1)	0	2 (1)
Anomalous origin of the circumflex scapular artery from the brachial artery	4 (1)	4 (1)	4 (2)
Extra branch of axillary artery	4 (1)	0	2 (1)

Table 13. Percent frequency of the number of variants of the brachial artery on the right and left.

Brachial artery morphology	Right (n = 25) % (n)	Left (n = 25) % (n)	Total (n = 50) % (n)
Normal anatomy (no variants)	68 (17)	80 (20)	74 (37)
1 variant	24 (6)	8 (2)	16 (8)
2 variants	4 (1)	12 (3)	8 (4)
3 variants	4 (1)	0	2 (1)

Table 14. Percent frequency of brachial artery variants on the right and left.

Brachial artery variants	Right (n = 25) % (n)	Left (n = 25) % (n)	Total (n = 50_ % (n)
Superior bifurcation point of the brachial artery	20 (5)	12 (3)	16 (8)
Inferior bifurcation point of the brachial artery	8 (2)	4 (1)	6 (3)
Anomalous origin of the interosseous arteries from the radial artery	8 (2)	8 (2)	8 (4)
Miscellaneous	4 (1)	4 (1)	4 (2)

Suprarenal and Phrenic Artery Variants

Normal anatomy of the suprarenal arteries, including the superior suprarenal arteries, middle suprarenal artery, and inferior suprarenal artery, and the inferior phrenic arteries was observed in 60% (15 cases) of the body donors. Variant anatomy was observed in 40% (10 cases) of the body donors (Figure 11). The most commonly observed variants included an origin of the inferior phrenic artery from the celiac trunk, a common stem for the inferior phrenic arteries from the abdominal aorta, and a common stem for the middle suprarenal artery and inferior phrenic artery from the abdominal aorta. An origin of the inferior phrenic artery from the celiac trunk was observed in 4 cases (16%) (Figure 11). In three of the cases the left inferior phrenic artery emerged from the celiac trunk and in 1 case, both the right and left inferior phrenic arteries emerged from the celiac trunk. A common stem for the inferior phrenic arteries was seen in 3 cases (12%), (Figure 11). The common stem for the middle suprarenal artery and the inferior phrenic artery was seen in 2 cases (8%), (Figure 11), both of which occurred on the right side. Other variants of the suprarenal and phrenic arteries observed were seen in singular cases. In one such case, there were 2 right middle suprarenal arteries off the abdominal aorta. In another case there were multiple variants involving an origin of the right and left inferior phrenic arteries from the celiac trunk (mentioned previously) as well as a common stem for the left middle suprarenal artery and an esophageal branch from the celiac trunk (Figure 11).

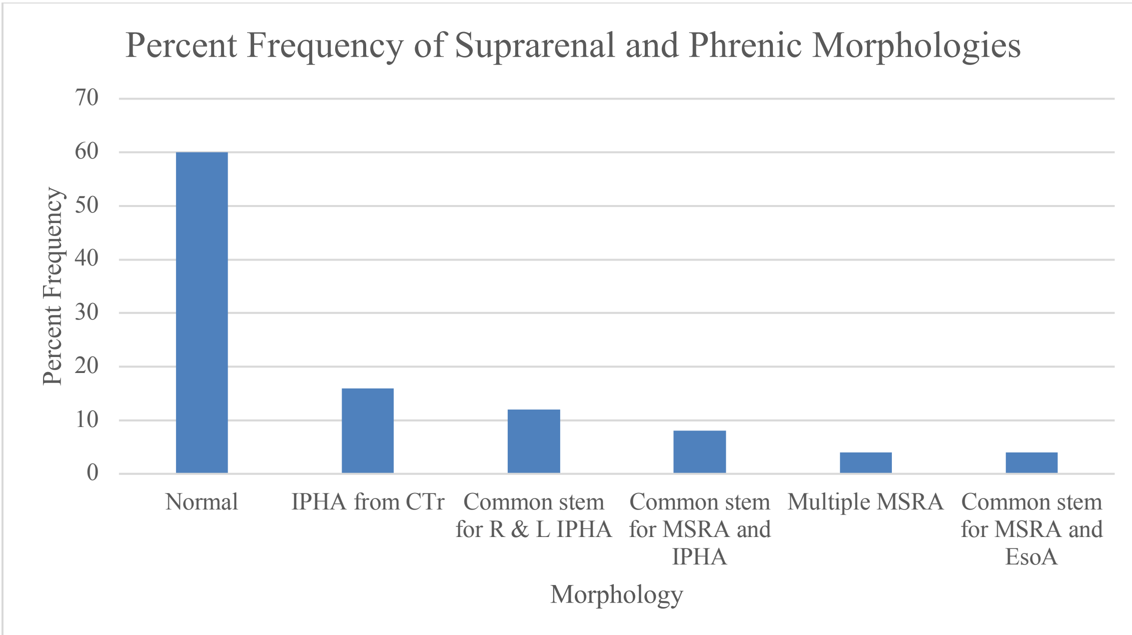

Figure 11: Percent frequency of suprarenal and phrenic artery morphologies. IPHA = inferior phrenic artery, CTr = celiac trunk, R = right, L = left, MSRA = middle suprarenal artery, EsoA = esophageal artery.

Iliac Artery Variants

Normal anatomy of the internal and external iliac arteries was observed in 40% (10 cases) of the body donors and variant anatomy was observed in 60% (15 cases) of the body donors (Figure 12). Of the 15 cases, variants occurred on the right in 46.7% (7 cases) of the body donors, on the left in 33.3% (5) of the body donors, and bilaterally in 20% (3 cases) of the body donors. The most common variants of the internal iliac artery observed were an anomalous origin of the inferior gluteal artery from the superior gluteal artery, multiple internal pudendal arteries, and multiple inferior gluteal arteries. The inferior gluteal artery originated from the superior gluteal artery in 6 cases (24%), 4 of which were observed on the right side and 2 on the left side (Figure 12, Table 15).

Multiple internal pudendal arteries were also observed in 6 cases (24%), with 4 on the right side and 2 on the left side (Figure 12, Table 15). Most cases only had a duplicate internal pudendal artery, but in one case there were 3 internal pudendal arteries. Multiple inferior gluteal arteries were observed in 4 cases (16%), with 2 cases having the variant on the right side and 2 cases having it on the left side (Figure 12, Table 15). The only other variant of the internal iliac artery observed involved a common stem of the superior and inferior gluteal arteries on the left side. There was one case with a variant of the left external iliac artery in which a branch of the inferior epigastric artery traveled through the obturator canal to anastomose with the internal iliac artery, forming a variant known as the corona mortis.

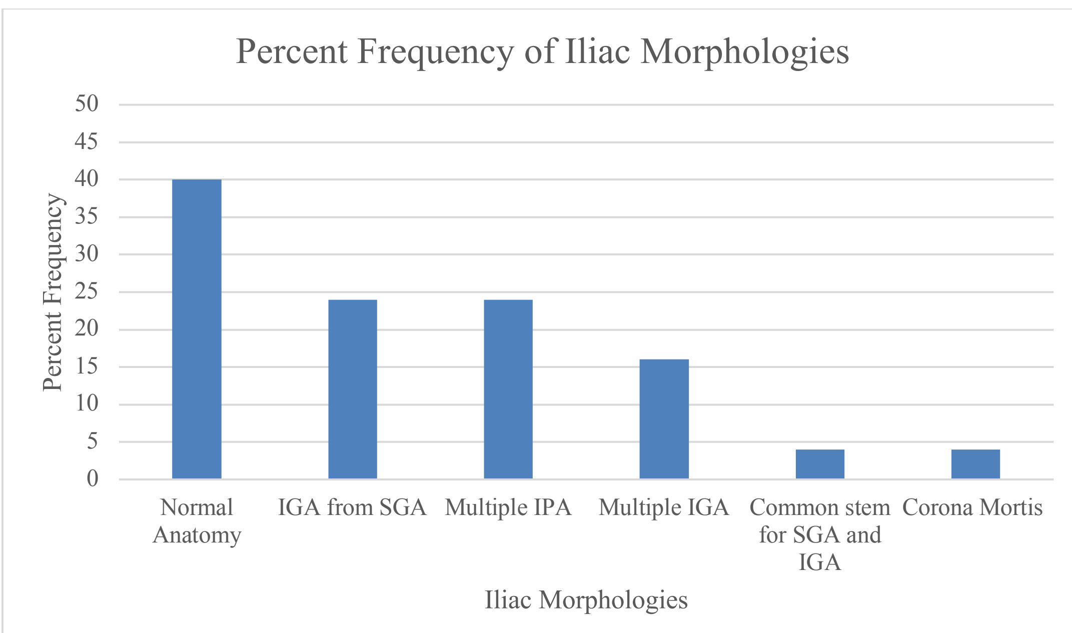

Figure 12: Percent frequency of internal and external iliac artery morphologies.
IGA = inferior gluteal artery, SGA = superior gluteal artery, IPA = internal pudendal artery

Table 15. Percent frequency of internal and external iliac artery variants on the right and left.

Iliac Variants	Right (n = 25) % (n)	Left (n = 25) % (n)	Total (n =50) % (n)
Anomalous origin of IGA from SGA	16 (4)	8 (2)	12 (6)
Multiple IPA	16 (4)	8 (2)	12 (6)
Multiple IGA	8 (2)	8 (2)	8 (4)
Common stem for SGA and IGA	0	4 (1)	2 (1)
Corona Mortis	0	4 (1)	2 (1)

Lower Extremity Variants

Normal anatomy of the lower extremity was seen in 32% (8 cases) of the body donors. Variant anatomy of the lower extremity was seen in 68% (17 cases) of the body donors. Variants were seen on the right side in 5 of 17 cases (29.4%), on the left side in 7 of 17 cases (41.2%), and bilaterally in 5 cases (29.4%). Of the 17 cases, a single variant was seen in 10 cases (58.8%), 2 variants were seen in 4 cases (23.5%), and 3 variants were seen in 3 cases (17.6%). If the lower extremities of each body donor are counted individually, creating a total of 50 lower extremities, normal anatomy was seen in 56% (28 cases) of body donors, a single variant was seen in 32% (16 cases) of body donors, and 2 variants were seen in 12% (6 cases) of body donors (Table 16).

The most common variants identified were anomalous origins of the medial circumflex femoral artery and/or the lateral circumflex femoral artery from the femoral artery, a common stem for the deep femoral artery and the lateral circumflex femoral artery off the femoral artery, and anomalous origins of the branches of the lateral circumflex femoral artery. An anomalous origin of the lateral circumflex femoral artery directly from the femoral artery was seen in 6 cases (24%), all of which occurred on the left side and an anomalous origin of the medial circumflex femoral artery was seen in 4 cases (16%), 2 of which occurred on the right and 2 on the left (Table 17). An anomalous origin of the medial and lateral circumflex femoral arteries from the femoral artery occurred in 1 case (4%) on the right. A common stem of the lateral circumflex femoral artery and the deep femoral artery off the femoral artery was seen in 5 cases (20%), 2 of which occurred on the right and 3 on the left (Table 17).

An anomalous origin of the descending branch of the lateral circumflex femoral artery from the deep femoral artery occurred in 2 cases (8%), 1 on the right side and 1 on the left side and in another case (4%) from the left femoral artery (Table 17). The ascending branch of the lateral circumflex femoral artery aberrantly originated from the deep femoral artery on the right side in 1 case (4%).

The next most common variants involved common stems of the medial and lateral circumflex femoral arteries with various branches. A common stem for the medial circumflex femoral artery and the deep femoral artery off the femoral artery was seen in 2 cases (8%), both of which occurred on the right side (Table 17). The medial circumflex femoral artery also participated in a common stem with muscular branches off the deep femoral artery on the left side in 1 case (4%). A common stem for the lateral circumflex femoral artery and its descending branches off the deep femoral artery was seen in 3 cases (12%) on the right and in 1 case (4%) from the right femoral artery (Table 17). The only other variant of the lower extremity observed was a high branch point of the deep femoral artery from the left femoral artery.

Table 16. Percent frequency of the number of variants of the lower extremity arteries on the right and left.

	Right (n = 25) **% (n)**	**Left (n = 25)** **% (n)**	**Total (n = 50)** **% (n)**
No variants	60 (15)	52 (13)	56 (28)
1 variant	28 (7)	36 (9)	32 (16)
2 variants	12 (3)	12 (3)	12 (6)

Table 17. Percent frequency of variant morphologies of the lower extremity arteries on the right and left.

	Right (n = 25) % (n)	Left (n = 25) % (n)	Total (n = 50) % (n)
Anomalous origin of lateral circumflex femoral artery from the femoral artery	0	24 (6)	12 (6)
Anomalous origin of the medial circumflex femoral artery from the femoral artery	8 (2)	8 (2)	8 (4)
Anomalous origin of the medial and lateral circumflex femoral arteries from the femoral artery	4 (1)	0	2 (1)
Common stem of the lateral circumflex femoral artery and the deep femoral artery off the femoral artery	8 (2)	12 (3)	10 (5)
Anomalous origin of the descending branch of the lateral circumflex femoral artery from the deep femoral artery	4 (1)	4 (1)	4 (2)
Anomalous origin of the descending branch of the lateral circumflex femoral artery from the femoral artery	0	4 (1)	2 (1)
Anomalous origin of the ascending branch of the lateral circumflex femoral artery from the deep femoral artery	4 (1)	0	2 (1)
Common stem for the medial circumflex femoral artery and the deep femoral artery from the femoral artery	8 (2)	0	4 (2)
Common stem for the medial circumflex femoral artery and muscular branches from the deep femoral artery	0	4 (1)	2 (1)
Common stem for the lateral circumflex femoral artery and its descending branch from the deep femoral artery	12 (3)	0	6 (3)
Common stem for the lateral circumflex femoral artery and its descending branch from the femoral artery	4 (1)	0	2 (1)
High branch point of the deep femoral artery from the femoral artery	0	4 (1)	2 (1)

Comparison of Variants Across Multiple Regions of the Body

Central Vs. Peripheral

Examination of the relationship between central variants (e.g. arch of the aorta, unpaired abdominal aortic branches) and peripheral variants (e.g. upper and lower extremities), reveals that the most common arterial variants to occur in tandem in the sample were those of the variant foregut with variants of the left subclavian artery, – seen in 52% of cases (Table 18) - the upper and lower extremities, - 36–44% of cases and 40–44% of cases, respectively (Table 18) - and the right iliac artery – seen in 36% of cases (Table 18). Similar frequencies were observed for the variant midgut + variant left subclavian artery (44%), variant midgut + variant upper extremities (36-40%), and the variant midgut + variant lower extremities (32–36%) (Table 18). Examination of the relationship between normal central arterial anatomy and normal peripheral arterial anatomy, revealed a reversal of the pattern of frequencies; with very few cases having normal abdominal arterial anatomy combined with normal peripheral arterial anatomy (Table 19).

Indeed, variants of the abdominal arterial anatomy were consistently observed to be the most frequent variants to co-occur with any other arterial anatomy. This pattern holds true for the aortic arch, in which both normal and variant arterial morphologies of the aortic arch most commonly occurred with variations of the foregut and midgut (Table 20). 64% of cases had normal aortic arch + variant foregut arterial anatomy and 56% of cases had normal aortic arch + variant midgut arterial anatomy (Table 20). 16% of cases had variant aortic arch + variant foregut arterial anatomy and 12% had variant aortic arch

+ variant midgut arterial anatomy. Although there is a difference in the frequency of cases between the normal and variant aortic arch, both were more often associated with variants of the foregut/midgut than any other central arterial variant. Peripherally, variants of the left subclavian artery, right and left upper extremities, and the left lower extremity were the most common variants to occur in tandem with the normal aortic arch arterial morphology (Table 21). The variant arterial morphologies of the aortic arch were most often seen in combination with variants of the left subclavian artery, the right and left upper extremities, and the left lower extremity (Table 21). The same pattern held true for the coronary arteries, but there was an increase of cases that were associated with variations in the right and left iliac arteries as well as the right and left lower extremities (Tables 22, 23).

When looking at the foregut and midgut, both groups were most often seen in combination with variants in one another. The variant foregut and midgut were also the only groups where the variant anatomy was most often paired with variant anatomy in the other categories, as opposed to the normal central anatomy being paired with variant peripheral anatomy (Tables 24–27). Both the variant foregut and midgut were frequently found in combination with variations of the right and left renal arteries (Tables 24, 26). However, variations in the foregut occurred more often with variations in the hindgut than the renal arteries. This pattern was not observed with the variant midgut, in which the combination of the variant midgut and hindgut was the least frequently observed amongst the central variant group (Table 26). Peripherally, the variant foregut and midgut most often occurred in tandem with variations of the left subclavian artery, the right and left upper extremities, the right iliac artery, and the right and left lower extremities (Tables 25, 27).

Both the normal and variant hindgut were most often observed in tandem with variations of the foregut and midgut, although this pairing was more frequently associated with the normal hindgut (Table 28). Peripherally, the variant hindgut was most observed in association with variations of the right and left upper extremity (Table 29). Whereas, the normal hindgut was most often observed with variations of the left subclavian artery, the right upper extremity, the right iliac, and the right and left lower extremities (Table 29).

A similar pattern is seen amongst the variant right and left renal arteries. Centrally, the normal and variant renal arteries were most often observed in combination with variations in the foregut and the midgut (Tables 30, 32). The combination of normal right and left renal arteries and a variant aortic arch was also commonly observed. Peripherally, the variant right renal arteries were most often observed in tandem with variations of the left upper extremity and the right lower extremity (Table 31). The normal right renal arteries were observed most commonly with variations of the left subclavian artery, right upper extremity, and left lower extremity (Table 31). The same pattern was observed for the normal left renal arteries as well (Table 33). The variant left renal arteries were most often observed in tandem with variations of the left subclavian artery and the left upper extremity (Table 33).

Table 18. Percent frequency of the variant central arterial anatomy with the variant peripheral arterial anatomy.

	Variant Brain	Variant Right Carotids	Variant Left Carotids	Variant Right Subclavian	Variant Left Subclavian	Variant Right UE	Variant Left UE	Variant Right Suprarenal	Variant Left Suprarenal	Variant Gonadal	Variant Right Iliac	Variant Left Iliac	Variant Right LE	Variant Left LE
Variant Aortic Arch	0%	0%	0%	4%	20%	12%	4%	8%	8%	0%	8%	8%	16%	8%
Variant Coronary Artery	0%	4%	0%	0%	16%	4%	12%	0%	4%	0%	4%	4%	8%	12%
Variant Foregut	4%	8%	0%	20%	52%	44%	36%	28%	28%	0%	36%	20%	40%	44%
Variant Midgut	4%	8%	0%	16%	44%	40%	36%	20%	20%	0%	24%	20%	36%	32%
Variant Hindgut	4%	0%	0%	8%	12%	24%	24%	16%	8%	0%	12%	8%	16%	8%
Variant Right Renal	0%	4%	0%	8%	16%	12%	20%	8%	8%	0%	8%	4%	20%	4%
Variant Left Renal	4%	4%	0%	12%	16%	12%	16%	8%	4%	0%	8%	12%	12%	4%

Table 19. Percent frequency of the normal central arterial anatomy with the normal peripheral arterial anatomy.

	Normal Brain	Normal Right Carotid	Normal Left Carotid	Normal Right Subclavian	Normal Left Subclavian	Normal Right UE	Normal Left UE	Normal Right Suprarenal	Normal Left Suprarenal	Normal Gonadal	Normal Right Iliac	Normal Left Iliac	Normal Right LE	Normal Left LE
Normal Aortic Arch	76%	72%	80%	56%	40%	40%	44%	60%	60%	76%	52%	56%	56%	40%
Normal Coronary Artery	76%	76%	80%	52%	36%	32%	48%	52%	56%	76%	44%	52%	48%	44%
Normal Foregut	8%	8%	8%	4%	8%	0%	4%	8%	8%	4%	8%	4%	8%	8%
Normal Midgut	20%	20%	20%	12%	12%	8%	16%	12%	12%	16%	8%	16%	12%	8%
Normal Hindgut	56%	48%	56%	40%	16%	28%	40%	44%	36%	52%	32%	40%	32%	20%
Normal Right Renal	64%	64%	68%	48%	24%	28%	48%	48%	48%	64%	40%	44%	48%	28%
Normal Left Renal	68%	64%	68%	52%	24%	28%	44%	48%	44%	64%	40%	52%	40%	28%

Table 20. Percent frequency of normal and variant aortic arch anatomy with variant central arterial anatomy.

	Variant Coronary Artery	Variant Foregut	Variant Midgut	Variant Hindgut	Variant Right Renal	Variant Left Renal
Normal Aortic Arch	16%	64%	56%	24%	24%	28%
Variant Aortic Arch	4%	16%	12%	0%	4%	0%

Table 21. Percent frequency of normal and variant aortic arch anatomy with variant peripheral arterial anatomy.

	Variant Brain	Variant Right Carotid	Variant Left Carotid	Variant Right Subclavian	Variant Left Subclavian	Variant Right UE	Variant Left UE	Variant Right Suprarenal	Variant Left Suprarenal	Variant Gonadal	Variant Right Iliac	Variant Left Iliac	Variant Right LE	Variant Left LE
Normal Aortic Arch	4%	8%	0%	24%	40%	40%	36%	20%	20%	4%	28%	24%	24%	40%
Variant Aortic Arch	0%	0%	0%	4%	20%	12%	4%	8%	8%	0%	8%	8%	16%	8%

Table 22. Percent frequency of normal and variant coronary artery anatomy with variant central arterial anatomy.

	Variant Aortic Arch	Variant Foregut	Variant Midgut	Variant Hindgut	Variant Right Renal	Variant Left Renal
Normal Coronary Artery	16%	64%	52%	28%	20%	24%
Variant Coronary Artery	4%	16%	16%	4%	8%	4%

Table 23. Percent frequency of normal and variant coronary artery anatomy with variant peripheral arterial anatomy.

	Variant Brain	Variant Right Carotid	Variant Left Carotid	Variant Right Subclavian	Variant Left Subclavian	Variant Right UE	Variant Left UE	Variant Right Suprarenal	Variant Left Suprarenal	Variant Gonadal	Variant Right Iliac	Variant Left Iliac	Variant Right LE	Variant Left LE
Normal Cornary Artery	4%	4%	0%	28%	44%	48%	28%	28%	24%	4%	36%	28%	32%	36%
Variant Coronary Artery	0%	4%	0%	0%	20%	4%	12%	0%	4%	0%	4%	4%	8%	12%

Table 24. Percent frequency of normal and variant foregut anatomy with variant central arterial anatomy.

	Variant Aortic Arch	Variant Coronary Artery	Variant Midgut	Variant Hindgut	Variant Right Renal	Variant Left Renal
Normal Foregut	0%	0%	4%	4%	0%	4%
Variant Foregut	16%	16%	64%	28%	24%	24%

Table 25. Percent frequency of normal and variant foregut anatomy with variant peripheral arterial anatomy.

	Variant Brain	Variant Right Carotid	Variant Left Carotid	Variant Right Subclavian	Variant Left Subclavian	Variant Right UE	Variant Left UE	Variant Right Suprarenal	Variant Left Suprarenal	Variant Gonadal	Variant Right Iliac	Variant Left Iliac	Variant Right LE	Variant Left LE
Normal Foregut	0%	0%	0%	4%	0%	8%	4%	0%	0%	4%	0%	4%	0%	0%
Variant Foregut	4%	8%	0%	20%	52%	44%	36%	28%	28%	0%	36%	20%	40%	44%

Table 26. Percent frequency of normal and variant midgut anatomy with variant central arterial anatomy.

	Variant Aortic Arch	Variant Coronary Artery	Variant Foregut	Variant Hindgut	Variant Right Renal	Variant Left Renal
Normal Midgut	4%	0%	16%	4%	4%	8%
Variant Midgut	12%	16%	64%	8%	20%	20%

Table 27. Percent frequency of normal and variant midgut anatomy with variant peripheral arterial anatomy.

	Variant Brain	Variant Right Carotid	Variant Left Carotid	Variant Right Subclavian	Variant Left Subclavian	Variant Right UE	Variant Left UE	Variant Right Suprarenal	Variant Left Suprarenal	Variant Gonadal	Variant Right Iliac	Variant Left Iliac	Variant Right LE	Variant Left LE
Normal Midgut	0%	0%	0%	8%	8%	12%	4%	8%	8%	4%	12%	4%	8%	12%
Variant Midgut	4%	8%	0%	16%	44%	40%	36%	20%	20%	0%	24%	20%	32%	32%

Table 28. Percent frequency of normal and variant hindgut anatomy with variant central arterial anatomy.

	Variant Aortic Arch	Variant Coronary Artery	Variant Foregut	Variant Midgut	Variant Right Renal	Variant Left Renal
Normal Hindgut	8%	12%	52%	40%	8%	12%
Variant Hindgut	8%	4%	28%	28%	16%	16%

Table 29. Percent frequency of normal and variant hindgut anatomy with variant peripheral arterial anatomy.

	Variant Brain	Variant Right Carotid	Variant Left Carotid	Variant Right Subclavian	Variant Left Subclavian	Variant Right UE	Variant Left UE	Variant Right Suprarenal	Variant Left Suprarenal	Variant Gonadal	Variant Right Iliac	Variant Left Iliac	Variant Right LE	Variant Left LE
Normal Hindgut	0%	8%	0%	16%	40%	28%	16%	12%	20%	4%	24%	16%	24%	36%
Variant Hindgut	4%	0%	0%	8%	12%	24%	24%	16%	8%	0%	12%	8%	16%	8%

Table 30. Percent frequency of normal and variant right renal arterial anatomy with variant central arterial anatomy.

	Variant Aortic Arch	Variant Coronary Artery	Variant Foregut	Variant Midgut	Variant Hindgut	Variant Left Renal
Normal Right Renal	16%	8%	56%	48%	16%	12%
Variant Right Renal	4%	8%	24%	20%	16%	16%

Table 31. Percent frequency of normal and variant right renal arterial anatomy with variant peripheral arterial anatomy.

	Variant Brain	Variant Right Carotid	Variant Left Carotid	Variant Right Subclavian	Variant Left Subclavian	Variant Right UE	Variant Left UE	Variant Right Suprarenal	Variant Left Suprarenal	Variant Gonadal	Variant Right Iliac	Variant Left Iliac	Variant Right LE	Variant Left LE
Normal Right Renal	4%	4%	0%	20%	44%	40%	20%	20%	20%	4%	28%	24%	20%	40%
Variant Right Renal	0%	4%	0%	8%	16%	12%	20%	8%	8%	0%	8%	4%	20%	4%

Table 32. Percent frequency of normal and variant left renal arterial anatomy with variant central arterial anatomy.

	Variant Aortic Arch	Variant Coronary Artery	Variant Foregut	Variant Midgut	Variant Hindgut	Variant Right Renal
Normal Left Renal	20%	12%	56%	48%	16%	12%
Variant Left Renal	0%	4%	24%	20%	16%	16%

Table 33. Percent frequency of normal and variant left renal arterial anatomy with variant peripheral arterial anatomy.

	Variant Brain	Variant Right Carotid	Variant Left Carotid	Variant Right Subclavian	Variant Left Subclavian	Variant Right UE	Variant Left UE	Variant Right Suprarenal	Variant Left Suprarenal	Variant Gonadal	Variant Right Iliac	Variant Left Iliac	Variant Right LE	Variant Left LE
Normal Left Renal	0%	4%	0%	16%	44%	40%	24%	20%	24%	4%	28%	16%	28%	40%
Variant Left Renal	4%	4%	0%	12%	16%	12%	16%	8%	4%	0%	8%	12%	12%	4%

Aorta

When multiple central variants are considered at once, the variant aortic arch was most often associated with simultaneous variants of the foregut and midgut (12%), (Table 34). Another common pattern observed was a variant aortic arch with variants of the foregut, midgut, and hindgut (8%), (Table 35). The most commonly observed pattern for the normal aortic arch arterial anatomy, included the normal aortic arch + variants of the foregut + midgut seen in 52% of cases (Table 35). The next most common pattern was the normal aortic arch anatomy + variants of the foregut + midgut + normal anatomy of the right or left renal arteries, observed in 36% of cases for both the right and left renal arteries (Table 35).

Peripherally, variants of the aortic arch arterial anatomy + variants of the foregut were most often observed with variants of the left subclavian artery (16%), right upper extremity (12%), right iliac artery (12%), and right lower extremity (16%), (Table 36). The same pattern held true when groupings of the variant aortic arch + variant midgut and variant aortic arch + variant hindgut were considered with the peripheral variants (Table 36).

Table 34. Percent frequency of the variant aortic arch paired with another central variant occurring simultaneously with the other central variants.

	Variant Coronary Artery	Variant Foregut	Variant Midgut	Variant Hindgut	Variant Right Renal	Variant Left Renal
Variant Aortic Arch + Variant Coronary Artery	N/A	4%	4%	4%	4%	0%
Variant Aortic Arch + Variant Foregut	4%	N/A	12%	8%	4%	0%
Variant Aortic Arch + Variant Midgut	4%	12%	N/A	8%	4%	0%
Variant Aortic Arch + Variant Hindgut	4%	8%	8%	N/A	4%	0%
Variant Aortic Arch + Variant Right Renal	4%	4%	4%	4%	N/A	0%
Variant Aortic Arch + Variant Left Renal	0%	0%	0%	0%	0%	N/A

Table 35. Percent frequency of the normal and variant aortic arch occurring simultaneously with multiple central arterial morphologies. CA = coronary artery.

	Normal CA + Foregut + Midgut	Variant CA + Foregut + Midgut	Normal Foregut + Midgut	Variant Foregut + Midgut	Normal Foregut + Midgut + Hindgut	Variant Foregut + Midgut + Hindgut	Variant Foregut + Midgut, Normal Right Renal	Variant Foregut + Midgut + Right Renal	Variant Foregut + Midgut, Normal Left Renal	Variant Foregut + Midgut + Left Renal	Variant Foregut + Midgut + Both Renals
Normal Aortic Arch	4%	12%	4%	52%	4%	16%	36%	16%	36%	16%	8%
Variant Aortic Arch	0%	4%	0%	12%	0%	8%	8%	4%	12%	0%	0%

Table 36. Percent frequency of the variant aortic arch paired with another central variant occurring simultaneously with peripheral arterial variants.

	Variant Brain	Variant Right Carotid	Variant Left Carotid	Variant Right Subclavian	Variant Left Subclavian	Variant Right UE	Variant Left UE	Variant Right Suprarenal	Variant Left Suprarenal	Variant Gonadal	Variant Right Iliac	Variant Left Iliac	Variant Right LE	Variant Left LE
Variant Aortic Arch + Variant Coronary Artery	0%	0%	0%	0%	4%	0%	4%	0%	0%	0%	0%	0%	4%	0%
Variant Aortic Arch + Variant Forgeut	0%	0%	0%	4%	16%	12%	4%	8%	8%	0%	12%	4%	16%	8%
Variant Aortic Arch + Variant Midgut	0%	0%	0%	4%	12%	8%	4%	4%	4%	0%	8%	4%	12%	4%
Variant Aortic Arch + Variant Hindgut	0%	0%	0%	0%	8%	4%	4%	4%	0%	0%	4%	0%	8%	0%
Variant Aortic Arch + Variant Right Renal	0%	0%	0%	0%	4%	0%	4%	0%	0%	0%	0%	0%	4%	0%
Variant Aortic Arch + Variant Left Renal	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Coronary Arteries

Like the aortic arch, variants of the coronary arteries were most often seen in tandem with variants of the foregut + midgut, seen in 16% of the cases (Table 37). The next most common groupings included the variant coronary artery + variant foregut + variant right renal artery, seen in 8% of cases, and the variant coronary artery + variant midgut + variant right renal artery, also seen in 8% of cases (Table 37).

When the normal coronary artery and the variant coronary artery were compared, the normal coronary artery was more frequently found in combination with other central variants (Table 38). The three most common groupings observed were 1.) normal coronary artery + variant foregut + midgut, seen in 48% of cases, 2.) normal coronary artery + variant foregut + midgut + normal right renal, seen in 36% of cases, and 3.) normal coronary artery + variant foregut + midgut + normal left renal, seen in 36% of cases (Table 38).

Peripherally, variants of the coronary artery most often occurred along with variants of the foregut, left subclavian artery (16%), left upper extremity (12%), and the right and left lower extremities (8% each), (Table 39). The same frequencies were observed when variants of the coronary artery + variants of the midgut were considered with the peripheral variants (Table 39). The next most common groupings of variants included the variant coronary artery + variant right renal + left subclavian artery, seen in 8% of cases, and the variant coronary artery + variant right renal + variant right lower extremity, seen in 8% of cases (Table 39).

Table 37. Percent frequency of the variant coronary arteries paired with a central variant, occurring simultaneously with the other central variants.

	Variant Aortic Arch	Variant Foregut	Variant Midgut	Variant Hindgut	Variant Right Renal	Variant Left Renal
Variant Coronary Artery + Variant Aortic Arch	N/A	4%	4%	4%	4%	0%
Variant Coronary Artery + Variant Foregut	4%	N/A	16%	4%	8%	4%
Variant Coronary Artery + Variant Midgut	4%	16%	N/A	4%	8%	4%
Variant Coronary Artery + Variant Hindgut	4%	4%	4%	N/A	4%	0%
Variant Coronary Artery + Variant Right Renal	4%	8%	8%	4%	N/A	4%
Variant Coronary Artery + Variant Left Renal	0%	4%	4%	0%	4%	N/A

Table 38. Percent frequency of the normal and variant coronary arteries occurring simultaneously with multiple central arterial morphologies. AA = aortic arch.

	Normal AA + Foregut + Midgut	Variant AA + Foregut + Midgut	Normal Foregut + Midgut	Variant Foregut + Midgut	Normal Foregut + Midgut + Hindgut	Variant Foregut + Midgut + Hindgut	Variant Foregut + Midgut, Normal Right Renal	Variant Foregut + Midgut + Right Renal	Variant Foregut + Midgut, Normal Left Renal	Variant Foregut + Midgut + Left Renal	Variant Foregut + Midgut + Both Renals
Normal Coronary Artery	4%	8%	4%	48%	4%	20%	36%	12%	36%	12%	8%
Variant Coronary Artery	0%	4%	0%	16%	0%	4%	8%	8%	12%	4%	4%

Table 39. Percent frequency of the variant coronary arteries paired with a central variant occurring simultaneously with peripheral arterial variants.

	Variant Brain	Variant Right Carotid	Variant Left Carotid	Variant Right Subclavian	Variant Left Subclavian	Variant Right UE	Variant Left UE	Variant Right Suprarenal	Variant Left Suprarenal	Variant Gonadal	Variant Right Iliac	Variant Left Iliac	Variant Right LE	Variant Left LE
Variant Coronary Artery + Variant Aortic Arch	0%	0%	0%	0%	4%	0%	4%	0%	0%	0%	0%	0%	4%	0%
Variant Coronary Artery + Variant Foregut	0%	4%	0%	0%	16%	4%	12%	0%	4%	0%	0%	0%	8%	8%
Variant Coronary Artery + Variant Midgut	0%	4%	0%	0%	16%	4%	12%	0%	4%	0%	0%	0%	8%	8%
Variant Coronary Artery + Variant Hindgut	0%	0%	0%	0%	4%	0%	4%	0%	0%	0%	0%	0%	4%	0%
Variant Coronary Artery + Variant Right Renal	0%	4%	0%	0%	8%	0%	4%	0%	4%	0%	0%	0%	8%	0%
Variant Coronary Artery + Variant Left Renal	0%	4%	0%	0%	4%	0%	0%	0%	4%	0%	0%	0%	4%	0%

Foregut

Variants of the abdominal vasculature were more often observed to co-occur with other central and peripheral variants than any other category of arterial variants. Specifically examining cases with variant foregut arterial anatomy, the variant foregut + midgut + hindgut was the most frequent grouping of central variants observed, with 24% of cases displaying this morphology (Table 40). The next most common grouping was the variant foregut + variant midgut + variant right renal, seen in 20% of the cases (Table 40). Similarly, the variant foregut + variant midgut + variant left renal was seen in 16% of the cases as was the variant foregut + variant right renal + variant left renal (Table 40). When the normal and variant foregut were compared, the variant foregut was more often found in combination with other central variants (Table 41).

The combination of the variant foregut + variant midgut was most often associated with peripheral arterial variants (Table 42). Specifically, the variant foregut + midgut was most often associated with variants of the left subclavian artery, seen in 44% of cases, the right and left upper extremities (36% and 32% respectively), and the right and left lower extremities (32% each), (Table 42). The next most common grouping involved the variant foregut and hindgut with variations in the right and left upper extremities (20% each), the right suprarenal arteries (16%), and the right lower extremity (16%), (Table 42).

Table 40. Percent frequency of the variant foregut paired with a central variant, occurring simultaneously with the other central variants.

	Variant Aortic Arch	Variant Coronary Artery	Variant Midgut	Variant Hindgut	Variant Right Renal	Variant Left Renal
Variant Foregut + Variant Aortic Arch	N/A	4%	12%	8%	4%	0%
Variant Foregut + Variant Coronary Artery	4%	N/A	16%	4%	8%	4%
Variant Foregut + Variant Midgut	12%	16%	N/A	24%	20%	16%
Variant Foregut + Variant Hindgut	8%	4%	24%	N/A	16%	12%
Variant Foregut + Variant Right Renal	4%	8%	20%	16%	N/A	16%
Variant Foregut + Variant Left Renal	0%	4%	16%	12%	16%	N/A

Table 41. Percent frequency of the normal and variant foregut occurring simultaneously with multiple central arterial morphologies. AA = aortic arch, CA = coronary artery.

	Normal AA + CA	Variant AA + CA	Normal Midgut + Hindgut	Variant Midgut + Hindgut	Normal Midgut + Right Renal	Variant Midgut + Right Renal	Normal Midgut + Left Renal	Variant Midgut + Left Renal
Normal Foregut	8%	0%	4%	4%	4%	0%	4%	4%
Variant Foregut	52%	4%	12%	24%	12%	20%	8%	16%

Table 42. Percent frequency of the variant foregut paired with a central variant occurring simultaneously with peripheral arterial variants.

	Variant Brain	Variant Right Carotid	Variant Left Carotid	Variant Right Subclavian	Variant Left Subclavian	Variant Right UE	Variant Left UE	Variant Right Suprarenal	Variant Left Suprarenal	Variant Gonadal	Variant Right Iliac	Variant Left Iliac	Variant Right LE	Variant Left LE
Variant Foregut + Variant Aortic Arch	0%	0%	0%	4%	16%	12%	4%	8%	8%	0%	12%	4%	16%	8%
Variant Foregut + Variant Coronary Artery	0%	4%	0%	0%	16%	4%	12%	0%	4%	0%	0%	0%	8%	8%
Variant Foregut + Variant Midgut	4%	8%	0%	16%	44%	36%	32%	20%	20%	0%	24%	16%	32%	32%
Variant Foregut + Variant Hindgut	4%	0%	0%	8%	12%	20%	20%	16%	8%	0%	12%	4%	16%	8%
Variant Foregut + Variant Right Renal	0%	4%	0%	4%	12%	12%	20%	8%	8%	0%	8%	4%	20%	4%
Variant Foregut + Variant Left Renal	4%	4%	0%	12%	16%	8%	12%	8%	4%	0%	8%	8%	12%	4%

Midgut

When variants of the midgut were combined with other central variants, the frequency of each case was very similar to that observed with the variants in the foregut (Tables 40 and 43). As stated previously, the grouping of the variant foregut + midgut + hindgut was the most frequently observed combination of central variants, seen in 24% of cases (Table 43). Following that pattern, the grouping of the variant foregut + midgut + any of the central variants was the most commonly observed combination compared to any of the other central variants (Table 43).

Peripherally, the variant foregut + variant midgut was most often observed with other peripheral variants (Table 44). The frequency of cases involving variant foregut + variant midgut + peripheral arterial variants is the same as stated previously for the variant foregut (Tables 42 and 44). The next most common peripheral groupings observed were the variant midgut + variant hindgut + variant right/left upper extremity, seen in 20% of cases for both the right/left UE (Table 44).

Table 43. Percent frequency of the variant midgut paired with a central variant, occurring simultaneously with the other central variants.

	Variant Aortic Arch	Variant Coronary Artery	Variant Foregut	Variant Hindgut	Variant Right Renal	Variant Left Renal
Variant Midgut + Variant Aortic Arch	N/A	4%	12%	8%	4%	0%
Variant Midgut + Variant Coronary Artery	4%	N/A	16%	4%	8%	4%
Variant Midgut + Variant Foregut	12%	16%	N/A	24%	20%	16%
Variant Midgut + Variant Hindgut	8%	4%	24%	N/A	12%	12%
Variant Midgut + Variant Right Renal	4%	8%	20%	12%	N/A	12%
Variant Midgut + Variant Left Renal	0%	4%	16%	12%	12%	N/A

Table 44. Percent frequency of the variant midgut paired with a central variant occurring simultaneously with peripheral arterial variants.

	Variant Brain	Variant Right Carotid	Variant Left Carotid	Variant Right Subclavian	Variant Left Subclavian	Variant Right UE	Variant Left UE	Variant Right Suprarenal	Variant Left Suprarenal	Variant Gonadal	Variant Right Iliac	Variant Left Iliac	Variant Right LE	Variant Left LE
Variant Midgut + Variant Aortic Arch	0%	0%	0%	4%	12%	8%	4%	4%	4%	0%	8%	4%	12%	4%
Variant Midgut + Variant Coronary Artery	0%	4%	0%	0%	16%	4%	12%	0%	4%	0%	0%	0%	8%	8%
Variant Midgut + Variant Foregut	4%	8%	0%	16%	44%	36%	32%	20%	20%	0%	24%	16%	32%	32%
Variant Midgut + Variant Hindgut	4%	0%	0%	8%	12%	20%	20%	16%	8%	0%	8%	8%	12%	4%
Variant Midgut + Variant Right Renal	0%	4%	0%	4%	12%	8%	16%	8%	8%	0%	4%	4%	16%	0%
Variant Midgut + Variant Left Renal	4%	4%	0%	8%	12%	8%	12%	8%	4%	0%	0%	12%	8%	0%

Hindgut

The most common grouping of central variants involving the hindgut was simultaneous variations of the foregut, midgut, and hindgut (24%), (Table 45). The next most common grouping involved the variant foregut and hindgut with the variant right renal artery (16%), (Table 45).

Peripherally, the most common cases observed involved the variant foregut + variant hindgut with the variant right and left upper extremities (20% each), the right suprarenal arteries (16%), and the right lower extremity (16%), (Table 46). The next most common grouping of variants involved the variant midgut + variant hindgut with the variant right and left upper extremities (20% each), and the right suprarenal arteries seen in 16% of the cases (Table 46). Lastly, in 16% of the cases, the grouping of the variant hindgut + variant right renal + variant left upper extremity was observed (Table 46).

Table 45. Percent frequency of the variant hindgut paired with a central variant, occurring simultaneously with the other central variants.

	Variant Aortic Arch	Variant Coronary Artery	Variant Foregut	Variant Midgut	Variant Right Renal	Variant Left Renal
Variant Hindgut + Variant Aortic Arch	N/A	4%	8%	8%	4%	0%
Variant Hindgut + Variant Coronary Artery	4%	N/A	4%	4%	4%	0%
Variant Hindgut + Variant Foregut	8%	4%	N/A	24%	16%	12%
Variant Hindgut + Variant Midgut	8%	4%	24%	N/A	12%	12%
Variant Hindgut + Variant Right Renal	4%	4%	16%	12%	N/A	8%
Variant Hindgut + Variant Left Renal	0%	0%	12%	12%	8%	N/A

Table 46. Percent frequency of the variant hindgut paired with a central variant occurring simultaneously with peripheral arterial variants.

	Variant Brain	Variant Right Carotid	Variant Left Carotid	Variant Right Subclavian	Variant Left Subclavian	Variant Right UE	Variant Left UE	Variant Right Suprarenal	Variant Left Suprarenal	Variant Gonadal	Variant Right Iliac	Variant Left Iliac	Variant Right LE	Variant Left LE
Variant Hindgut + Variant Aortic Arch	0%	0%	0%	0%	8%	4%	4%	4%	0%	0%	4%	0%	8%	0%
Variant Hindgut + Variant Coronary Artery	0%	0%	0%	0%	4%	0%	4%	0%	0%	0%	0%	0%	4%	0%
Variant Hindgut + Variant Foregut	4%	0%	0%	8%	12%	20%	20%	16%	8%	0%	12%	4%	16%	8%
Variant Hindgut + Variant Midgut	4%	0%	0%	8%	12%	20%	20%	16%	8%	0%	8%	8%	12%	4%
Variant Hindgut + Variant Right Renal	0%	0%	0%	4%	4%	12%	16%	4%	4%	0%	8%	0%	12%	4%
Variant Hindgut + Variant Left Renal	4%	0%	0%	8%	4%	12%	12%	4%	0%	0%	4%	8%	4%	4%

Renal Arteries

Both the variant right and left renal arteries yielded the greatest frequency of cases when paired with the variant foregut or midgut (Tables 47 and 48). The most common groupings for the variant right renal artery included, 1.) variant right renal artery + variant foregut + variant midgut, seen in 20% of the cases, 2.) variant right renal artery + variant foregut + variant hindgut, seen in 16% of the cases, and 3.) variant right renal artery + variant foregut + variant left renal artery, seen in 16% of the cases (Table 47). The left renal artery displayed similar results to the right renal artery, with the most common grouping involving the variant left renal artery + variant foregut + variant midgut (16% of cases), (Table 48). The next most common combinations involved the variant left renal artery + variant foregut + variant right renal artery (16%) and the variant left renal artery + variant foregut + variant hindgut (12%), (Table 48).

Peripherally, the combination of the renal arteries with the foregut or midgut and the peripheral variants yielded the highest frequencies. For the right renal artery, the most commonly observed groupings included the variant right renal artery + variant foregut + variant left upper extremity (20% of cases), and the variant right renal artery + variant foregut + variant right lower extremity (20% of cases), (Table 49). Similar frequencies were observed for the groupings of the variant right renal artery + variant midgut + variant left upper extremity (16% of cases) and the variant right renal artery + variant midgut + variant right lower extremity (16% of cases), (Table 49).

However, for the left renal artery, the frequency distribution of groupings with the variant peripheral cases was much more spread out (Table 50). When variants of the left renal artery were observed with variants of the foregut, the most common peripheral variants to occur with them included the left subclavian artery (16%), the right subclavian artery (12%), the left upper extremity (12%), and the right lower extremity (12%) (Table 50). This pattern is similar in cases involving the variant left renal artery + the variant midgut with variants in the left subclavian artery (12%) and the left upper extremity (12%) being the most commonly observed. There was also an increase in the frequency of cases involving the variant left renal artery + variant midgut + variant left iliac artery (12%) (Table 50). When the variant left renal artery is observed with the variant hindgut, the most common peripheral variants include the right and left upper extremities (12% each) and the left iliac artery (8%) (Table 50).

When the normal and variant renal arterial morphologies are compared, the most common groupings observed included arterial variants of the foregut and midgut (Table 51). However, there were more cases of normal right/left renal anatomy + variant foregut + variant midgut (40% of cases) than variant right/left renal anatomy + variant foregut + variant midgut (12% of cases) (Table 51). The next most commonly observed grouping involving normal renal arterial anatomy, was the normal right/ left renal + normal midgut + normal hindgut, seen in 12% of cases (Table 51). For the variant renal anatomy, the next most common grouping of variants involved variants of the right/left renal arteries + variant foregut + midgut + hindgut, observed in 4% of cases (Table 51).

Table 47. Percent frequency of the variant right renal artery paired with a central variant, occurring simultaneously with the other central variants.

	Variant Aortic Arch	Variant Coronary Artery	Variant Foregut	Variant Midgut	Variant Hindgut	Variant Left Renal
Variant Right Renal + Variant Aortic Arch	N/A	4%	4%	4%	4%	0%
Variant Right Renal + Variant Coronary Artery	4%	N/A	8%	8%	4%	4%
Variant Right Renal + Variant Foregut	4%	8%	N/A	20%	16%	16%
Variant Right Renal + Variant Midgut	4%	8%	20%	N/A	12%	12%
Variant Right Renal + Variant Hindgut	4%	4%	16%	12%	N/A	8%
Variant Right Renal + Variant Left Renal	0%	4%	16%	12%	8%	N/A

Table 48. Percent frequency of the variant left renal artery paired with a central variant, occurring simultaneously with the other central variants.

	Variant Aortic Arch	Variant Coronary Artery	Variant Foregut	Variant Midgut	Variant Hindgut	Variant Right Renal
Variant Left Renal + Variant Aortic Arch	N/A	0%	0%	0%	0%	0%
Variant Left Renal + Variant Coronary Artery	0%	N/A	4%	4%	0%	4%
Variant Left Renal + Variant Foregut	0%	4%	N/A	16%	12%	16%
Variant Left Renal + Variant Midgut	0%	4%	16%	N/A	12%	12%
Variant Left Renal + Variant Hindgut	0%	0%	12%	12%	N/A	8%
Variant Left Renal + Variant Right Renal	0%	4%	16%	12%	8%	N/A

Table 49. Percent frequency of the variant right renal artery paired with a central variant occurring simultaneously with peripheral arterial variants.

	Variant Brain	Variant Right Carotid	Variant Left Carotid	Variant Right Subclavian	Variant Left Subclavian	Variant Right UE	Variant Left UE	Variant Right Suprarenal	Variant Left Suprarenal	Variant Gonadal	Variant Right Iliac	Variant Left Iliac	Variant Right LE	Variant Left LE
Variant Right Renal + Variant Aortic Arch	0%	0%	0%	0%	4%	0%	4%	0%	0%	0%	0%	0%	4%	0%
Variant Right Renal + Variant Coronary Artery	0%	4%	0%	0%	8%	0%	4%	0%	4%	0%	0%	0%	8%	0%
Variant Right Renal + Variant Foregut	0%	4%	0%	4%	12%	12%	20%	8%	8%	0%	8%	4%	20%	4%
Variant Right Renal + Variant Midgut	0%	4%	0%	4%	12%	8%	16%	8%	8%	0%	4%	4%	16%	0%
Variant Right Renal + Variant Hindgut	0%	0%	0%	4%	4%	12%	16%	4%	4%	0%	8%	0%	12%	4%
Variant Right Renal + Variant Left Renal	0%	4%	0%	4%	8%	8%	12%	4%	4%	0%	4%	4%	12%	4%

Table 50. Percent frequency of the variant left renal artery paired with a central variant occurring simultaneously with peripheral arterial variants.

	Variant Brain	Variant Right Carotid	Variant Left Carotid	Variant Right Subclavian	Variant Left Subclavian	Variant Right UE	Variant Left UE	Variant Right Suprarenal	Variant Left Suprarenal	Variant Gonadal	Variant Right Iliac	Variant Left Iliac	Variant Right LE	Variant Left LE
Variant Left Renal + Variant Aortic Arch	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Variant Left Renal + Variant Coronary Artery	0%	4%	0%	0%	4%	0%	0%	0%	4%	0%	0%	0%	4%	0%
Variant Left Renal + Variant Foregut	4%	4%	0%	12%	16%	8%	12%	8%	4%	0%	8%	8%	12%	4%
Variant Left Renal + Variant Midgut	4%	4%	0%	8%	12%	8%	12%	8%	4%	0%	0%	12%	8%	0%
Variant Left Renal + Variant Hindgut	4%	0%	0%	8%	4%	12%	12%	4%	0%	0%	4%	8%	4%	4%
Variant Left Renal + Variant Right Renal	0%	4%	0%	4%	8%	8%	12%	4%	4%	0%	4%	4%	12%	4%

Table 51. Percent frequency of the normal and variant right and left renal arteries occurring simultaneously with multiple central arterial morphologies.

	Normal Foregut + Midgut	Variant Foregut + Midgut	Normal Foregut + Midgut + Hindgut	Variant Foregut + Midgut + Hindgut	Normal Foregut + Hindgut	Variant Foregut + Hindgut	Normal Midgut + Hindgut	Variant Midgut + Hindgut	Variant Foregut + Midgut + Right renal	Variant Foregut + Midgut + Left Renal
Normal Right Renal	4%	44%	4%	12%	4%	0%	16%	4%	N/A	4%
Variant Right Renal	0%	20%	0%	12%	0%	4%	0%	0%	N/A	12%
Normal Left Renal	4%	48%	4%	16%	4%	0%	12%	0%	8%	N/A
Variant Left Renal	0%	16%	0%	8%	0%	4%	4%	4%	12%	N/A
Normal Left + Right Renal	4%	40%	4%	8%	4%	0%	12%	0%	N/A	N/A
Variant Left + Right Renal	0%	12%	0%	4%	0%	4%	0%	0%	N/A	N/A

Individual Cases

NZFST

Sex: Female

Age: 94

Cause of death (COD): cardiac arrest/atrial fibrillation/hypertension

Summary of Variants Seen (Figures 13-14):

- The common hepatic artery gives off multiple accessory hepatic arteries
- The proper hepatic artery gives off the cystic artery
- The descending branch of the **left colic artery** of the IMA bifurcates into its own set of ascending and descending branches. Creates a total of 2 ascending branches and 1 descending branch
- There is an **accessory right renal artery** off the abdominal aorta going to the **right kidney**
- There is an **accessory left renal artery** off the abdominal aorta going to the **left kidney**
- In the **right upper extremity**, there is an anomalous origin of the lateral thoracic artery from the **subscapular artery**
- In the **right upper extremity**, there is a <u>high branch point</u> of the radial and ulnar arteries, about halfway down the arm, and the radial artery crosses over the ulnar artery

- In the **left upper extremity**, there is an anomalous origin of the lateral thoracic artery from the **subscapular artery**
- In the left upper extremity, there are 2 circumflex scapular branches
- In the **right internal iliac**, there is an anomalous origin of the inferior gluteal artery from the **superior gluteal artery**
- In the **right lower extremity**, there is a common stem for the lateral circumflex femoral artery and the deep femoral artery off the femoral artery
- In the **left lower extremity**, there is an anomalous origin of lateral circumflex femoral artery from the **femoral artery**

Detailed Overview:

ARCH OF THE AORTA

The brachiocephalic trunk is normal and branches into the right subclavian and right common carotid arteries normally. The left common carotid is normal. The left subclavian is normal.

HEART

The right coronary artery is normal. The right marginal artery is normal. The posterior interventricular artery is normal and comes off the right coronary artery. The left coronary artery is normal. The left circumflex artery is normal. The left anterior descending (LAD) artery is normal. The left marginal artery is normal.

FOREGUT

The celiac trunk has a normal branching pattern. It branches close to the SMA on the abdominal aorta. The splenic artery is normal. All the branches of the splenic artery are cut off so cannot find the left gastro-omental artery. The left gastric artery is normal. The common hepatic artery is normal. The proper hepatic artery bifurcates quickly after it becomes the proper hepatic artery (after the gastroduodenal artery branches off). **There are multiple accessory hepatic arteries coming off the common hepatic artery. The cystic artery branches off the proper hepatic artery**. The right hepatic artery looks like it is going towards the gallbladder, but then goes past it and into the liver. The gastroduodenal artery is normal. The right gastro-omental artery is normal and branches from gastroduodenal artery. The supraduodenal artery is normal and comes off gastroduodenal artery. The superior pancreaticoduodenal artery is normal and comes off the gastroduodenal artery. There is a cut branch off the gastroduodenal artery which could have been the right gastric artery or the anterior/posterior pancreaticoduodenal artery. Either way, cannot find the right gastric artery off the proper hepatic artery or the anterior/posterior pancreaticoduodenal arteries.

MIDGUT

The SMA branches normally. The inferior pancreaticoduodenal artery is normal. The middle colic artery is normal. The right colic artery is normal. The jejunal and ileal arteries are normal. The ileocolic artery is normal. The cecal arteries are normal.

HINDGUT

The IMA is normal and branches normally. The left colic artery branches normally into the ascending and descending branches. The descending branch bifurcates into an ascending and descending branch as well so that there are 2 ascending branches in total. The sigmoid arteries are normal, but some of them are cut. The superior rectal artery is cut before it reaches the rectum.

RIGHT RENAL

The right renal artery is normal and comes off the abdominal aorta normally, it bifurcates as it reaches the kidney. **Also have an accessory renal artery off the abdominal aorta going to the inferior pole of the kidney**. The inferior suprarenal artery is normal and comes off the renal artery. Cannot find the inferior phrenic artery, superior suprarenal artery, middle suprarenal artery, or ovarian artery.

LEFT RENAL

The left renal artery is normal and branches normally from the abdominal aorta. **Also have an accessory renal artery going to the inferior pole of the kidney.** The inferior suprarenal artery is normal and branches normally from the renal artery. Cannot find the middle suprarenal artery, inferior phrenic artery, the superior suprarenal artery, or the ovarian artery.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal. The anterior communicating artery was normal. The posterior communicating arteries are torn because the brain and cerebellum/brain stem got detached from each other. The vertebral arteries made the basilar artery normally.

RIGHT CAROTIDS

The right common carotid is normal, bifurcates into the internal and external carotids normally. The internal artery is normal but cut at the angle of the mandible. The external carotid artery is normal but cut before it gives off its terminal branches. The superior thyroid artery, lingual artery, and facial artery are all normal. The facial artery gives off the superior and inferior labial arteries normally and continues normally as the angular artery.

LEFT CAROTIDS

The left common carotid is normal and bifurcates into the internal and external carotids normally. The internal carotid artery is normal but cut shortly after the bifurcation. The external carotid artery is normal but cut before it can give off its terminal branches. The superior thyroid artery is normal. The lingual artery is normal. The facial artery is normal, gives off the superior and inferior labial arteries normally and continues as the angular artery normally.

RIGHT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal. Its branches, the inferior thyroid artery, the transverse cervical artery, and the subscapular artery, are all going in their normal paths, but cut before they reach their targets. Costocervical trunk is normal. Dorsal scapular is normal and comes off the subclavian.

LEFT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal; it is cut, but it can be seen on the removed rib cage traveling normally. The thyrocervical trunk is normal, but its branches are cut. Can still see the ascending cervical artery and the inferior thyroid arteries headed towards their targets, but they are cut before they make it. The dorsal scapular artery is normal and comes off the subclavian. Cannot find the costocervical trunk.

RIGHT UPPER EXTREMITY

Axillary artery is normal. Superior thoracic artery is present off artery but cut before it reaches target. Thoracoacromial trunk is cut, can still see some pectoral branches and clavicular branches. **Subscapular artery gives off the lateral thoracic artery**. Its other branches are normal, but the branches are cut from the main trunk. The anterior and posterior circumflex humerals are normal**. There is a high branch point of the brachial artery into the ulnar and radial arteries located about halfway down the arm. The radial artery crosses the ulnar artery at the branch point to continue its course.** The ulnar artery still branches in the cubital fossa to give off the common interosseous artery. Cannot find the ulnar collateral arteries or the radial recurrent artery.

LEFT UPPER EXTREMITY

Left arm is disarticulated from the body. Axillary artery is cut. Thoracoacromial trunk is present, most branches are cut, still have the pectoral branches. Superior thoracic artery is present but cut. **Lateral thoracic artery comes off the subscapular artery. Subscapular gives off more branches than normal. There are 2 circumflex scapular**

arteries and another unnamed branch headed towards the anterior scapula. The thoracodorsal is normal. Anterior circumflex humeral is present, posterior circumflex humeral is cut. Continues as the brachial artery normally. The deep brachial artery is normal. The superior ulnar collateral artery is normal. Radial and ulnar arteries are normal and bifurcate in the cubital fossa. Common interosseous artery and part of the anterior interosseous artery are present and are normal. The superficial palmar arch is cut. Cannot find the posterior interosseous artery or radial recurrent artery.

RIGHT ILIAC

The common iliac is normal and bifurcates into the internal and external iliacs normally. The internal iliac is normal and has a much more typical branching pattern.

Anterior division: The obturator artery is normal. The umbilical artery is cut but can match the lumens for it. The superior vesicle arteries are normal; they arise from anterior trunk rather than the umbilical artery. The middle rectal artery is normal. The internal pudendal artery is normal. No vaginal or uterine arteries.

Posterior division: the superior gluteal artery is normal but gives off the inferior gluteal artery. Cannot find the lateral sacral artery.

Iliolumbar artery is independent and branches off about ½ inch before the bifurcation of the internal iliac into the anterior and posterior divisions.

The external iliac is normal. The inferior epigastric artery is normal. The deep circumflex iliac is normal.

LEFT ILIAC

The common iliac is normal and bifurcates into the internal and external iliacs normally. The internal iliac is normal and bifurcates into the anterior and posterior divisions, though the anterior division is much smaller. Most branches come off the posterior division

Anterior division: umbilical artery is normal and gives off superior vesicle arteries. Inferior vesicle arteries are normal.

Posterior division: The obturator artery is the only medial branch, comes off inferior to the internal pudendal artery. The internal pudendal artery is normal and is the first branch off the posterior division. The lateral sacral artery is the next branch and is normal. The superior gluteal is the next branch and is normal, though it has an extra branch that travels with it. The inferior gluteal is the terminal branch and is normal.

The iliolumbar artery is an independent branch that originates about ¾ of an inch after the bifurcation of the common iliac artery. Cannot find the vaginal, uterine, or middle rectal arteries, but this donor has no uterus and there is a surgical device in the vagina to prevent prolapse, so the lack of vessels probably has something to do with that.

The external iliac is normal. The inferior epigastric is normal. The deep circumflex iliac artery is normal.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and branches from the femoral artery postero-medially. **The lateral circumflex femoral artery comes off the femoral artery. There is a small common trunk for the deep femoral artery**

and the lateral circumflex femoral artery. The medial circumflex femoral artery is normal and comes off the deep femoral artery at the same level as the branch point for the lateral circumflex femoral. The femoral artery continues normally through the adductor hiatus. The anterior and posterior tibial arteries are normal. Dorsalis pedis is normal. Cannot find the fibular artery.

LEFT LOWER EXTREMITY

Femoral artery is normal. **The lateral circumflex femoral artery branches off the femoral artery before the branch point for the deep femoral artery**. The deep femoral artery branches off the femoral artery laterally before diving to a more posterior orientation. The medial circumflex femoral artery is normal and comes off the deep femoral, inferior to the branch point of the lateral circumflex femoral. The femoral artery continues normally through the adductor hiatus. The anterior and posterior tibial arteries are normal. Cannot find dorsalis pedis or the fibular artery.

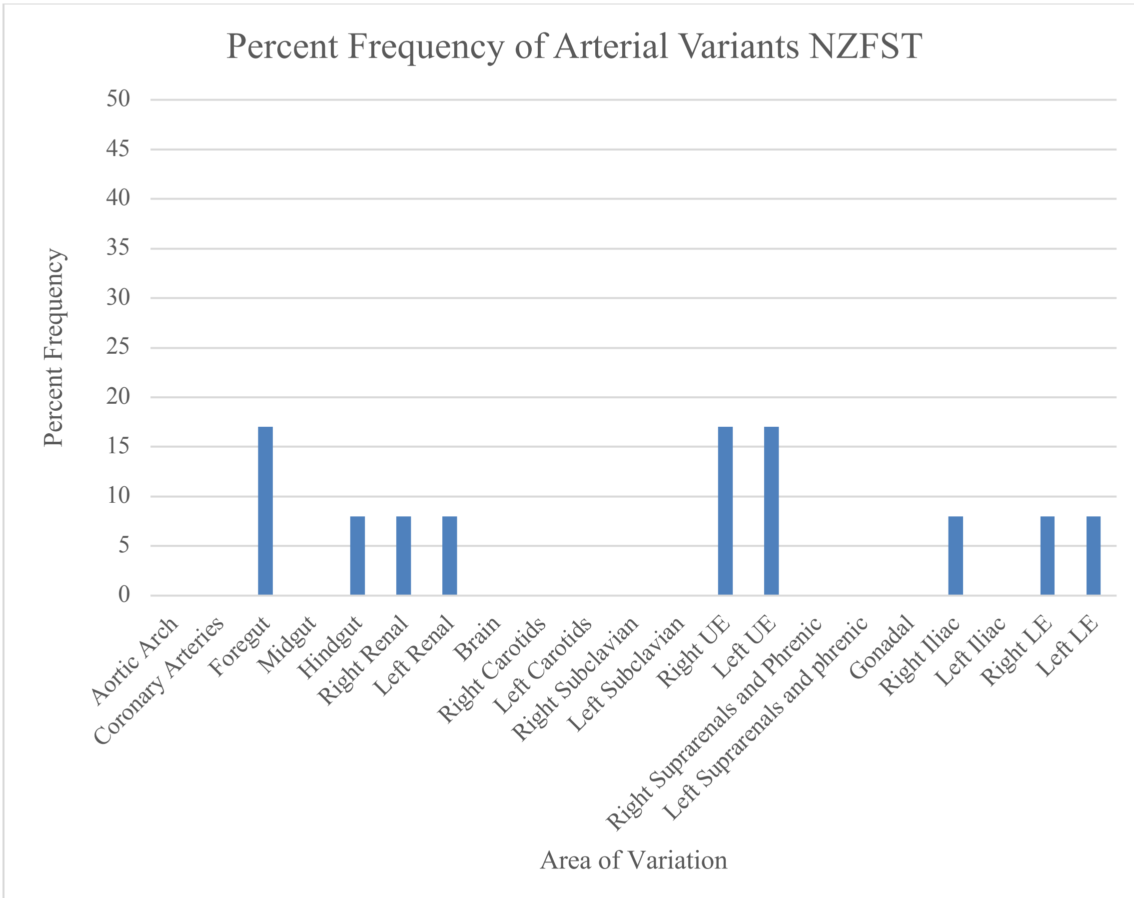

Figure 13: Percent frequency of arterial variants observed in body donor, NZFST.

NZFST

Key:
CHA = common hepatic artery
PHA = proper hepatic artery
SubA = subscapular artery
CirSA = circumflex scapular artery
BrA = brachial artery
AccRa = accessory renal artery
LCA = left colic artery
SGA = superior gluteal artery
FA = femoral artery
DFA = deep femoral artery
LCFA = lateral circumflex femoral artery

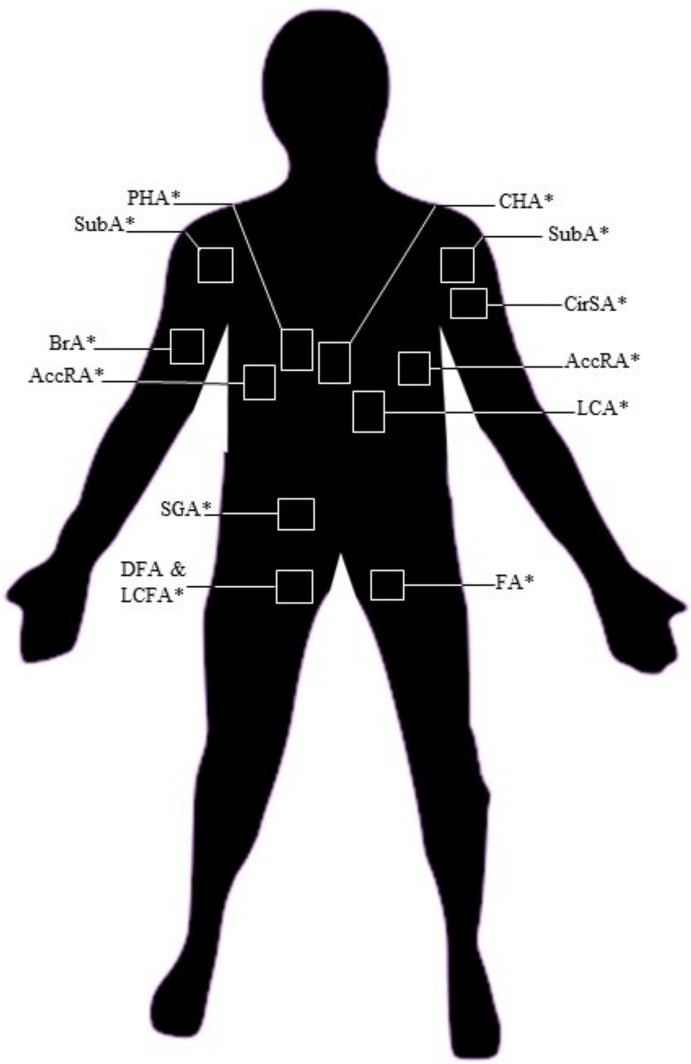

Figure 14: A schematic of the location and number of arterial variants found in body donor, NZFST.

DIBNCFSMJO

Sex: Female

Age: 74

COD: Adenocarcinoma of the pancreas

Summary of Variants Found (Figures 15-16):

- **4 branches off the aortic arch, left vertebral** comes off the aorta in between the left common carotid and the left subclavian
- Abdominal vasculature is altered by pancreatic tumors (cause of death)
- In the **left subclavian**, there is a <u>common stem for the thyrocervical trunk and internal thoracic artery</u>
- In the right internal iliac, the orientation of the anterior and posterior divisions is switched so that the posterior division is more anteriorly oriented
- In the **left internal iliac**, there are **2 inferior gluteal arteries**. The second inferior gluteal artery is given off just before the bifurcation of the terminal branch into the inferior gluteal and internal pudendal arteries

Detailed Overview:

ARCH OF THE AORTA

The aortic arch has 4 branches. The brachiocephalic trunk is normal and branches into the right common carotid and right subclavian arteries normally. The left common carotid artery is normal. The left subclavian artery is normal. **The left vertebral**

artery comes off the aorta between the left common carotid and the left subclavian artery.

HEART

The left coronary artery is normal. Its branches divide a little bit closer to the origin of the artery from the arch of the aorta than the other hearts. The left anterior descending artery is normal. The left circumflex artery is normal but branches off close to the origin of the left coronary artery. The left marginal artery is normal. The right coronary artery is normal. The right marginal artery is normal. The posterior interventricular artery comes off the right coronary artery but is cut away from the heart so that it is a loose branch, so it cannot be seen where it laid when it was on the heart.

FOREGUT

This donor had multiple pancreatic tumors so most of the branches of the celiac were altered by pathology and got cut out as the students were trying to remove the tumors and get the viscera out of the abdominal cavity. Can see the remains of the common hepatic artery and it is normal. The gastroduodenal artery comes off the common hepatic normally. The common hepatic continues normally as the proper hepatic artery which bifurcates normally into the right and left hepatic arteries. Cannot see any other arteries.

MIDGUT

Cannot see the trunk of the SMA on the abdominal aorta. Can see that arterial branches are going to the small intestines but cannot trace them back to anything.

HINDGUT

The IMA is normal. The left colic artery is normal, and its ascending and descending branches are normal. The sigmoid branches are normal. The superior rectal artery is cut.

RIGHT RENAL

Right renal artery comes off the abdominal aorta normally. The renal artery bifurcates as it approaches the kidney. Cannot find the inferior suprarenal artery, middle suprarenal artery, inferior phrenic artery, or the ovarian artery.

LEFT RENAL

The left renal artery branches off the abdominal aorta normally. The adrenal gland was dissected out of the body, so cannot find the inferior suprarenal artery, middle suprarenal artery, or the inferior phrenic artery. Cannot find the ovarian artery.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal. The anterior and posterior communicating arteries are normal. The basilar artery is normal.

RIGHT CAROTIDS

The right common carotid bifurcates normally into the internal and external carotids. The internal carotid is normal, cut shortly after the carotid bifurcation. The external carotid is normal. Gives off the superior thyroid, lingual, facial, and ascending pharyngeal arteries normally. The facial artery is cut before reaching the face but can match the lumens for it. Gives off the labial arteries normally and continues as the angular artery normally. The ophthalmic artery from the internal carotid artery is normal in the orbit.

LEFT CAROTIDS

Left common carotid bifurcates normally into the internal and external carotids. Both are cut at the angle of the mandible. Can see lumens where the external carotid gave off the superior thyroid and lingual arteries, but do not actually have the branches themselves. The facial artery is still in the neck and can see its path on the face. The facial artery is normal and gives off the superior and inferior labial arteries and the angular artery normally.

RIGHT SUBCLAVIAN

The vertebral artery is normal. The thyrocervical trunk is normal but cannot see all its branches. The suprascapular and transverse cervical arteries are normal. The internal thoracic is normal. The costocervical trunk is normal. Cannot find the dorsal scapular artery.

LEFT SUBCLAVIAN

No vertebral (because it comes off the aorta). **The thyrocervical trunk and the internal thoracic artery comes from a common trunk.** Cannot find the branches of the thyrocervical trunk. The internal thoracic artery is normal, cut but can see that it is normal on the rib cage. Cannot find the dorsal scapular artery or the costocervical trunk.

RIGHT UPPER EXTREMITY

Axillary artery is normal. Thoracoacromial trunk is normal. Lateral thoracic artery cannot be found. Subscapular artery and its branches are normal. Anterior circumflex humeral is normal, but posterior circumflex humeral is cut. The axillary artery continues normally as the brachial artery. The deep brachial artery is cut but can see the trunk for it. The ulnar and radial arteries are normal. The radial recurrent artery is cut but can still see trunk for it and it is normal. Common interosseous artery is normal, but anterior and posterior cannot be seen. Cannot see palmar arches.

LEFT UPPER EXTREMITY

Axillary artery is normal. Thoracoacromial trunk is normal. Cannot find lateral thoracic artery. Subscapular artery and its branches, the circumflex scapular and thoracodorsal arteries, are normal. The anterior and posterior circumflex humeral arteries are normal. Continues normally as the brachial artery. Branching to the deep brachial artery is normal. Branching into radial and ulnar arteries is normal as well as their course to the wrist. Superior and inferior ulnar collateral arteries could not be found. Radial recurrent artery is normal. Common interosseous is normal but cannot see the anterior or posterior interosseous arteries. The superficial palmar arch is normal.

RIGHT ILIAC

Common iliac is normal and bifurcates into the internal and external iliacs normally. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally. However, the orientation of the anterior and posterior divisions is switched so that the posterior division is more anteriorly oriented.

Anterior division: the umbilical artery is normal. The uterine artery is normal. The obturator artery is cut. The vaginal, inferior vesicle, and middle rectal arteries are all normal. Terminates with the terminal branch that bifurcates into the inferior gluteal artery and the internal pudendal artery. The internal pudendal artery gives off a cut branch that was probably the obturator.

Posterior division: have 2 lateral sacral arteries. Superior gluteal is normal

Iliolumbar artery is a separate branch off the internal iliac before it bifurcates.

The external iliac is normal. The inferior epigastric is normal. The inferior epigastric artery bifurcates and the second branch travels along the body wall and heads towards the pubic symphysis. Cannot find the deep circumflex iliac.

LEFT ILIAC

The common iliac is normal and bifurcates into the internal and external iliacs normally. The internal iliac is normal and divides into the anterior and posterior divisions normally.

Anterior division: The umbilical artery is normal and gives off the superior vesicle arteries. The obturator artery is normal, gives off the uterine artery. The inferior vesicle arteries are normal. The vaginal and middle rectal arteries are normal. The inferior gluteal and internal pudendal arteries are the terminal branches. **Have a double inferior gluteal artery; a second inferior gluteal artery is given off just before the bifurcation of the terminal branch into the inferior gluteal and internal pudendal arteries.**

Posterior division: The superior gluteal artery is normal. Gives off 2 lateral sacral arteries

Iliolumbar artery may have come off internal iliac before it bifurcated. Have a lumen for it but cannot see the artery.

External iliac is normal. The inferior epigastric artery is normal. Cannot find the deep circumflex iliac artery.

RIGHT LOWER EXTREMITY

Femoral artery is cut, but the branching is normal. The deep femoral artery branches from the femoral postero-laterally and is normal, but is cut from femoral, can still see the lumen for it at the cut point though. The lateral circumflex femoral artery is normal and comes off the deep femoral. Cannot find the medial circumflex femoral artery. Femoral continues as popliteal normally. Anterior tibial, posterior tibial, and fibular arteries are normal.

LEFT LOWER EXTREMITY

Femoral artery is normal. Deep femoral artery is normal and branches from the femoral postero-laterally. Lateral circumflex femoral is normal and comes off the deep femoral. The medial circumflex femoral comes off the deep femoral normally, superior to the branch point of the lateral circumflex femoral. Femoral continues as the popliteal artery normally. Anterior tibial, posterior tibial, and fibular arteries are normal. Cannot see the continuation of the anterior tibial into the dorsalis pedis.

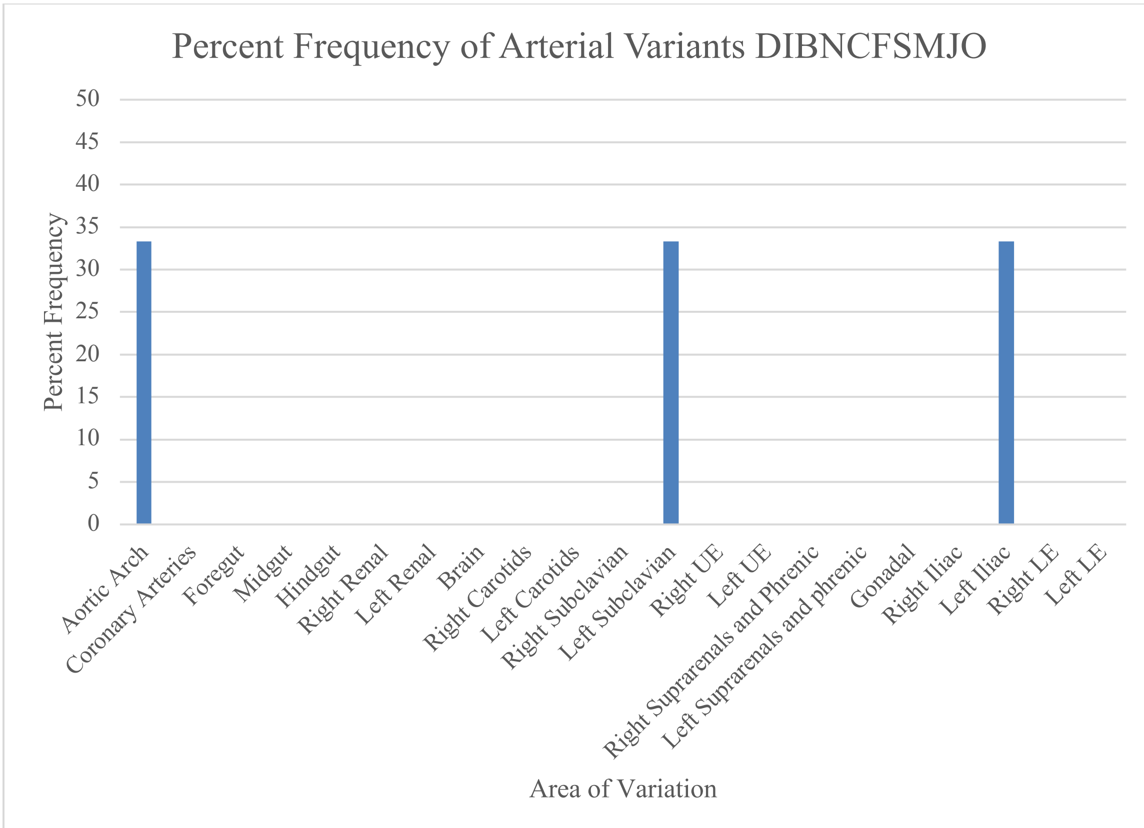

Figure 15: Percent frequency of arterial variants observed in body donor, DIBNCFSMJO.

DIBNCFSMJO

Key
AA = aortic arch
TCTr = thyrocervical trunk
ITA = internal thoracic artery
IGA = inferior gluteal artery

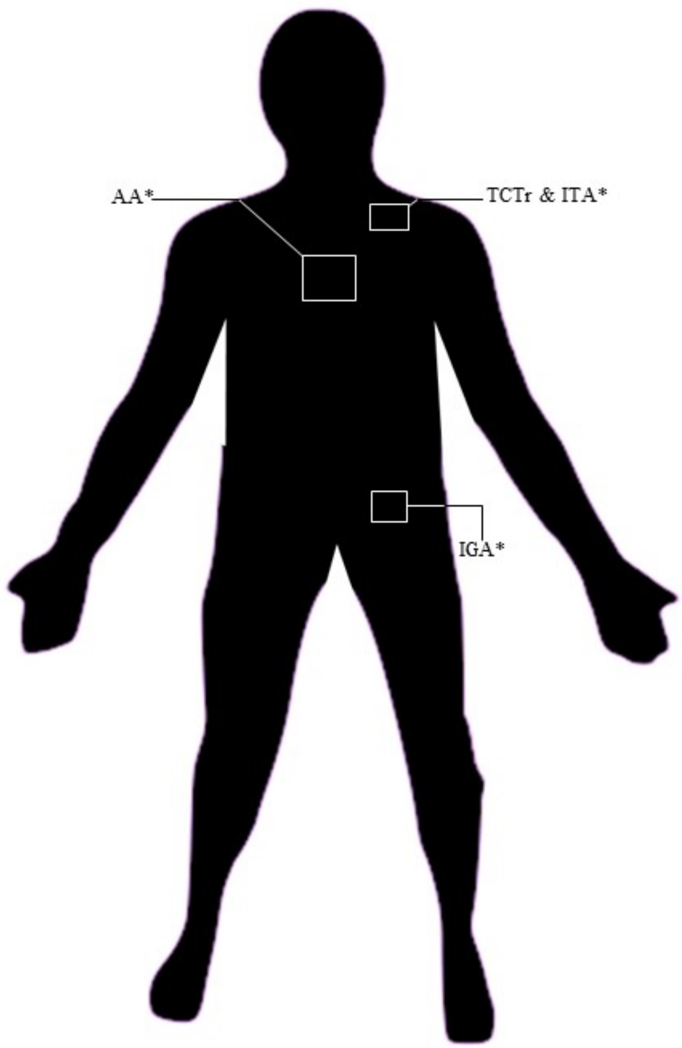

Figure 16: A schematic of the location and number of arterial variants found in body donor, DIBNCFSMJO.

CVDLMFZ

Sex: female

Age: 93

COD: congestive heart failure/coronary artery disease

Summary of variants seen (Figures 17-18)

- Have **4 branches off the aortic arch, left vertebral** comes off between left common carotid and left subclavian arteries
- The **celiac trunk has 4 branches**, 3 are the normal branches plus (1.) the **left inferior phrenic** artery
- Anomalous origin of the **right gastric artery** and **cystic artery** from the **gastroduodenal artery**
- There is **a common stem for the middle colic and right colic arteries** off the SMA
- In the **right subclavian**, there is a <u>common stem for the thyrocervical trunk and internal thoracic artery</u>
- In the **left subclavian**, there is a <u>common stem for the thyrocervical trunk and internal thoracic artery</u>
- In the **right upper extremity**, there are multiple (2?) anterior circumflex humeral arteries

- In the **right internal iliac**, the **superior gluteal artery** bifurcates and gives off the inferior gluteal artery
- In the **left internal iliac**, the **obturator artery** makes an anastomosis with the external iliac via a branch of the inferior epigastric that goes through the obturator canal
- In the **right lower extremity**, there is a <u>common stem for the deep femoral and lateral circumflex femoral arteries</u> off the femoral artery
- In the **left lower extremity**, there is an anomalous origin of the **lateral circumflex femoral artery** from the **femoral artery** and there is a common trunk for the descending branches of the lateral circumflex femoral artery and the lateral circumflex femoral artery itself
- In the **left lower extremity**, there is a <u>high branch point</u> of the deep femoral artery off the femoral artery, just inferior to the border of the ilioinguinal ligament

Detailed Overview:

ARCH OF THE AORTA

Have 4 branches off the aortic arch. The brachiocephalic trunk is normal and branches into the right subclavian and right common carotid arteries normally. The left common carotid artery is normal. **The left vertebral artery comes off the aortic arch posterior to the left common carotid artery.** The left subclavian artery is normal.

HEART

The right coronary artery is normal. The right marginal artery is normal. The posterior interventricular artery is normal and comes off the right coronary artery. The left coronary artery is normal. The left anterior descending artery is normal. The left diagonal artery is normal. The left marginal artery is normal. The left circumflex artery is normal.

FOREGUT

The celiac trunk gives off the splenic artery, the left gastric artery, and the common hepatic artery normally. The splenic artery is normal, but its branches are cut so that the left gastro-omental artery cannot be found. The left gastric artery is normal. The celiac trunk was cut after the left gastric was given off, so it is only held to the trunk through some fascia. **The celiac trunk gives off the left inferior phrenic artery.** The common hepatic artery is normal. The common hepatic artery gives off the gastroduodenal artery and then continues as the proper hepatic artery normally. Cannot find the branching of the left and right hepatic arteries off the proper hepatic artery. **The cystic artery comes off the gastroduodenal artery**. The right gastro-omental artery comes off the gastroduodenal artery normally. **The right gastric artery comes off the gastroduodenal artery**. It is cut where it branches from the gastroduodenal artery, but you can match the lumens for it. The supraduodenal artery branches normally from the gastroduodenal artery. Cannot find the superior pancreaticoduodenal artery.

MIDGUT

The SMA and its branches are normal. The inferior pancreaticoduodenal artery is cut. The jejunal and ileal arteries are normal**. There is a common stem for the middle colic and right colic arteries**. The ileocolic artery is normal.

HINDGUT

The IMA and its branches are normal. The left colic artery is cut. The sigmoid arteries are normal. The superior rectal artery is normal.

RIGHT RENAL

The right renal artery branches normally from the abdominal aorta. It bifurcates as it reaches the kidney. The middle suprarenal artery is normal and comes from the abdominal aorta. Cannot find the inferior suprarenal artery.

LEFT RENAL

The left renal artery branches normally from the abdominal aorta. Middle suprarenal artery comes off the abdominal aorta normally. Cannot find the inferior suprarenal artery.

BRAIN

The Circle of Willis is normal. The anterior, middle, and cerebral arteries are normal, though the anterior and posterior cerebral arteries are smaller on the right side. The anterior and posterior communicating arteries are normal. The basilar artery is normal.

RIGHT CAROTIDS

The common carotid bifurcates normally into the internal and external carotids. The internal and external carotids got cut right after they bifurcate so cannot see any of the branches coming off the external carotid. Can see a little bit of the facial artery in the chin but gets cut. The ophthalmic artery from the ICA is normal.

LEFT CAROTIDS

The left common carotid is normal and bifurcates into the internal and external common carotids normally. The internal carotid is normal but is cut shortly after bifurcation. The external carotid has a branch right after it is given it off, making the carotid body look like a trifurcation. The branch was cut but was probably the ascending pharyngeal. The superior thyroid artery is normal. Cannot find the facial or lingual arteries.

RIGHT SUBCLAVIAN

The vertebral artery is normal. **The thyrocervical trunk and the internal thoracic artery came off a common trunk.** The dorsal scapular artery is normal and comes off the subclavian. The rest of the branches are cut off.

LEFT SUBCLAVIAN

Left subclavian got badly damaged during dissection and all the branches were cut off. Have 2 lumens on the artery that show that **the thyrocervical trunk and the internal thoracic artery came off a common trunk.**

RIGHT UPPER EXTREMITY

Axillary artery is normal. Thoracoacromial trunk is normal. Lateral thoracic artery is normal. Subscapular artery, circumflex scapular artery, and thoracodorsal arteries are normal. **Anterior circumflex humeral is good, but there are multiples of it**. Posterior circumflex humeral artery cannot be found. The axillary artery continues normally as the brachial artery. Deep brachial artery is normal. Cannot find ulnar collateral arteries. The radial and ulnar arteries branch normally in the cubital fossa and continue normally into the hand. Cannot find interosseous arteries. Superficial palmar arch is normal.

LEFT UPPER EXTREMITY

Axillary artery is normal. Superior thoracic artery is normal. Thoracoacromial trunk is normal. Lateral thoracic artery cannot be found. Subscapular artery, circumflex scapular artery, and thoracodorsal artery are normal. Posterior circumflex humeral is normal, but anterior circumflex humeral is cut. The axillary artery continues normally as the brachial artery. Deep brachial artery is normal. Superior ulnar collateral artery is normal, inferior ulnar collateral artery cannot be found. The brachial artery branches normally to the ulnar and radial arteries and they continue normally into the hand. The common interosseous artery is normal but cannot see it branch into anterior or posterior interosseous arteries. Superficial palmar arch is normal.

RIGHT ILIAC

The common iliac is normal and branches into the internal and external iliacs normally. The internal iliac is normal and bifurcates into the anterior and posterior divisions.

Anterior division: no clear trunk, just lots of branches coming off at once. Cannot find the obturator artery. The umbilical artery is normal and gives rise to the superior vesicle arteries. Have an inferior vesicle branch. There is a branch given off that goes to the anterior pelvic wall by the pubic symphysis. The internal pudendal artery is the terminal branch of the anterior division and is normal.

Posterior division: the superior gluteal artery is normal. **Superior gluteal artery bifurcates and gives off the inferior gluteal artery.** Have 2 lateral sacral branches. The iliolumbar comes off the posterior division normally.

External iliac is normal. The inferior epigastric artery is normal. It bifurcates, and its other branch goes down the obturator canal. Cannot find the deep circumflex iliac.

LEFT ILIAC

Common iliac is normal and bifurcated into the internal and external iliacs normally. The internal iliac bifurcates into the anterior and posterior divisions normally.

Anterior division: has a normal branching pattern of one long trunk with everything coming off it. Umbilical artery is normal and gives rise to superior and inferior vesicle arteries. The obturator artery is normal and gives off the middle rectal artery. **The obturator makes an anastomosis with the external iliac via a branch of the inferior epigastric that goes through the obturator canal**. terminates by bifurcating into the inferior gluteal and internal pudendal arteries, both of which are normal.

Posterior division: The superior gluteal artery is normal and gives rise to the iliolumbar artery and the lateral sacral artery, both of which are normal.

The internal iliac is normal. Inferior epigastric is normal, bifurcates and its other branch goes through the obturator canal. No deep circumflex iliac.

RIGHT LOWER EXTREMITY

Femoral artery is normal. Deep femoral is normal and comes off the femoral artery postero-laterally. **Lateral circumflex femoral artery comes off a common trunk with the deep femoral.** There is some controversy about this though because it is a common trunk in some literature, but not in every paper. Medial circumflex femoral cannot be found. Femoral artery continues through the adductor hiatus normally. Cannot see genicular arteries. Anterior and posterior tibials are normal. Fibular artery is normal. Cannot see dorsalis pedis.

LEFT LOWER EXTREMITY

Femoral artery is normal. Lateral circumflex femoral artery comes off the femoral artery. Have a common trunk for the descending branches of the lateral circumflex femoral artery and the lateral circumflex femoral artery itself. Deep femoral artery is normal, but has a high branch point, right by the border of the ilioinguinal ligament. It branches off the femoral artery laterally before diving posteriorly under the lateral circumflex femoral artery. Medial circumflex femoral artery comes off the deep femoral, superior to the branch point for the lateral circumflex femoral. The femoral artery continues through the adductor hiatus normally. Anterior tibial is normal and dorsalis pedis is normal. Posterior tibial is normal. Cannot see fibular artery.

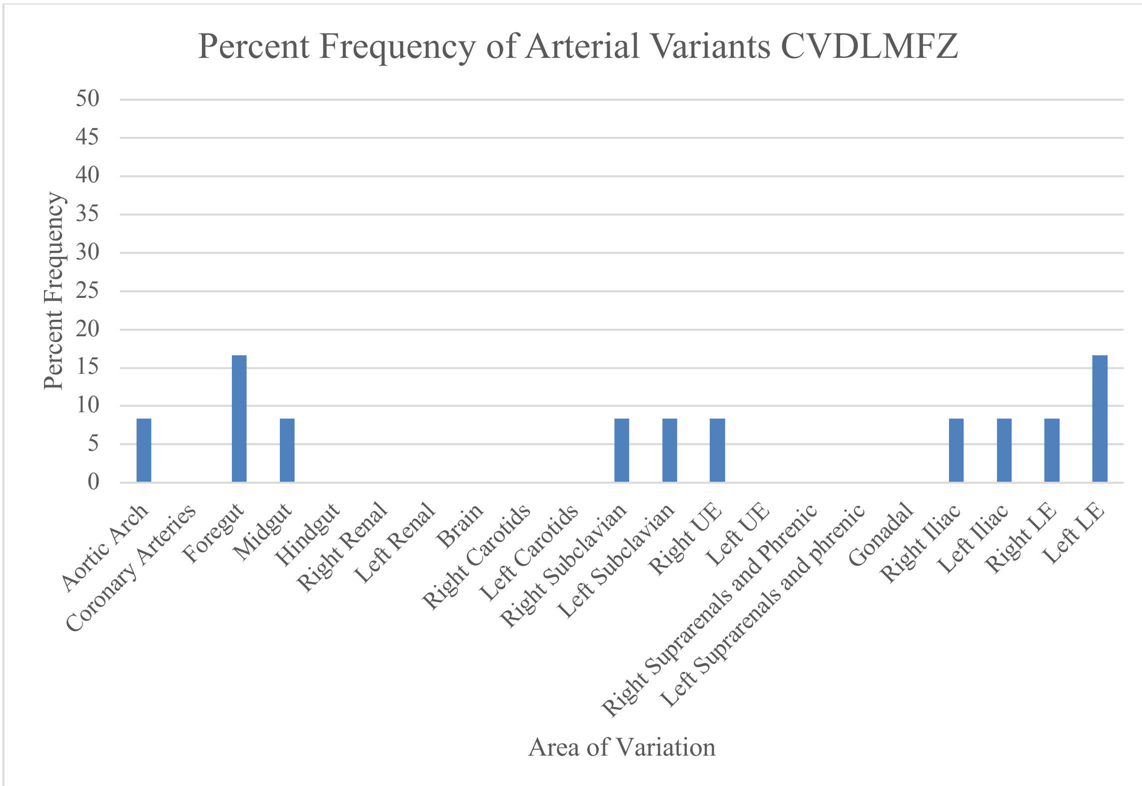

Figure 17: Percent frequency of arterial variants observed in body donor, CVDLMFZ.

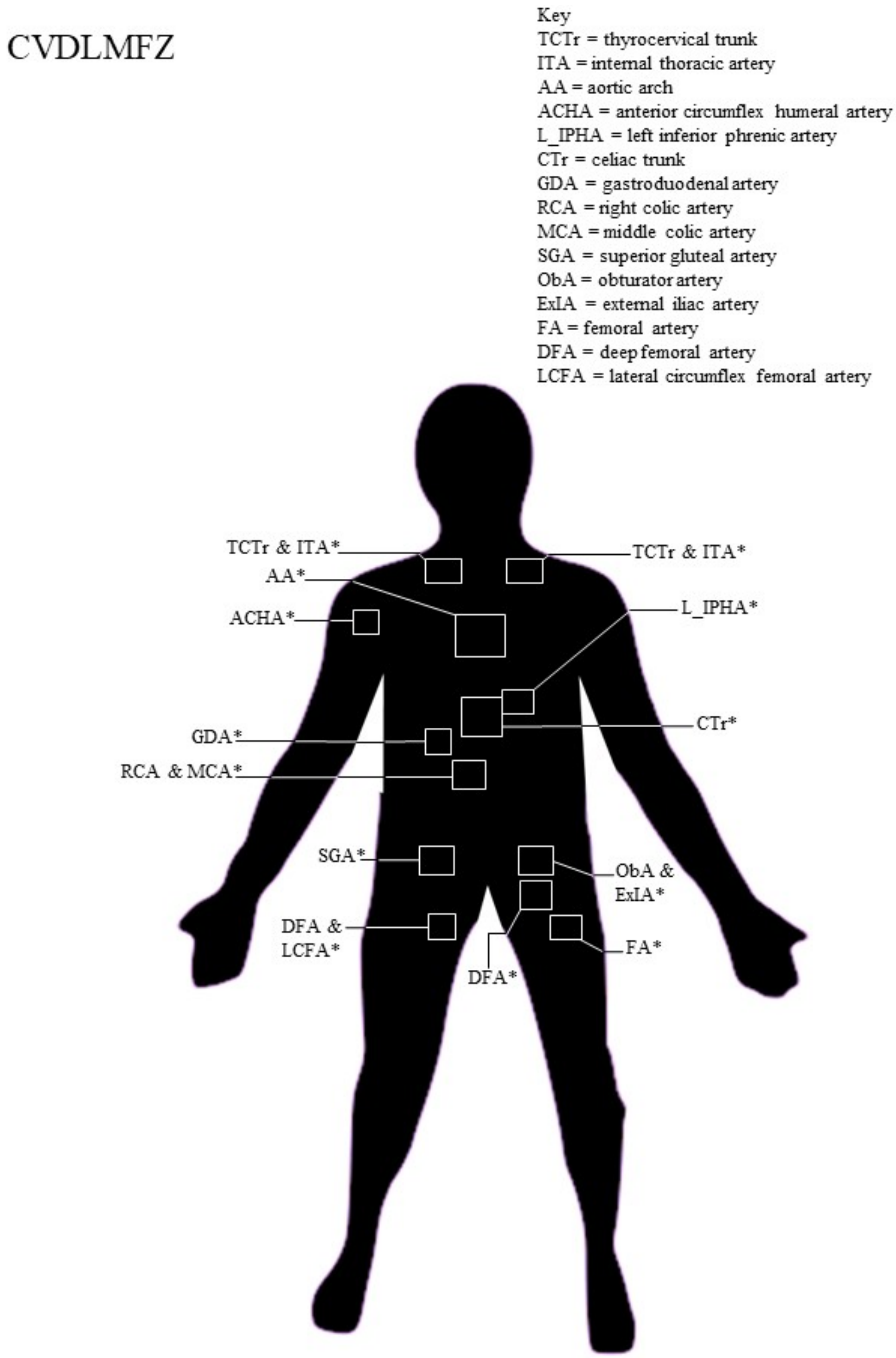

Figure 18: A schematic of the location and number of arterial variants found in body donor, CVDLMFZ.

KFOLJOT

Sex: F

Age: 86

COD: chronic lymphocytic leukemia

Summary of variants seen (Figures 19-20)

- Abdominal vasculature was altered by tumors
- **Two right renal arteries** off the abdominal aorta
- In the **right subclavian**, there is a <u>common stem for the thyrocervical trunk and internal thoracic artery</u>
- In the **left subclavian**, there is a <u>common stem for the thyrocervical trunk and internal thoracic artery</u>
- In the **right internal iliac**, the anterior trunk was oriented more posteriorly, and the posterior division was more anterior. Made the superior gluteal artery have a much more anterior course than normal and it gave off branches to the anterior pelvic wall.

Detailed Overview:

ARCH OF THE AORTA

The brachiocephalic trunk is normal but cut where it crosses the trachea. It branches into the right subclavian and right common carotid arteries normally. The left common carotid artery is normal. The left subclavian artery is normal but cut where it branches from the aortic arch. The thoracic aorta is really deflated and did not keep any of its round shape.

HEART

The left coronary artery is normal. The left anterior descending artery is normal. The left marginal artery is normal. The left circumflex artery is normal. The right coronary artery is normal, but it is cut about an inch way from its origin off the aorta, but you can still match the lumens. The right marginal artery is normal, but cut after dividing from right coronary artery, but can still match its lumen to the part of the artery on the heart. The posterior interventricular artery is normal and comes off the right coronary artery.

FOREGUT AND MIDGUT

This body had tons of abdominal tumors which made it difficult to find any blood vessels because they were buried in tumors or accidentally cut out as the group tried to cut the tumors out. It looks like most of the blood flow in the abdomen came from one common trunk that appears to be a hybrid of the celiac trunk and the SMA. There are large arteries going to the liver, stomach/duodenum, jejunum, and ileum.

HINDGUT

IMA is normal. Left colic artery is normal. Sigmoid arteries are normal. Superior rectal artery is normal.

RIGHT RENAL

There are two renal arteries off the abdominal aorta going to the kidney. The more superior renal artery is posterior to the other renal artery and bifurcates as it reaches the kidney. The more inferior renal artery also bifurcates as it reaches the kidney. Cannot find the inferior or middle suprarenal arteries or the inferior phrenic artery. Cannot find the ovarian artery.

LEFT RENAL

The left renal artery comes off the abdominal aorta normally. It bifurcates as it approaches the kidney. The left renal kidney was buried in the middle of a tumor. Cannot find inferior phrenic, superior suprarenal, middle suprarenal, inferior suprarenal, or ovarian artery.

BRAIN

Circle of Willis is normal. The anterior, posterior, and middle cerebral arteries are normal. The anterior and posterior communicating arteries are normal. The basilar artery is normal. The superior cerebellar arteries are normal.

RIGHT CAROTIDS

The common carotid bifurcates normally into internal and external carotid arteries. The internal carotid artery is normal but gets cut shortly after bifurcation. The external carotid continues up the neck normally. Gives off the ascending pharyngeal artery, the superior thyroid, lingual and facial arteries normally. The superior thyroid artery gives off the superior laryngeal artery normally. The external gets cut right after it gives off the posterior auricular artery which is cut as well. Can see a little bit of the superficial temporal artery giving off the maxillary artery. The facial artery is normal and gives off the submental and superior and inferior labial branches normally before continuing as the angular artery. The ophthalmic artery of the ICA is normal.

LEFT CAROTIDS

Common carotid branches normally into the internal and external carotids. The internal carotid artery is normal but cut shortly after bifurcation. The external carotid is normal. The superior thyroid, lingual and facial branches are normal. Have the branch points for the ascending pharyngeal and occipital arteries, but they get cut before reaching their targets. The external carotid is cut after giving off the posterior auricular artery. Can see a small bit of the superficial temporal artery giving off the maxillary artery normally. The facial artery is normal and gives off the superior and inferior labial arteries normally before being cut.

RIGHT SUBCLAVIAN

The vertebral artery is normal**. The thyrocervical trunk and the internal thoracic artery come off a common trunk**. The thyrocervical trunk and its branches, the suprascapular, transverse cervical, and inferior thyroid arteries, are normal. The internal thoracic is normal. The costocervical trunk is normal. The dorsal scapular artery is normal and comes off the subclavian.

LEFT SUBCLAVIAN

Vertebral artery is normal. **The thyrocervical trunk and the internal thoracic artery come off a common trunk**. The thyrocervical trunk is normal. The suprascapular and inferior thyroid arteries are normal. The transverse cervical artery is cut. The internal thoracic artery is cut, but normal when matched to the length of it running in the rib cage. Cannot find the costocervical trunk. The dorsal scapular is normal and comes off the subclavian.

RIGHT UPPER EXTREMITY

Axillary artery is normal. Thoracoacromial trunk is present, but the branches are cut. Cannot find the lateral thoracic artery. Subscapular artery, circumflex scapular artery, and thoracodorsal arteries are normal. Anterior and posterior circumflex humeral arteries are normal. The axillary artery continues as the brachial artery normally. Deep brachial artery is normal. The superior ulnar collateral is normal but cannot find the inferior. Radial and ulnar arteries branch normally at cubital fossa and carry on to wrist normally. The radial artery is cut at the wrist. Cannot find the interosseous arteries.

LEFT UPPER EXTREMITY

Axillary artery is normal. Thoracoacromial trunk is normal. Cannot find the lateral thoracic artery. Subscapular artery, circumflex scapular artery, and thoracodorsal arteries are normal. Anterior and posterior circumflex humeral arteries are normal. The axillary artery continues as the brachial artery normally. The deep brachial artery is normal. Cannot find the ulnar collaterals. The ulnar and radial arteries bifurcate normally in the cubital fossa and are normal. Cannot find the interosseous arteries. Superficial palmar arch is good

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliacs. The internal iliac is normal and has anterior and posterior divisions. The anterior and posterior divisions or switched in their orientation such that the posterior division is more anterior, and the anterior division is more posterior.

Anterior division: has the cauda equina appearance. The umbilical artery is normal and gives off superior and inferior vesicle arteries. The branches for the internal pudendal and inferior gluteal got cut out but can see that the arteries still exited via the greater sciatic foramen. The inferior gluteal artery was oriented more anteriorly than normal.

Posterior division: superior gluteal artery is more anterior than normal. Gives off branches that go to the anterior pelvic wall. Iliolumbar artery still comes off the posterior division.

External iliac is normal. The inferior epigastric artery is normal but has a bifurcation. Could not follow the second branch. Cannot find the deep circumflex iliacs.

LEFT ILIAC

The common iliac is normal and bifurcates into the internal and external iliacs normally. The internal iliac is normal, branches out, but does not have very clear anterior or posterior division.

Anterior division: more like a short trunk that everything branches off. The umbilical artery is cut. Cannot find the obturator artery. The inferior and superior vesicle arteries, uterine, and middle rectal arteries are normal and come off the umbilical artery and the internal pudendal artery. The internal pudendal artery is normal and gives off a branch to the uterus. The inferior gluteal artery is normal.

Posterior division: the posterior trunk is cut but can match the lumens for it. The superior gluteal artery is normal and gives off the lateral sacral artery normally.

The iliolumbar artery is an independent branch that comes off the internal iliac before it bifurcates.

The external iliac is normal. Have a trunk for the inferior epigastric but it got cut. Can see the other branch of the inferior epigastric that goes to the obturator canal. Cannot find the deep circumflex iliac.

RIGHT LOWER EXTREMITY

Femoral artery is normal. The deep femoral artery is normal and branches from the femoral artery posteriorly. The lateral circumflex femoral artery is normal and branches from the deep femoral artery. Cannot find the medial circumflex femoral artery. The femoral artery continues normally through the adductor hiatus. The arteries of the lower leg are all cut at the knee. Cannot follow their paths through the lower leg because they are cut out of the body.

LEFT LOWER EXTREMITY

Femoral artery is normal. The deep femoral artery is normal and branches from the femoral artery postero-laterally. The lateral circumflex femoral artery is normal and branches from the deep femoral artery. Cannot find the medial circumflex femoral artery. The femoral artery continues normally through the adductor hiatus. Anterior tibial and dorsalis pedis are normal. Cannot find the posterior tibial or fibular arteries

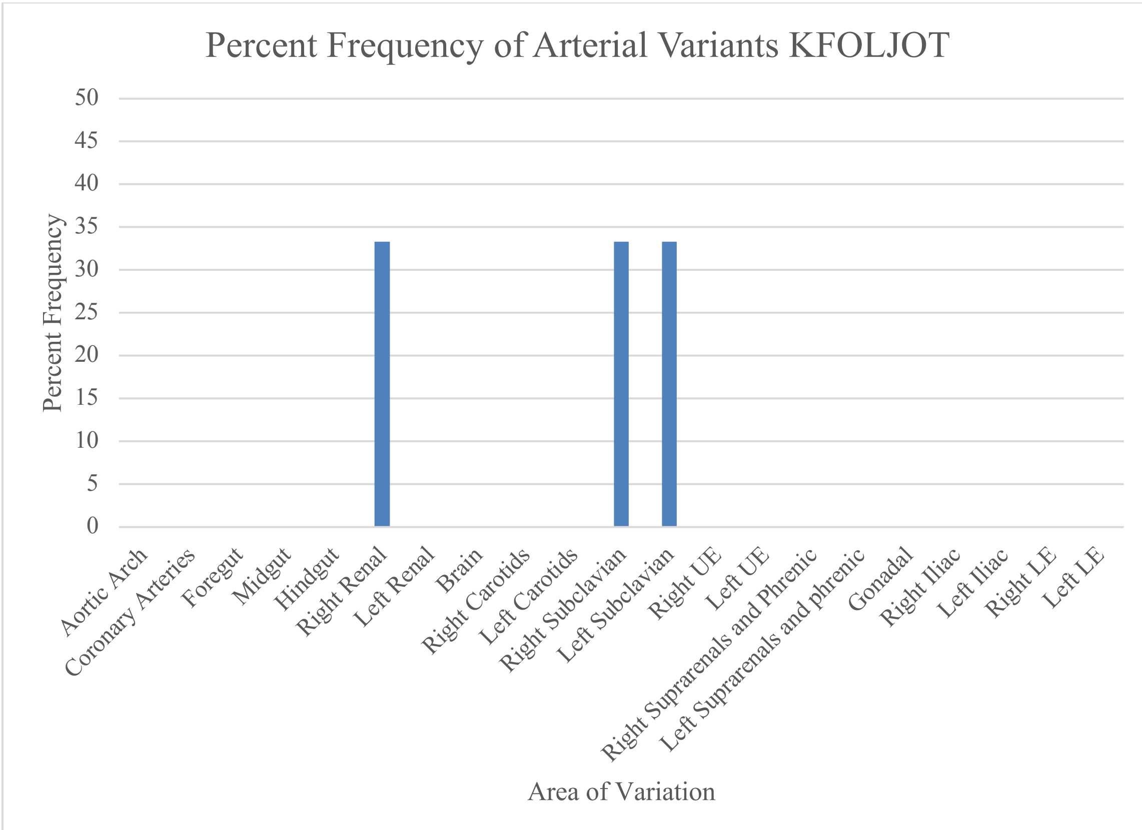

Figure 19: Percent frequency of arterial variants observed in body donor, KFOLJOT.

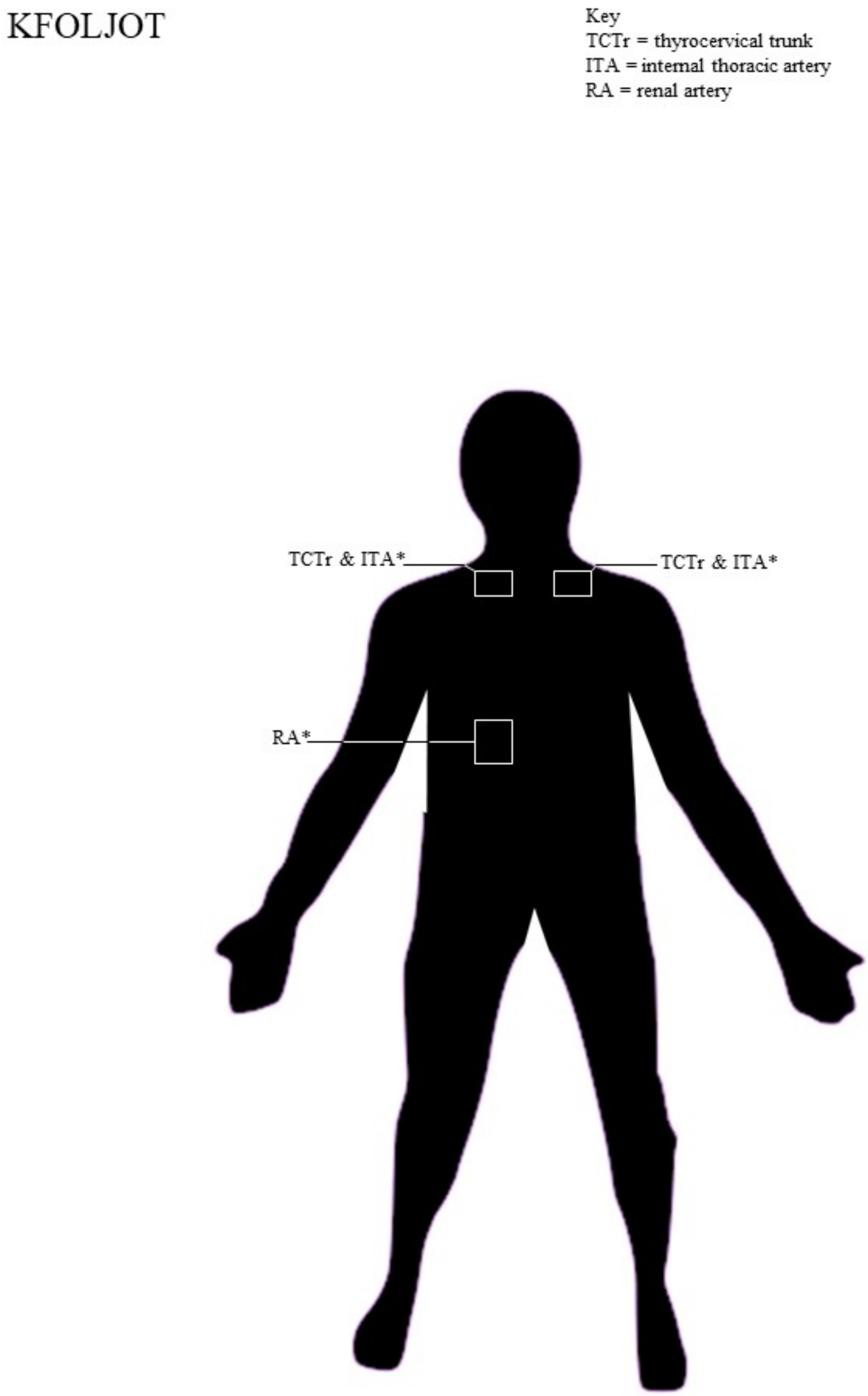

Figure 20: A schematic of the location and number of arterial variants found in body donor, KFOLJOT.

GJUZQBUSJDL

Sex: M

Age: 72

COD: Acute respiratory failure/cardiac arrest

Summary of variants seen (Figures 21-22)

- **Celiac trunk** only has **2 of the main abdominal branches**, the splenic and the left gastric, plus (1.) **the left inferior phrenic artery** (Figure 23)
- The **common hepatic artery has an anomalous origin off the SMA** (Figure 24)
- The **gastroduodenal artery** gives off the **right gastric artery** (Figure 24)
- **There is a common stem for the right colic and ileocolic arteries**
- In the **right internal iliac**, the posterior and anterior divisions are switched so that the posterior division is more anterior, causing the superior gluteal artery to exit the pelvis much more anteriorly
- In the **left lower extremity**, there is an anomalous origin of the **lateral circumflex femoral artery** from the **femoral artery**

Detailed Overview:

ARCH OF THE AORTA

Brachiocephalic trunk is normal, branches into the right subclavian and right common carotid arteries normally. The left common carotid is normal. The left subclavian is normal.

HEART

Right coronary artery is normal. The right marginal branch is set a bit more posteriorly than other hearts but is otherwise normal. The posterior interventricular artery is normal and comes off the right coronary artery. The left coronary artery is normal. The left anterior descending artery is normal. The left diagonal artery is normal. The left marginal artery is normal, has a very large width. The left circumflex is hard to find; it gets lost in the fascia covering the lingula.

FOREGUT

Celiac trunk has 3 branches; the splenic, left gastric, and left inferior phrenic. Splenic artery is normal and comes off celiac trunk. Left gastric is normal and comes off celiac trunk. Splenic artery gives rise to the left gastro-omental and posterior gastric arteries normally. **The left inferior phrenic artery comes off the celiac trunk** (Figure 23).

MIDGUT

The common hepatic artery comes off the SMA (Figure 24). The common hepatic gives off the gastroduodenal artery normally. The proper hepatic artery is normal and divides into the cystic artery and the right and left hepatic arteries. **The gastroduodenal artery gives off the right gastric and the right gastro-omental arteries** (Figure 24). The gastroduodenal artery gives off the supraduodenal artery normally. The inferior pancreaticoduodenal artery is normal. The middle colic artery is normal. **There is a common stem for the right colic and ileocolic arteries.** The jejunal and ileal arteries are normal.

HINDGUT

The IMA and its branches are normal. The left colic artery is normal. The sigmoid arteries are cut. The superior rectal artery is normal.

RIGHT RENAL

The right renal artery comes off the abdominal aorta normally, but it is cut very shortly after branching off aorta. The lumens of the renal artery match the lumen on the aorta though. The artery bifurcates as it reaches the kidney. The inferior phrenic artery is normal on the diaphragm but is cut before it reaches its origin from the aorta. The middle suprarenal artery comes off the aorta, but the adrenal gland was dissected away so it does not go anywhere. Have the testicular artery coming off the abdominal aorta, but it is cut before reaching testes. Do not have the inferior suprarenal artery.

LEFT RENAL

The left kidney is very small and more of a fatty lump than an organ. Have a renal artery going to it normally from the abdominal aorta. The inferior suprarenal artery comes off the renal artery normally. The middle suprarenal artery is normal. The inferior phrenic artery comes from the celiac trunk and gives off superior suprarenal branches. Do not have the testicular artery.

BRAIN

The circle of Willis is normal. The anterior, middle and posterior cerebral arteries are normal. The anterior and posterior communicating arteries are normal. The superior cerebellar arteries are normal. The basilar artery is normal.

RIGHT CAROTIDS

The common carotid bifurcates normally into the internal and external carotids. The internal carotid is normal but gets cut quickly after bifurcation. The external carotid artery is normal. Gives off the superior thyroid artery, lingual artery, and facial arteries normally. The superior thyroid artery gives off the superior laryngeal artery normally. Also have branches for the ascending pharyngeal artery but that gets cut. Continues as the superficial temporal artery normally. Cannot see the posterior auricular artery. The facial artery is normal. Have the superior and inferior labial branches normally and the angular artery as it gives off the lateral nasal artery. The ophthalmic artery from the internal carotid is normal.

LEFT CAROTIDS

Left common carotid bifurcates normally into the internal and external carotids. Internal carotid is normal but has a sigmoid shape to it before it gets cut. The external carotid artery is normal. The superior thyroid artery branches off before the common carotid bifurcation. Have the branch for the superior laryngeal artery, but it got cut. Lingual and facial arteries are normal. Have branch points for ascending pharyngeal and posterior auricular arteries but cut before arteries can reach targets. Can see the superficial temporal artery by the ear and it is normal. Maxillary artery is normal. The facial artery is normal and gives off the inferior and superior labial branches normally. The sphenopalatine artery is normal.

RIGHT SUBCLAVIAN

Vertebral artery is normal. Thyrocervical trunk is normal. All its branches were going in the normal direction but got cut before they reached their targets. The internal thoracic is normal. The costocervical trunk is normal. The dorsal scapular is cut but have a lumen for it.

LEFT SUBCLAVIAN

Vertebral artery is normal. Thyrocervical trunk is cut. Internal thoracic is normal. Costocervical trunk is normal. Dorsal scapular artery is normal and comes off the subclavian.

RIGHT UPPER EXTREMITY

Axillary artery is normal. The lateral thoracic artery is normal. Thoracoacromial trunk is normal. Subscapular artery, circumflex scapular, and thoracodorsal arteries are good. Cannot find circumflex humeral arteries. Axillary artery continues normally as brachial artery. Deep brachial artery is normal, but it is cut along its path and being held together by fascia around it. Cannot find the ulnar collaterals. Radial and ulnar arteries are normal. Common interosseous artery can be seen but cannot see it branch into anterior and posterior interosseous arteries. Superficial palmar arch is normal.

LEFT UPPER EXTREMITY

Axillary artery is normal but cut. Can see pectoral branches from the thoracoacromial trunk, but no other branches and no clear trunk itself. Subscapular, circumflex scapular, and thoracodorsal arteries are normal. Cannot see anterior or posterior circumflex humeral arteries but have a cut end of anterior circumflex humeral. Axillary artery continues normally as brachial artery. Deep brachial artery is normal. Cannot find the ulnar collaterals. Radial and ulnar arteries branch normally, and radial artery continues normally to the wrist. Ulnar artery is cut after it gives off the common interosseous artery. Anterior interosseous artery is present, but cannot see its full path, but is otherwise normal. Cannot see the posterior interosseous artery.

RIGHT ILIAC

The common iliac is normal and bifurcates into the internal and external iliacs normally. The internal iliac is normal and branches into anterior and posterior trunks normally. The orientation of the anterior and posterior divisions is flipped so that the posterior division is more anterior.

Anterior division: has a pretty normal morphology with branches coming off a long trunk before it terminates. The umbilical artery is normal. The obturator artery is normal but branches close to the umbilical. Have a random branch to the anterior body wall. The artery terminates by bifurcating into inferior gluteal and internal pudendal arteries. The internal pudendal artery gives off an inferior vesical branch.

Posterior division: iliolumbar comes off the posterior trunk normally. Have 2 lateral sacral arteries coming off the posterior trunk. Terminates with the superior gluteal artery which is normal.

External iliac is normal. The inferior epigastric artery is normal. Cannot find the deep circumflex iliac artery.

LEFT ILIAC

The common iliac branches normally into the internal and external iliacs. The internal iliac is normal and branches into anterior and posterior trunks normally.

Anterior trunk has pretty standard branch pattern. Umbilical artery is normal. The obturator artery is normal. Terminates with the bifurcation of the inferior gluteal and internal pudendal arteries. Have no clear vesicle arteries or middle rectal artery, but there are lots of branches that got ripped off the anterior trunk, so they were probably there.

Posterior division gives rise to the iliolumbar and lateral sacral arteries normally. The superior gluteal artery is normal.

The external iliac is normal. The inferior epigastric artery is normal. Cannot find the deep circumflex iliac artery.

RIGHT LOWER EXTREMITY

Femoral artery is good but has some type of spiral shunt in it. Deep femoral artery comes off the femoral artery postero-laterally and has a spiral shunt in it. Cannot find medial or lateral circumflex femorals. Femoral artery continues normally through the adductor hiatus. Anterior tibial and dorsalis pedis are normal. Cannot see the posterior tibial or fibular arteries.

LEFT LOWER EXTREMITY

Femoral artery is normal. **Lateral circumflex femoral artery is coming off the femoral artery.** Deep femoral artery is normal and coming off the femoral artery postero-medially. The medial circumflex femoral artery comes off the deep femoral artery inferior to the branch point of the lateral circumflex femoral and is normal. Femoral artery continues normally through adductor hiatus. Popliteal artery is normal, can see lumens where genicular arteries were cut. Cannot see anterior or posterior tibial or fibular arteries.

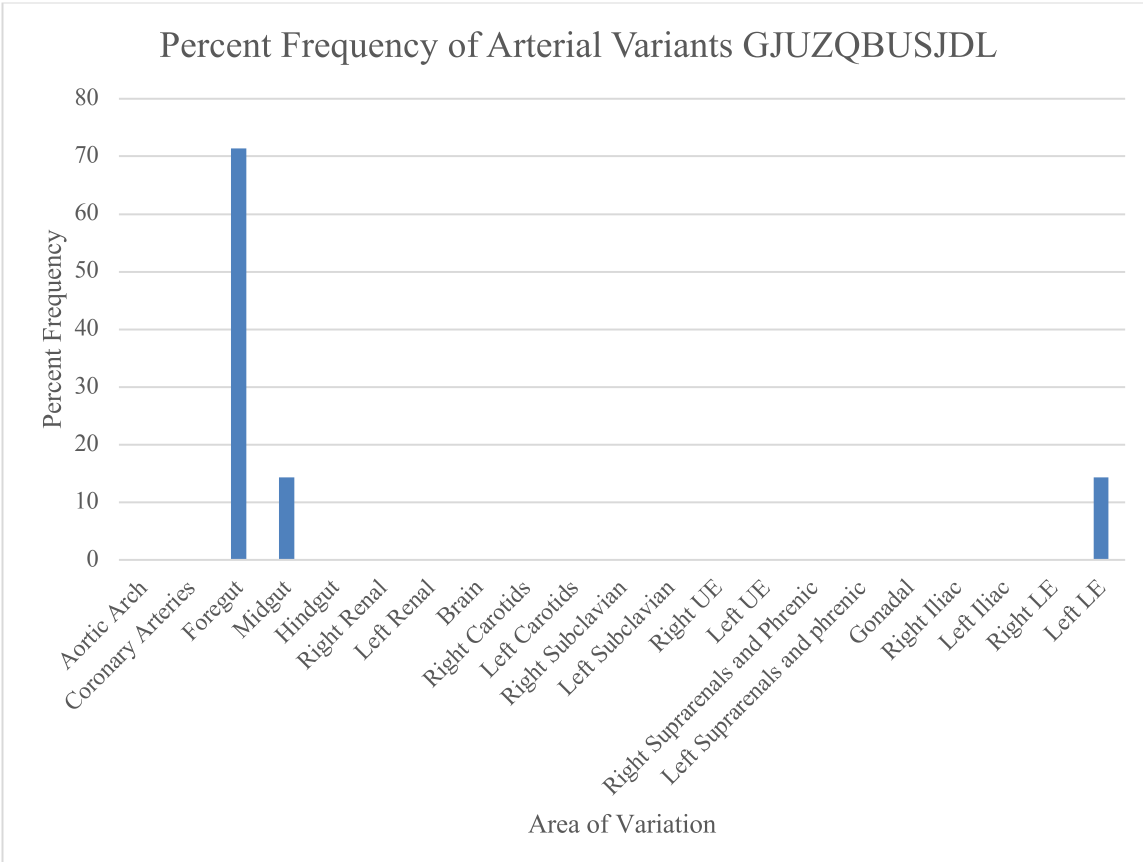

Figure 21: Percent frequency of arterial variants observed in body donor, GJUZQBUSJDL.

GJUZQBUSJDL

Key
CTr = celiac trunk
L_IPHA = left inferior phrenic artery
GDA = gastroduodenal artery
SMA = superior mesenteric artery
CHA = common hepatic artery
RCA = right colic artery
IICA = ileocolic artery
FA = femoral artery

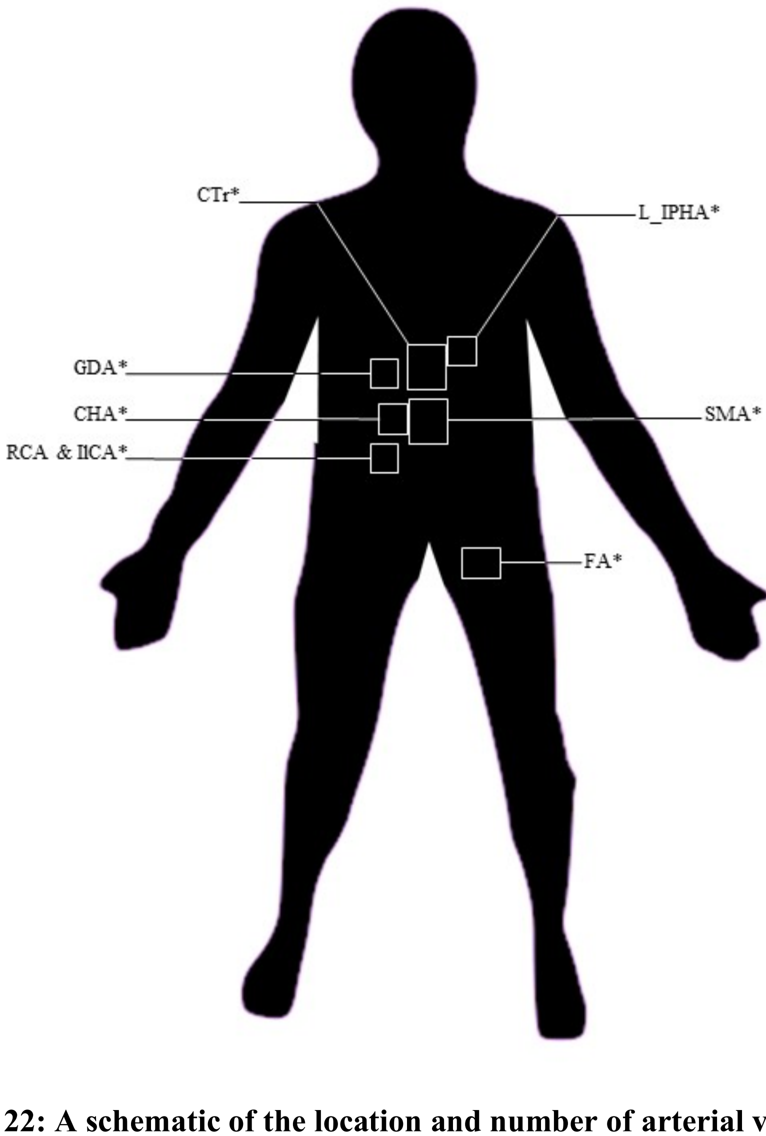

Figure 22: A schematic of the location and number of arterial variants found in body donor, GJUZQBUSJDL.

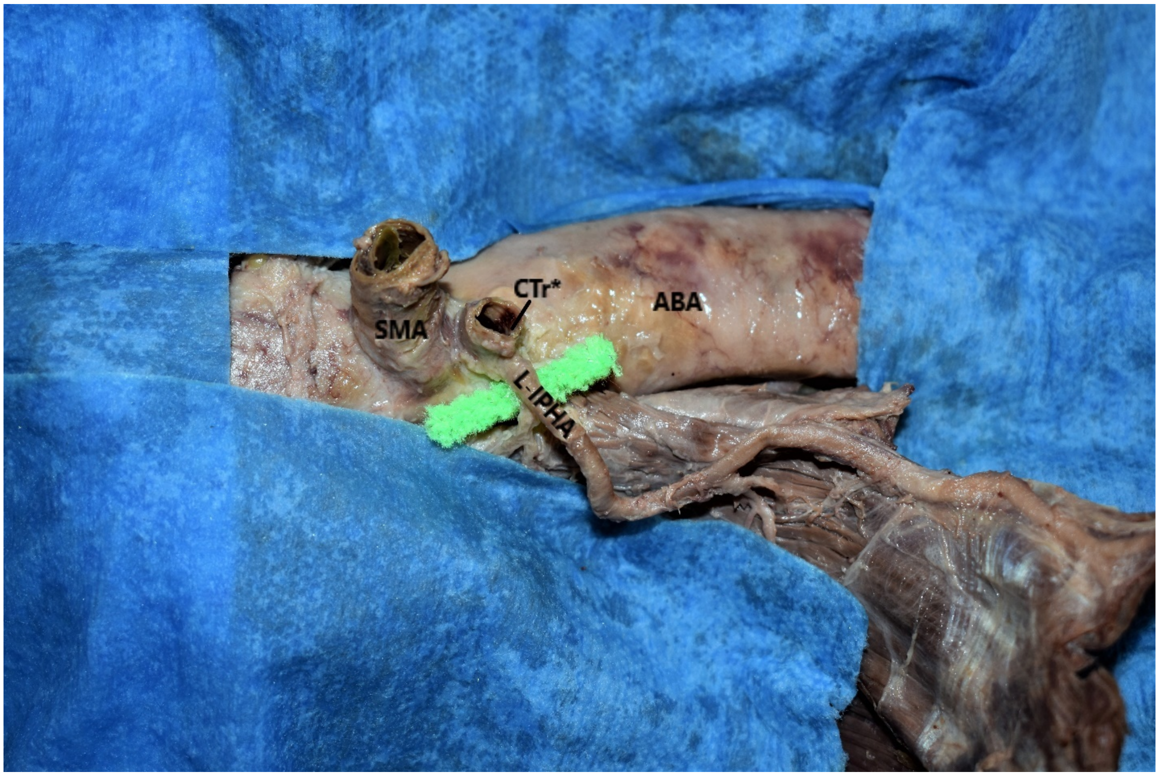

Figure 23: An anomalous origin of the left inferior phrenic artery from the celiac trunk in body donor, GJUZQBUSJDL.

SMA = superior mesenteric artery, CTr = celiac trunk, L-IPHA = left inferior phrenic artery, ABA = abdominal aorta, * = variant.

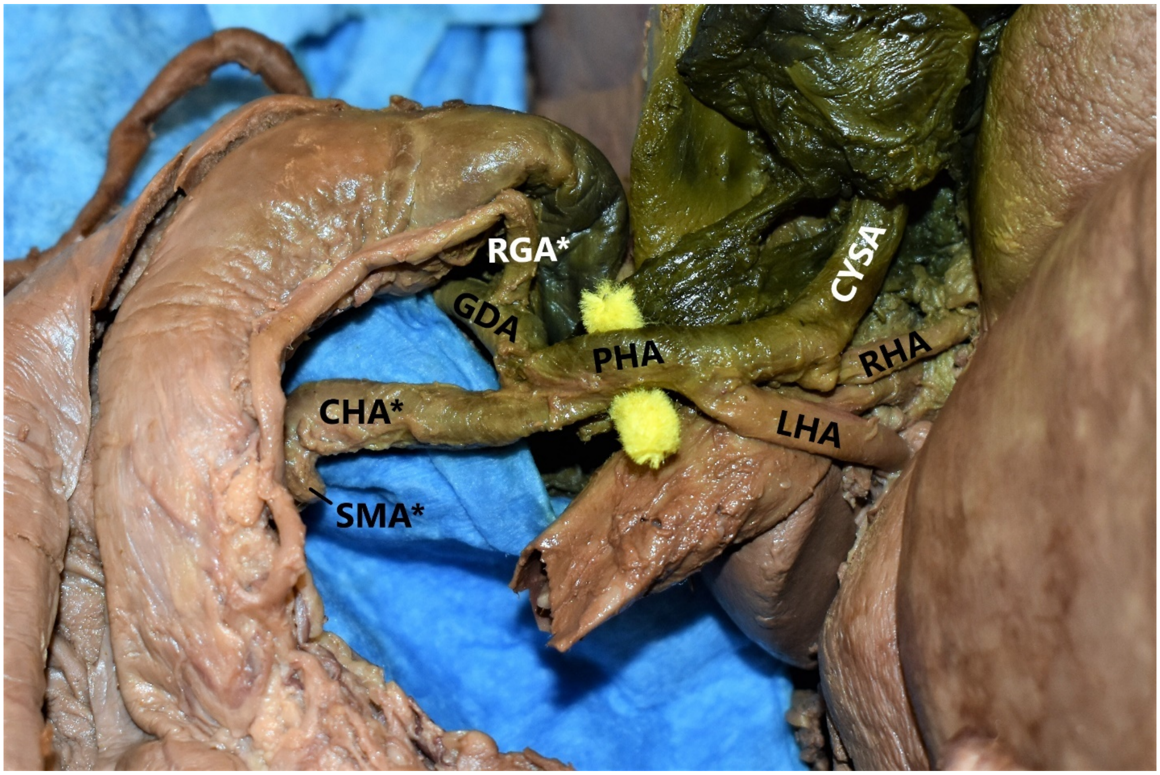

Figure 24: An anomalous origin of the common hepatic artery from the SMA and an anomalous origin of the right gastric artery from the gastroduodenal artery in body donor, GJUZQBUSJDL.

SMA = superior mesenteric trunk, CHA = common hepatic artery, GDA = gastroduodenal artery, RGA = right gastric artery, PHA = proper hepatic artery, LHA = left hepatic artery, RHA = right hepatic artery, CYSA = cystic artery, * = variant.

NBDLOJHIU

Sex: F

Age: 88

COD: Pneumonia/COPD/diabetes/coccyx wound/hypertension

Summary of variants seen (Figures 25-26)

- There is an **accessory left hepatic artery from the left gastric artery** (Figures 27-28)
- The **common hepatic artery** gives off a branch that goes towards the duodenum
- There is a **common trunk off the proper hepatic artery** for the right gastric artery and the branch that gives off the right and left hepatic arteries (Figure 28)
- The **SMA** gives off an **accessory right hepatic artery** that goes to the posterior liver (Figure 29)
- There is **a common stem for the middle colic and right colic arteries**
- In the **left subclavian artery**, there is a <u>common stem for the thyrocervical trunk and internal thoracic artery</u> (Figure 30)
- In the left upper extremity, the posterior circumflex humeral artery is still an independent branch, but it branches at the same level as the subscapular artery
- In the **right internal iliac**, the inferior gluteal artery bifurcates just before exiting pelvis, giving rise to a **second inferior gluteal artery**

- In the **left internal iliac**, the inferior gluteal bifurcates and gives off a **second internal pudendal artery**, both go through the greater sciatic foramen normally
- In the **left lower extremity**, there is an anomalous origin of the **lateral circumflex femoral artery** from the **femoral artery**

Detailed Overview:

ARCH OF THE AORTA

Brachiocephalic trunk is normal, branches normally into right common carotid artery and the right subclavian artery. The left common carotid artery is normal. The left subclavian artery is normal.

HEART

The left coronary artery is normal. The left anterior descending artery is normal. The left marginal artery is normal. The left circumflex artery is normal. The right coronary artery is normal. The right marginal artery is normal. The posterior interventricular comes off the right coronary artery normally.

FOREGUT

The left gastric, splenic, and common hepatic arteries come off the celiac trunk. **The left gastric artery gives off an accessory left hepatic artery to the posterior liver** (Figures 27–28). The splenic artery is normal. The left gastro-omental artery comes off the splenic artery normally but is cut in multiple places. Can still follow the lumens around the greater curvature of the stomach though. The proper hepatic artery bifurcates by liver and gives off the cystic artery and the left and right hepatic arteries. The gastroduodenal artery is normal and comes off the proper hepatic. It gives off the right gastro-omental artery, the supraduodenal artery, and the superior pancreaticoduodenal arteries normally. **The proper hepatic artery gives off the right gastric artery, but there is a common trunk for the right gastric artery and the branch that gives off the right and left hepatic arteries** (Figure 28). **There was another branch off the common hepatic artery, it traveled posteriorly of the pancreas and followed a branch of the SMA leading to the small intestines, but it was cut, and cannot find its termination point to determine what it was.**

MIDGUT

The SMA gives off an accessory right hepatic artery (Figure 29). The inferior pancreaticoduodenal artery is normal. **The right colic artery and the middle colic artery originate from a common stem**. The cecal arteries are normal. The ileocolic arteries are normal. The jejunal and ileal arteries are normal.

HINDGUT

The IMA is normal. The left colic is normal and bifurcates into the ascending and descending branches. Sigmoid arteries are normal. The superior rectal artery is normal.

RIGHT RENAL

The right renal artery branches off the abdominal aorta normally. It bifurcates quickly after branching from aorta and have one anterior and one posterior branch of the renal artery reach the kidney. The inferior suprarenal artery comes off the renal artery normally. The inferior phrenic artery comes off the aorta normally and gives rise to the superior suprarenal artery normally. Cannot find the middle suprarenal artery. Have the ovarian artery off the aorta, but it is cut before it reaches its target.

LEFT RENAL

The left renal artery branches from the abdominal aorta normally. It has one main trunk and then divides four times as it reaches the kidney. The middle suprarenal artery comes off the aorta normally. Cannot find the inferior phrenic artery, the superior or inferior suprarenal arteries, or the ovarian artery.

BRAIN

Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal. The anterior and posterior communicating arteries are normal. The basilar artery is normal.

RIGHT CAROTIDS

The common carotid bifurcates normally into the internal and external carotids. The point of bifurcation was a bit high. The internal carotid is normal but cut shortly after bifurcation. The external carotid is normal. The superior thyroid, lingual, and facial arteries are all normal. The occipital is given off but cut. External divides into the superficial temporal arteries and posterior auricular arteries normally. The facial artery is normal. Gives rise to the superior and inferior labial arteries, lateral nasal artery, and angular artery normally. The ophthalmic artery from the internal carotid is normal.

LEFT CAROTIDS

The common carotid bifurcates normally into internal and external carotids. The internal carotid is normal. The external carotid is normal. The superior thyroid artery is cut, have a lumen for it at the same level as the bifurcation of the common carotids. The lingual and facial arteries are normal. The occipital artery is given off but cut before it reaches its target. The external is cut before it bifurcates into its terminal branches. The facial artery is normal. Gives off the superior and inferior labial arteries normally. The maxillary artery is normal.

RIGHT SUBCLAVIAN

Vertebral artery is normal. Thyrocervical trunk is normal. Inferior thyroid artery is normal, cut just before it reaches its target. The suprascapular artery is normal. The transverse cervical is cut quickly after branching. The internal thoracic is normal. Cannot find the costocervical trunk. The dorsal scapular artery is normal and comes off the subclavian.

LEFT SUBCLAVIAN

Vertebral artery is normal. **Internal thoracic and thyrocervical trunk come off a common trunk** (Figure 30). The branches of the thyrocervical trunk, the inferior thyroid, suprascapular, and transverse cervical, are normal. The costocervical trunk is normal. The dorsal scapular artery is normal.

RIGHT UPPER EXTREMITY

Axillary artery is normal. Lateral thoracic artery is cut. Thoracoacromial artery is normal. Subscapular, circumflex scapular, and thoracodorsal arteries are normal. Anterior and posterior circumflex humeral arteries are normal. The axillary artery continues normally as the brachial artery. The deep brachial artery is normal. The superior ulnar collateral is normal, but the inferior cannot be found. The radial and ulnar arteries are normal and bifurcate in the cubital fossa. The common interosseous artery is normal. The anterior interosseous artery is cut, and the posterior cannot be found. The superficial palmar arch is normal.

LEFT UPPER EXTREMITY

Axillary artery is normal. Lateral thoracic artery is cut. Thoracoacromial branches are cut. Subscapular, circumflex scapular, and thoracodorsal arteries are normal. Anterior circumflex humeral is normal. Posterior circumflex humeral artery is normal and an independent artery, but it branches on the same level as the subscapular artery. The axillary artery continues normally as the brachial artery. The deep brachial artery is normal. Superior ulnar collateral is normal, but inferior cannot be found. Radial and ulnar arteries are normal and bifurcate in the cubital fossa. Radial recurrent artery is normal. Common, anterior and posterior interosseous arteries are normal. Superficial palmar arch is normal.

RIGHT ILIAC

Common iliac branches normally into the internal and external iliacs. The internal iliac branches normally into the anterior and posterior divisions.

Anterior division: umbilical artery is normal and is part of a terminal trifurcation with the superior vesicle artery and the inferior gluteal artery. **Inferior gluteal artery**

bifurcates just before exiting pelvis, giving rise to a second inferior gluteal artery. Do not have uterine or vaginal arteries because they got cut.

Posterior division: iliolumbar is normal, cut but can still match the lumens. The lateral sacral is cut. Posterior division gives off the internal pudendal artery. Ends by bifurcating into the superior gluteal artery and the obturator artery. The obturator artery is really torturous and gives off a branch to the anterior pelvic wall.

The external iliac is normal. The inferior epigastric is normal and bifurcates. The other branch goes down the obturator canal. Cannot find deep circumflex iliac.

LEFT ILIAC

Common iliac divides normally into internal and external iliacs. The internal iliac divides normally into anterior and posterior divisions.

Anterior division is like a giant bifurcation. Uterine artery and umbilical artery make up one of the branches of the bifurcation and are normal. The superior vesicle arteries come off the umbilical artery. The next part of the bifurcation is a common trunk where all the vessels come off. The internal pudendal is normal. **The inferior gluteal is normal and then bifurcates, giving off a second internal pudendal artery**. The obturator artery is normal and gives off a branch to the anterior wall of the pelvis. Have cut vessels that were probably the vaginal, middle rectal, or inferior vesicle arteries.

Posterior division is normal. Gives off lateral sacral and superior gluteal normally

Iliolumbar is an independent branch that comes off the internal iliac before it bifurcates.

External iliac is normal. The inferior epigastric is normal. Cannot find deep circumflex iliac.

RIGHT LOWER EXTREMITY

Femoral artery is normal. Deep femoral artery is normal and comes off the femoral artery laterally before diving posteriorly. The lateral circumflex femoral branches off the deep femoral normally. Cannot find the medial circumflex femoral. The femoral artery continues normally through the adductor hiatus. Cannot find any genicular branches. Anterior tibial artery is normal but cannot find dorsalis pedis. Posterior tibial artery is normal. Cannot find the fibular artery.

LEFT LOWER EXTREMITY

Femoral artery is normal. **Lateral circumflex femoral artery comes off the femoral artery,** branches at about the same point as the deep femoral artery. Deep femoral artery is otherwise normal and branches off the femoral artery postero-laterally. Cannot find medial circumflex femoral artery. The femoral artery continues through the adductor hiatus normally. Anterior tibial is normal as is dorsalis pedis. Posterior tibial artery is cut at the ankle. Cannot find the fibular artery.

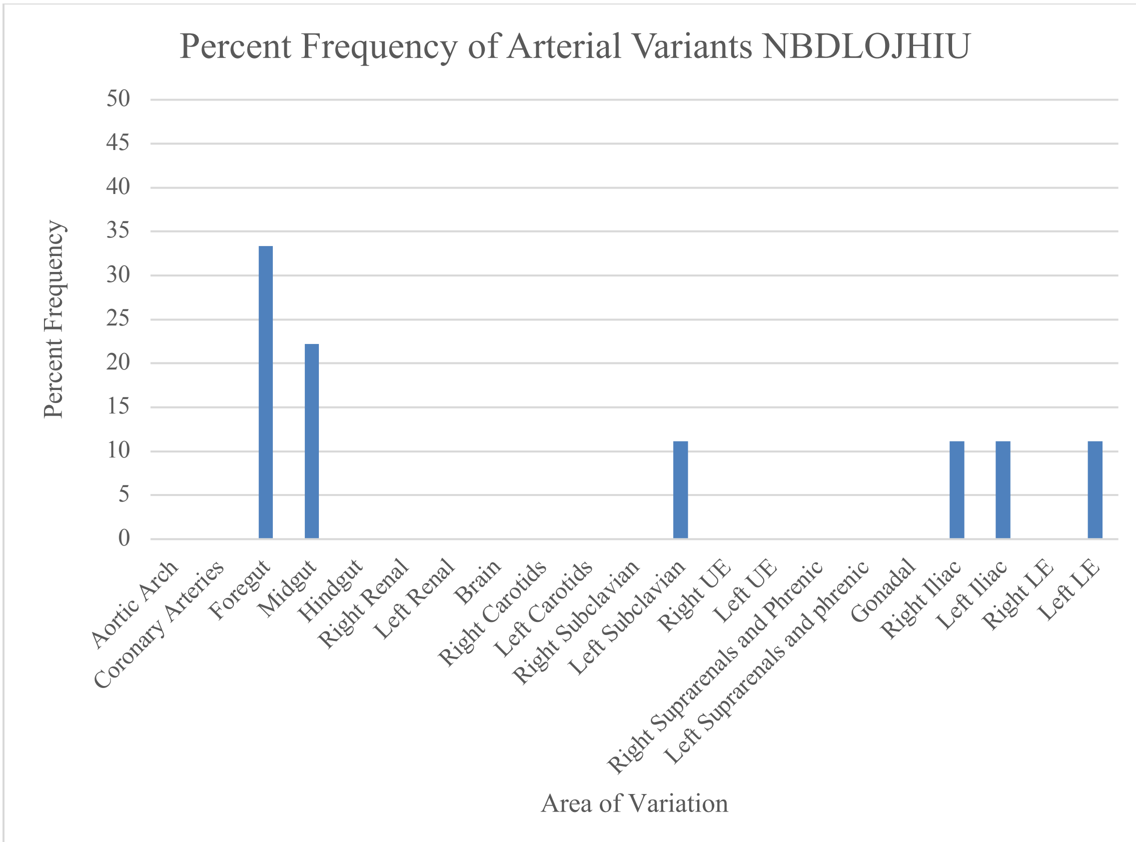

Figure 25: Percent frequency of arterial variants observed in body donor, NBDLOJHIU.

NBDLOJHIU

Key
TCTr = thyrocervical trunk
ITA = internal thoracic artery
CHA = common hepatic artery
AccLHA = accessory left hepatic artery
AccRHA = accessory right hepatic artery
LGA = left gastric artery
PHA = proper hepatic artery
SMA = superior mesenteric artery
AccDA = accessory duodenal artery
MCA = middle colic artery
RCA = right colic artery
IGA = inferior gluteal artery
IPA = internal pudendal artery
FA = femoral artery

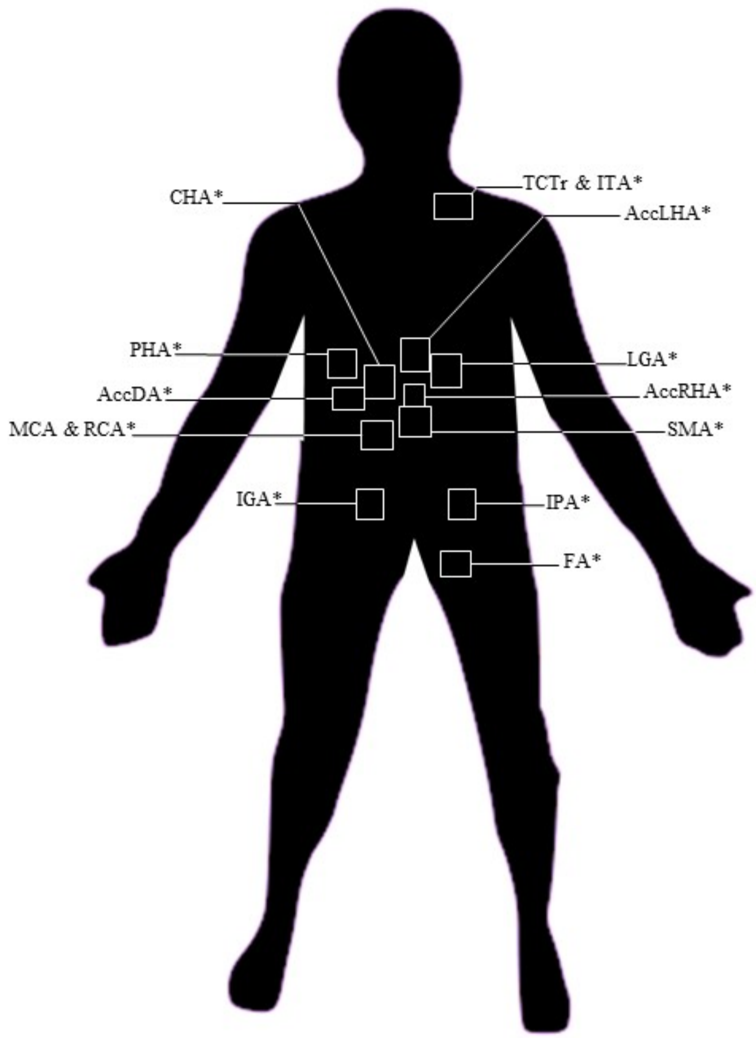

Figure 26: A schematic of the location and number of arterial variants found in body donor, NBDLOJHIU.

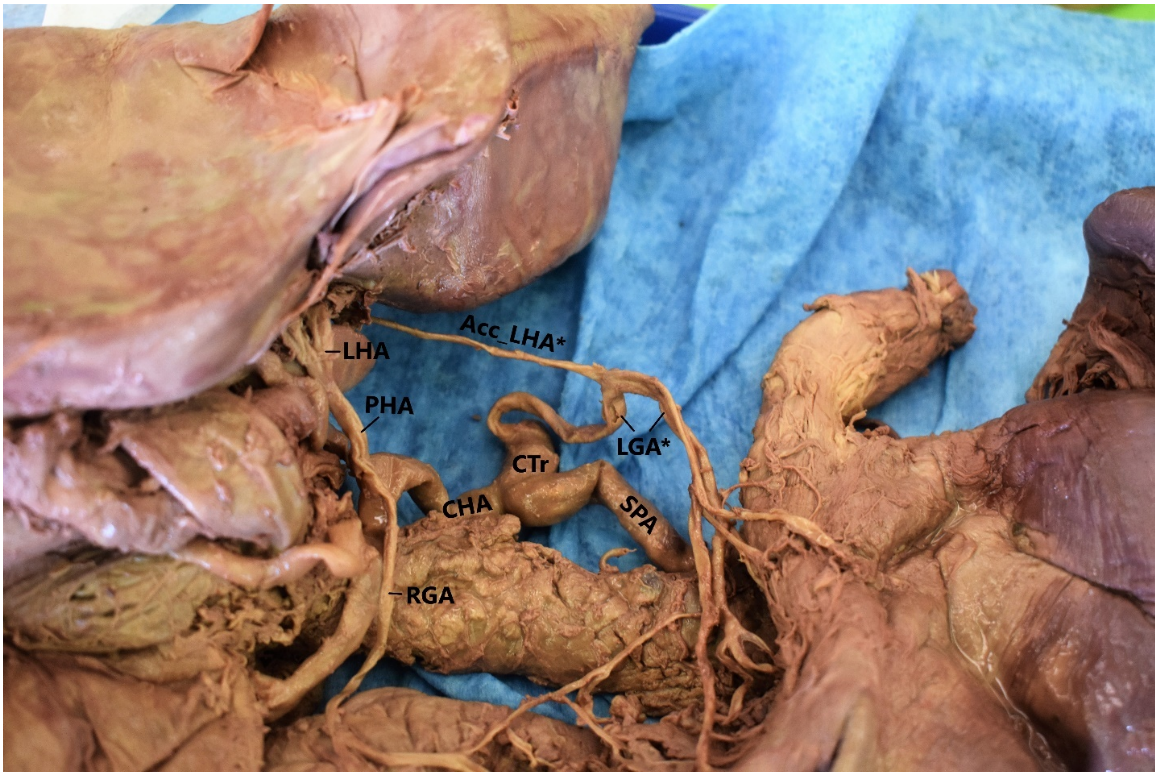

Figure 27: An accessory left hepatic artery from the left gastric artery in body donor, NBDLOJHIU.

CTr = celiac trunk, SPA = splenic artery, LGA = left gastric artery, Acc_LHA = accessory left hepatic artery, CHA = common hepatic artery, PHA = proper hepatic artery, LHA = left hepatic artery, RGA = right gastric artery, * = variant.

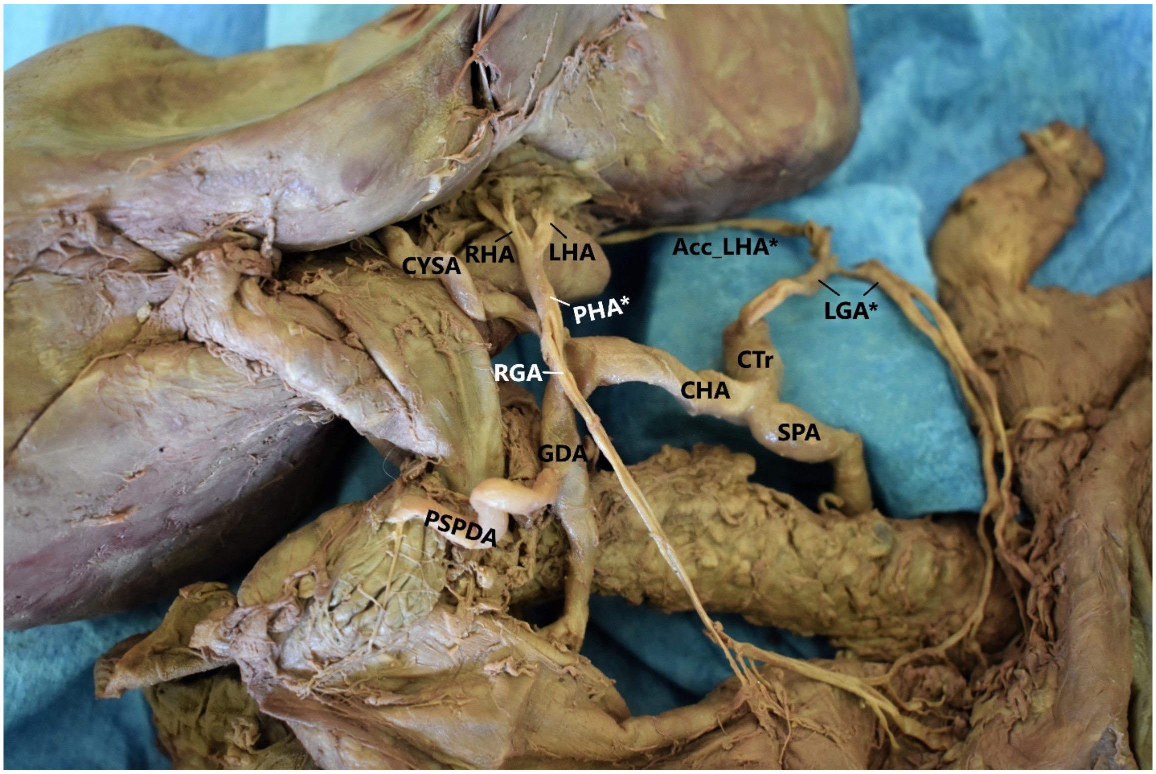

Figure 28: A common stem of the right gastric artery and the branch that gives off the right and left hepatic arteries off the proper hepatic artery in body donor, NBDLOJHIU. The accessory left hepatic artery from the left gastric artery can also be seen.

CTr = celiac trunk, SPA = splenic artery, LGA = left gastric artery, Acc_LHA = accessory left hepatic artery, CHA = common hepatic artery, GDA = gastroduodenal artery, PSPDA = posterior superior pancreaticoduodenal artery, PHA = proper hepatic artery, RGA = right gastric artery, RHA = right hepatic artery, LHA = left hepatic artery, CYSA = cystic artery, * = variant.

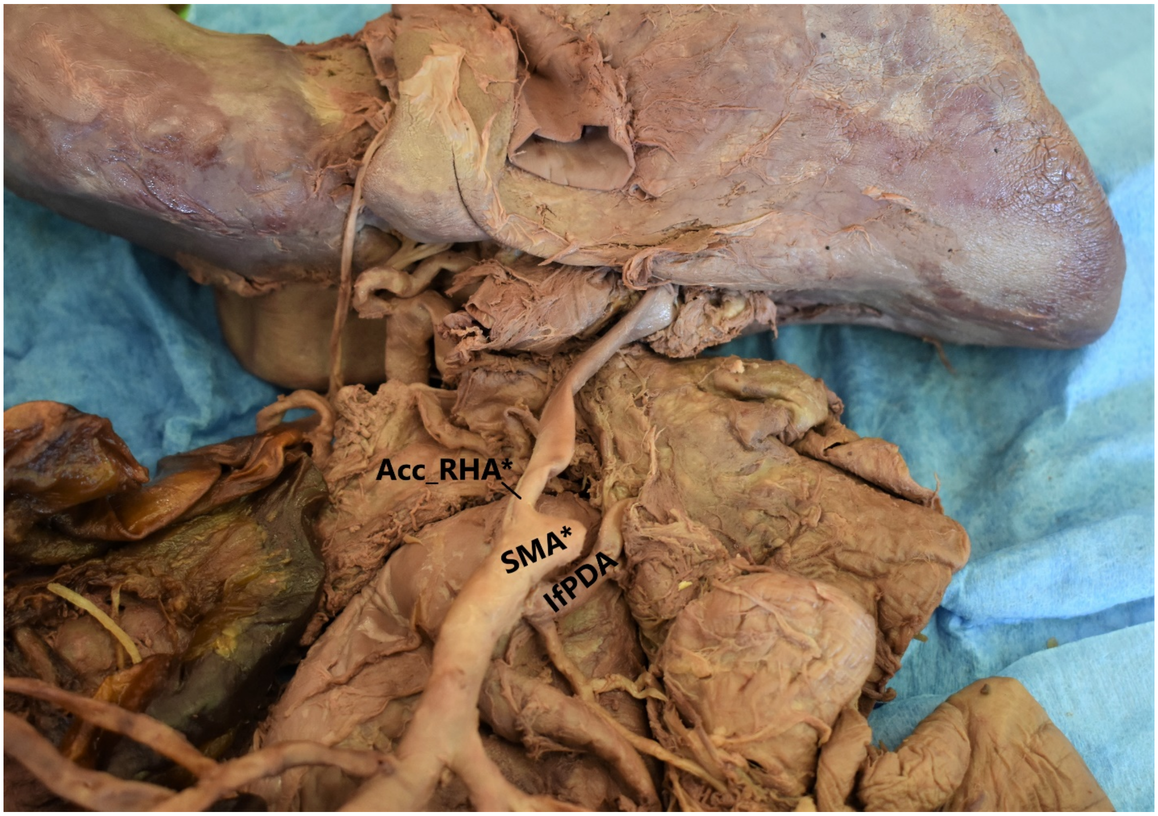

Figure 29: An accessory right hepatic artery coming off the SMA in a posterior view of the liver in body donor, NBDLOJHIU.

SMA = superior mesenteric artery, Acc_RHA = accessory right hepatic artery, IfPDA = inferior pancreaticoduodenal artery, * = variant.

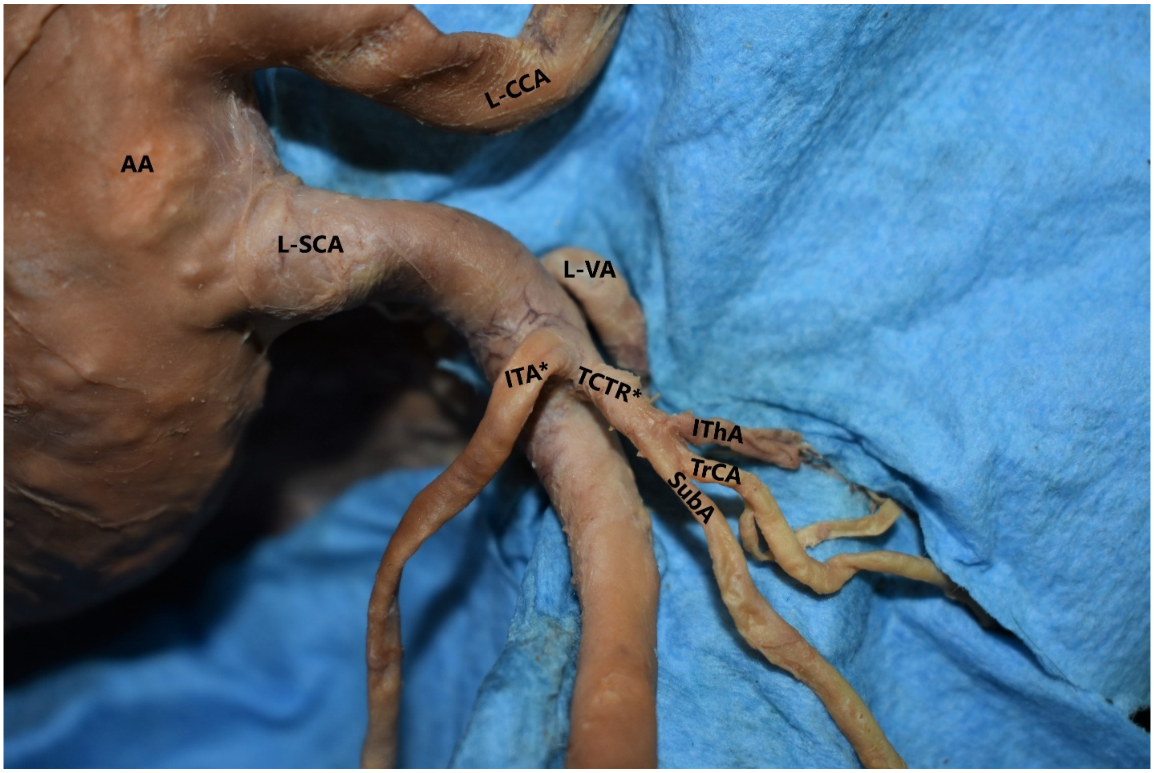

Figure 30: A common stem of the thyrocervical trunk and the internal thoracic artery off the left subclavian artery in body donor, NBDLOJHIU.

AA = aortic arch, L-CCA = left common carotid artery, L-SCA = left subclavian artery, L-VA = left vertebral artery, ITA = internal thoracic artery, TCTR = thyrocervical trunk, IThA = inferior thyroid artery, TrCA = transverse cervical artery, SubA = subscapular artery, * = variant.

NDMBVHIMJO

Sex: M

Age: 86

COD: Complications of hip fracture/mechanical fall

Summary of variants seen (Figures 31-32)

- The **left marginal artery** of the heart branches from the LAD
- The heart is a **left-dominant heart,** the left coronary artery gives off the posterior interventricular artery
- **Celiac trunk has 4 branches**, the 3 typical ones plus (1.) **additional common hepatic artery**
    - Anterior, superior **common hepatic artery** gives off the cystic artery, the right hepatic artery, and a **branch that goes to the duodenum**
    - Posterior, inferior CHA gives off gastroduodenal and left hepatic artery
- **Left gastric artery** was part of a common trunk with 2 other branches that got cut
- There is **a common stem for the right colic and middle colic arteries**
- In the **left subclavian**, there is a <u>common stem for the thyrocervical trunk and internal thoracic artery</u>
- In the **right upper extremity**, the **radial artery** gives off the **interosseous arteries**

- In the **left upper extremity**, the anterior and posterior circumflex humeral arteries branch very close to the same level as the subscapular artery
- In the **left upper extremity**, the brachial artery bifurcates early, about halfway down the arm. The ulnar artery is normal and continues straight to the wrist. The **radial artery** gives off the **interosseous arteries** in the cubital fossa
- In the **left lower extremity**, there is an anomalous origin of the **medial circumflex femoral artery** from the **femoral artery**

Detailed Overview:

ARCH OF THE AORTA

The brachiocephalic trunk is normal. It branches normally into the right subclavian and right common carotid arteries. The left common carotid artery is normal. The left subclavian artery is normal.

HEART

The left coronary artery branches from the aorta normally. It bifurcates into the left circumflex and a common trunk for all the other branches. The left anterior descending artery is normal. The left diagonal artery is normal. **The left marginal artery branches from the LAD, st**ill has a normal course. **The left circumflex artery gives rise to the posterior interventricular artery which means this is a left-dominant heart**. The right coronary artery is normal. The sinoatrial branch is normal. The right marginal is normal. The right coronary artery keeps going but is shorter because it does not wrap all the way around the posterior part of the heart because **this is a left-dominant heart.**

FOREGUT

Have 4 branches off the celiac trunk. There is the splenic artery, the left gastric artery, **and two common hepatic arteries. The left gastric artery comes from a common trunk that has 2 other branches, but those branches are cut**. The splenic artery gives off lots of splenic branches normally but cannot find the left gastro-omental artery. One common hepatic artery is oriented more anteriorly and superiorly. It gives off the cystic artery and the right hepatic artery. **It also has a branch that goes to the duodenum or pancreas, which is the supraduodenal artery**. The 2nd common hepatic artery gives off the gastroduodenal artery and the left hepatic artery. There is another branch after the gastroduodenal artery, but it is cut, it may have been the right gastric artery. The gastroduodenal artery gives off the right gastro-omental artery normally and the superior pancreaticoduodenal artery normally.

MIDGUT

The SMA and its branches are normal. The inferior pancreaticoduodenal branch got cut. **There is a common stem for the right and middle colic arteries.** The jejunal and ileal arteries are normal. The ileocolic and cecal arteries are normal.

HINDGUT

The IMA and its branches are normal. The left colic artery is normal. Branches into the ascending and descending branches normally. The sigmoid and superior rectal arteries got cut.

RIGHT RENAL

Right renal artery is normal and comes off the abdominal aorta. Bifurcates as it reaches the kidney. The inferior suprarenal artery branches off the renal artery normally. The middle suprarenal artery is normal but cut where it branches from the aorta. Can still match the lumens. Cannot find the inferior phrenic artery or the testicular artery.

LEFT RENAL

The left renal artery comes off the abdominal aorta normally. It bifurcates as it reaches the kidney. The middle suprarenal artery comes off the aorta normally, but there is no adrenal gland on this side, so it goes nowhere. Cannot find the inferior or superior suprarenal artery, the inferior phrenic artery, or the testicular artery.

BRAIN

The Circle of Willis is normal. The vertebral arteries make the basilar artery normally. The anterior, middle, and posterior cerebral arteries are normal. The anterior communicating arteries are normal. The posterior communicating arteries are normal, but the right side is much larger than the left. The superior cerebellar arteries are normal.

RIGHT CAROTIDS

The common carotid bifurcates normally into the internal and external carotids. The internal carotid is normal but cut shortly after bifurcation. The external carotid is normal and gives off the superior thyroid artery, which gives rise to the superior laryngeal artery, the lingual artery, and the facial artery. External is cut before it can give off terminal branches. The facial artery is normal. Gives off the superior and inferior labial arteries normally. The ophthalmic artery from the internal carotid is normal.

LEFT CAROTIDS

The common carotid bifurcates normally into the internal and external carotids. The internal carotid is normal but cut shortly after bifurcation. The external carotid is normal and gives off the superior thyroid artery, which gives rise to the superior laryngeal artery, the lingual artery, and the facial artery. External is cut before it can give off terminal branches. The facial artery is normal. Gives off the submental artery and the superior and inferior labial arteries normally. The maxillary artery is normal.

RIGHT SUBCLAVIAN

Right vertebral is normal. Thyrocervical trunk is cut, can see lumen for it. Internal thoracic is normal. The costocervical trunk is normal. The dorsal scapular is normal and comes off the subclavian.

LEFT SUBCLAVIAN

Vertebral is normal. Have another branch posterior to the vertebral that travels parallel to it, but do not know what it is. **The thyrocervical trunk and internal thoracic come off a common trunk**. The dorsal scapular comes off the suprascapular. The other branches of the thyrocervical trunk are cut. Have another branch posterior to the thyrocervical trunk that may have been the costocervical trunk.

RIGHT UPPER EXTREMITY

Axillary artery is normal. Cannot find the lateral thoracic. Thoracoacromial is normal. Subscapular, circumflex scapular, and thoracodorsal arteries are normal. Anterior and posterior circumflex humeral arteries are normal. Axillary artery continues normally as the brachial artery. The deep brachial artery is normal. Brachial artery branches at the normal spot on this side. Radial recurrent artery is normal. Cannot find ulnar collaterals. **Common interosseous artery comes off the radial artery**. Ulnar artery is normal and just continues straight to the wrist. The superficial palmar arch is normal.

LEFT UPPER EXTREMITY

Axillary artery is normal. Lateral thoracic artery is normal. Thoracoacromial artery is normal. Subscapular artery is normal, and its branches, the thoracodorsal and circumflex scapular, are normal. Anterior and posterior circumflex humerals are normal, but they branch almost at the same level as the subscapular artery. Axillary artery continues normally as the brachial artery. Deep brachial artery is good**. Brachial artery bifurcates early, about halfway between the elbow and shoulder. The ulnar artery is normal and continues from the early bifurcation point to the wrist where it is cut. Radial artery gives off the common interosseous artery in the cubital fossa.** Could not find ulnar collaterals, radial recurrent, or superficial palmar arch.

RIGHT ILIAC

Common iliac bifurcates normally into internal and external iliac arteries. The internal iliac is normal, but has a strange branching pattern, looks more like a common ganglion that all the branches come out of.

The sort of anterior division gives off the umbilical artery normally. The umbilical artery gives rise to middle rectal and superior and inferior vesicle branches.

The sort of posterior division gives rise to the lateral sacral and superior gluteal arteries, both of which are normal. The inferior gluteal artery comes off at the same time as the superior gluteal artery. the inferior gluteal artery gives off the obturator artery.

The internal pudendal artery comes off the ganglia by itself and is normal

Cannot find iliolumbar artery

The external iliac is normal. The inferior epigastric is normal. Cannot find the deep circumflex iliac.

LEFT ILIAC

The common iliac bifurcates normally into internal and external iliacs. The internal iliac is normal and bifurcates into the anterior and posterior divisions in a much more typical fashion.

Anterior division has one big bifurcation. The umbilical artery is one branch, but it is cut. The second branch travels for a bit and gives off the obturator artery. Bifurcates into inferior gluteal and internal pudendal arteries, both of which are normal. The internal pudendal gives off an inferior vesicle branch.

Posterior division: have 2 branches of lateral sacral arteries. Terminates with the superior gluteal normally.

Iliolumbar comes off independently before internal iliac bifurcates.

The external iliac is normal. The inferior epigastric is normal. Cannot find the deep circumflex iliac.

RIGHT LOWER EXTREMITY

Femoral is normal. Deep femoral is normal and comes off the femoral artery postero-laterally. Lateral circumflex femoral comes off the deep femoral normally. Cannot find medial circumflex femoral. There is a lumen that may have been for it on the femoral artery, superior to the branch point of the deep femoral. The femoral artery continues normally through the adductor hiatus Anterior and posterior tibial arteries are normal. Cannot find the fibular artery.

LEFT LOWER EXTREMITY

Femoral is normal. Deep femoral is normal, comes off the femoral postero-laterally. The lateral circumflex femoral comes off the deep femoral normally. **The medial circumflex femoral artery comes off the femoral artery**, superior to the branch point of the deep femoral artery. The femoral artery continues normally through the adductor hiatus. Anterior and posterior tibial arteries are normal. Cannot see the fibular artery.

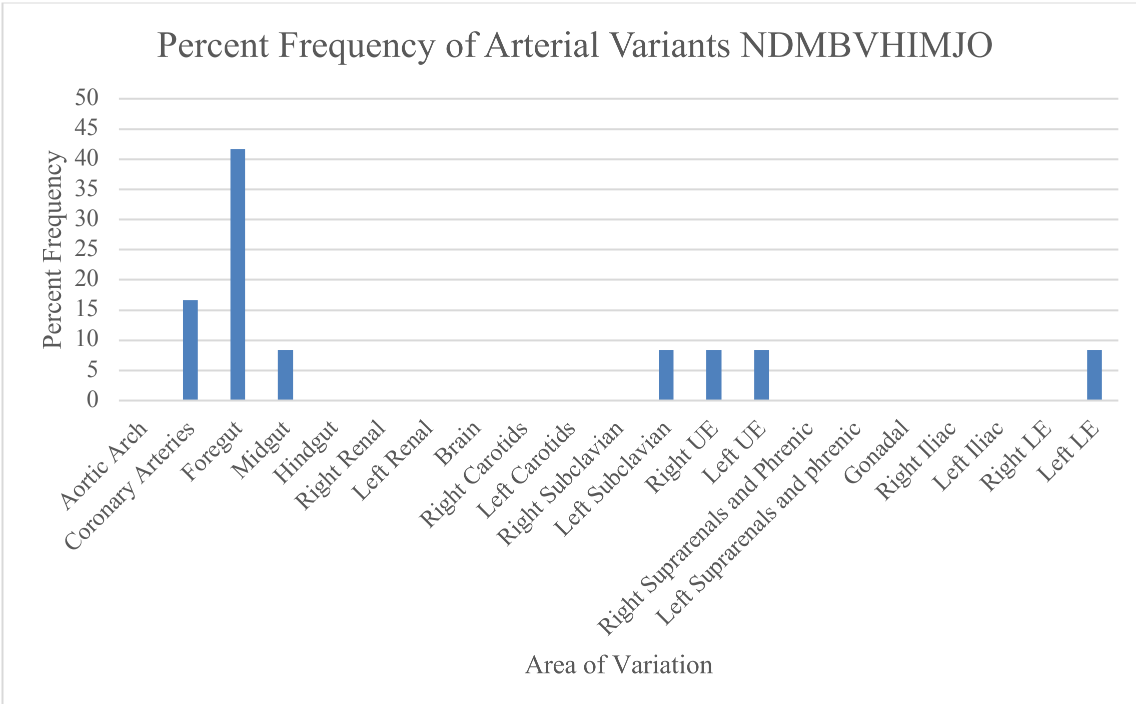

Figure 31: Percent frequency of arterial variants observed in body donor, NDMBVHIMJO.

NDMBVHIMJO

Key
LMA = left marginal artery
TCTr = thyrocervical trunk
ITA = internal thoracic artery
Left Dom. Heart = left dominant heart
LGA = left gastric artery
BrA = brachial artery
RadA = radial artery
CHA = common hepatic artery
FA = femoral artery
RCA = right colic artery
MCA = middle colic artery
AccDA = accessory duodenal artery

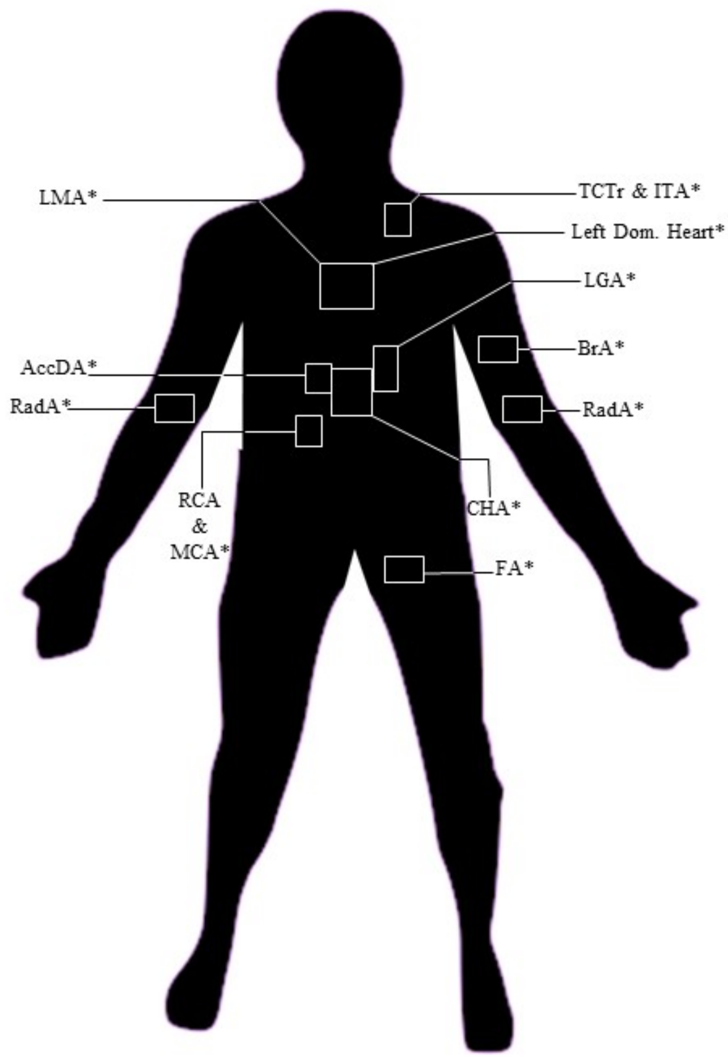

Figure 32: A schematic of the location and number of arterial variants found in body donor, NDMBVHIMJO.

IBVHIUPO

Sex: F

Age: 96

COD: Massive cerebral vascular accident

Summary of variants seen (Figures 33–34)

- The **left coronary artery trifurcates** into its 3 main branches
- The **proper hepatic artery bifurcates** into the <u>cystic artery</u> and a <u>common trunk for the right gastric artery and the left/right hepatic arteries</u>
- The **right colic and ileocolic come from a common trunk**, they bifurcate and then come back together, forming a swelling that all their subsequent branches come from
- On the **left subclavian**, there is a <u>common stem for the thyrocervical trunk and internal thoracic artery</u>
- In the **left upper extremity**, the posterior circumflex humeral artery branches at the same level as the subscapular artery
- In the **left upper extremity**, the <u>bifurcation of the ulnar and radial arteries</u> is about ½ inch after the subscapular artery. The radial artery is larger in width and is the dominant artery
- In the **left upper extremity**, the **radial artery** gives off the **deep brachial artery** and **the interosseous arteries**

- In the **left lower extremity**, there is a common stem for the deep femoral artery and lateral circumflex femoral artery

Detailed Overview:

AORTA

The brachiocephalic trunk is normal, bifurcates into the right common carotid and right subclavian normally. Left common carotid is normal. Left subclavian is normal.

HEART

The right coronary artery is normal. The right marginal is normal. The right coronary artery gives off the posterior interventricular artery normally. **The left coronary artery trifurcates into its 3 main branches.** The LAD left marginal, and left circumflex are normal.

FOREGUT

Celiac trunk is normal and gives off its 3 branches normally. The left gastric is normal but gets cut at the cardia of the stomach. The splenic artery is normal. It gives off a branch very quickly after branching from the celiac trunk that is the dorsal pancreatic artery. The other branches of the splenic have been cut. Cannot find the left gastro-omental off the splenic. The common hepatic artery is normal. Gives off the gastroduodenal artery which is cut but can match the lumens of it. The gastroduodenal artery is normal. Gives off the superior pancreaticoduodenal and right gastro-omental arteries normally. Cannot find the supraduodenal artery. The proper hepatic artery is normal. Bifurcates into a cystic and common trunk for right/left hepatic arteries. **The right gastric comes off the common trunk for the right/left hepatic arteries, it is cut, but can match the lumen to the one on the stomach. The cystic artery branches off before the right gastric is given off the proper hepatic artery.**

MIDGUT

SMA is normal. The inferior pancreaticoduodenal is normal. The middle colic is normal. The jejunal and ileal branches are normal. **The right colic and ileocolic artery come from a common trunk. They bifurcate and then come back together, creating a large swelling that all their branches then come from.**

HINDGUT

IMA branches normally. The left colic artery and its ascending and descending branches are normal. The sigmoid arteries are normal. The superior rectal arteries are normal.

RIGHT RENAL

Renal artery comes off the abdominal aorta normally. Bifurcates as it reaches the kidney. Inferior suprarenal artery is normal and comes off the renal artery. Middle suprarenal artery is normal. Cannot find the inferior phrenic, superior suprarenal, or ovarian artery.

LEFT RENAL

The renal artery comes off the abdominal aorta normally, trifurcates as it reaches the kidney. cannot find the suprarenal arteries or the ovarian artery.

BRAIN

The Circle of Willis is normal. The anterior middle and posterior cerebral arteries are normal. The anterior communicating arteries are normal. The posterior communicating arteries got torn when the brain was removed. The superior cerebellars are normal. The basilar is normal.

RIGHT CAROTIDS

The common carotid bifurcates normally into the internal and external carotids. The internal carotid is normal but cut shortly after bifurcation. The external carotid is normal but cut shortly after the carotid sinus. Gives off the superior thyroid artery normally, which then gives off the superior laryngeal artery normally. External gives off ascending pharyngeal, but it is cut. External is cut after giving off lingual. Facial artery is normal. Gives off submental and superior and inferior labial branches before getting cut.

LEFT CAROTIDS

The common carotid bifurcates normally into the internal and external carotids. The internal carotid is normal but cut shortly after bifurcation point. The external is normal but cut before it gives off its terminal branches. The superior thyroid is normal and gives off the superior laryngeal normally. The lingual, facial, and ascending pharyngeal are normal. The facial artery is normal. Gives off the submental, superior and inferior labial branches, and the angular branch normally. The maxillary artery is normal. The ophthalmic artery from the internal carotid is normal.

RIGHT SUBCLAVIAN

Vertebral is normal. Thyrocervical trunk is normal. Its branches, the inferior thyroid and suprascapular are normal, but the transverse cervical is cut. The internal thoracic is normal. No costocervical trunk. The dorsal scapular is normal and comes off the subclavian.

LEFT SUBCLAVIAN

Vertebral is ok. **Thyrocervical trunk and internal thoracic come off a common trunk.** The branches of the thyrocervical trunk, the inferior thyroid, suprascapular, and transverse cervical, are normal. The costocervical trunk is normal. The dorsal scapular comes off the subclavian normally.

RIGHT UPPER EXTREMITY

The thoracoacromial trunk is ok, but all the branches, except for the pectoral branches, are cut. The lateral thoracic artery is normal. The subscapular artery and its branches are normal. The anterior and posterior circumflex humeral arteries are normal. The axillary artery continues normally to the brachial artery which gives off the deep brachial artery normally. The radial and ulnar arteries are normal and bifurcate at the cubital fossa. The interosseous arteries were normal. Could not find the ulnar collateral arteries, the radial recurrent artery, or the superficial palmar arch.

LEFT UPPER EXTREMITY

The thoracoacromial trunk and its branches are normal. The lateral thoracic artery is normal. The subscapular artery and its branches, the circumflex scapular and thoracodorsal arteries, are normal. The anterior and posterior circumflex humeral arteries are normal. The posterior circumflex humeral artery branches at the same level as the subscapular artery. **The bifurcation of the ulnar and radial arteries occurs early, about ½ inch after the subscapular artery branches from the axillary artery. The radial artery seems to be the dominant artery based on its width. The deep brachial artery branches from the radial artery. The common interosseous artery also branches from the radial artery.** The anterior and posterior interosseous arteries still branch from the common interosseous artery normally. The ulnar artery continues to the wrist and gives rise to the superficial palmar arch. The ulnar collateral arteries and the radial recurrent arteries were not found.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliacs. The internal iliac bifurcates normally into an anterior and posterior division.

Anterior division looks like a common trunk with everything coming off it. The inferior gluteal and internal pudendal arteries are normal. The uterine and umbilical arteries are normal. Can see the obturator going through the canal, but it got ripped from the internal iliac, so do not know where it came from.

Posterior division: superior gluteal is normal, gives off 2 lateral sacral branches.

Iliolumbar artery comes off internal iliac before it divides

External iliac is normal. Inferior epigastric got cut. Cannot find deep circumflex iliac.

LEFT ILIAC

The common iliac bifurcated normally into the internal and external carotids. The internal iliac divides normally into anterior and posterior divisions.

Anterior division is a common trunk with 2 major divisions. The first division is the uterine and umbilical arteries. The 2nd division is a long trunk that gives off vessels to the bladder and then bifurcates into the inferior gluteal artery and the internal pudendal artery. Cannot find the obturator artery.

Posterior division: gives of 2 lateral sacral arteries and then terminates as the superior gluteal artery.

Iliolumbar artery is an independent branch off the internal iliac

External iliac is normal. Deep circumflex iliac is normal. The inferior epigastric is normal, bifurcates and has a branch that goes down the adductor canal. This branch gives off a branch that goes to the inferior bladder.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery posteriorly. The lateral circumflex femoral artery is normal and comes off the deep femoral. The medial circumflex femoral comes off the deep femoral normally, inferior to the branch point of the lateral circumflex femoral. The femoral artery continues normally through the adductor hiatus. And anterior and tibial arteries are normal. Cannot find the fibular artery.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery if normal and comes off the femoral artery postero-laterally. The lateral circumflex femoral artery comes off the deep femoral artery normally. **There may be a common trunk of the deep femoral and the lateral circumflex femoral according to some literature.** The medial circumflex femoral artery comes off the deep femoral artery normally, inferior to the branch point of the lateral circumflex femoral. The femoral artery continues normally through the adductor hiatus. The anterior tibial artery is normal. Cannot see the posterior tibial or fibular arteries.

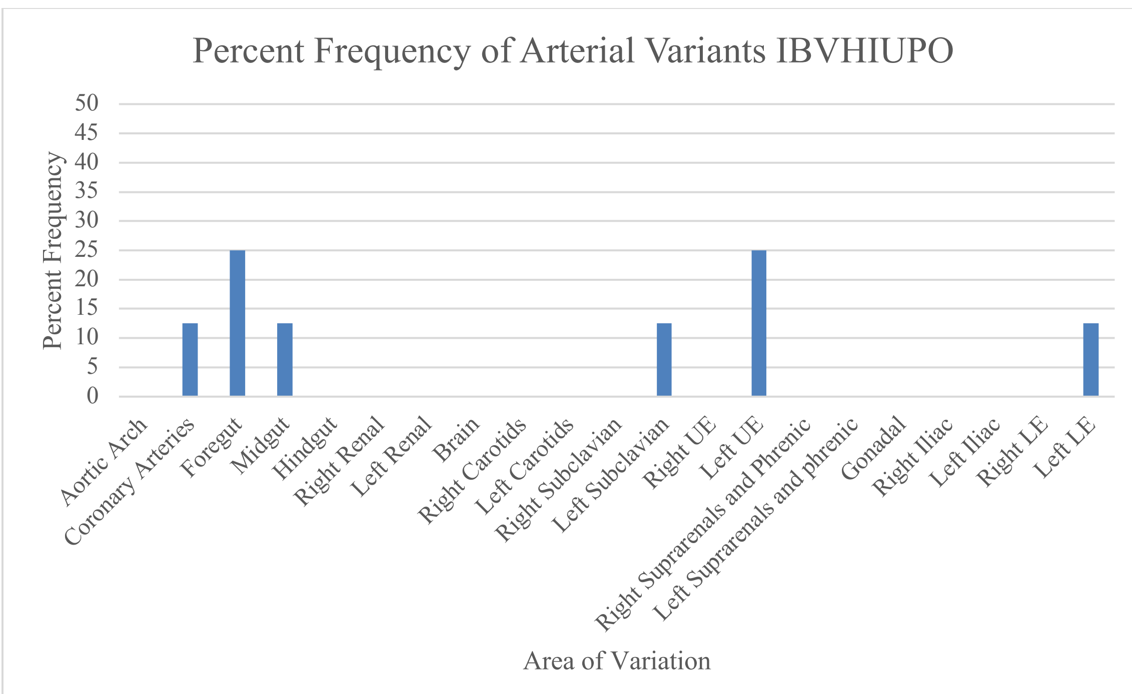

Figure 33: Percent frequency of arterial variants observed in body donor, IBVHIUPO.

IBVHIUPO

Key
TCTr = thyrocervical trunk
ITA = internal thoracic artery
L_CrA = left coronary artery
BrA = brachial artery
RadA = radial artery
PHA = proper hepatic artery
RCA = right colic artery
IlCA = ileocolic artery
DFA = deep femoral artery
LCFA = lateral circumflex femoral artery

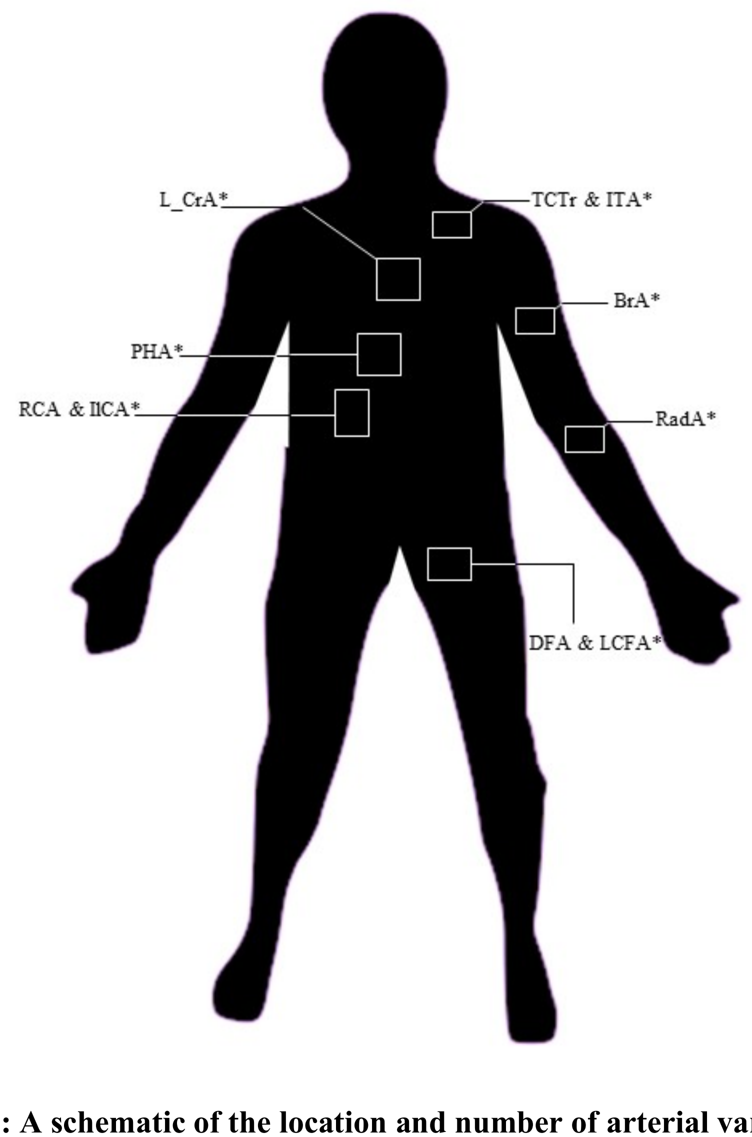

Figure 34: A schematic of the location and number of arterial variants found in body donor, IBVHIUPO.

NDEBEF

Sex: M

Age: 83

COD: Pulmonary fibrosis

Summary of variants seen (Figures 35-36)

- **Celiac trunk only has 2 branches**, the splenic artery and the common hepatic artery. **The left gastric comes off the abdominal aorta**
- There is a **common stem for the middle colic and right colic arteries**
- There are **2 right renal arteries** off the abdominal aorta
- There are **2 left renal arteries** off the abdominal aorta
- On the **left subclavian**, there is a <u>common stem for the thyrocervical trunk and internal thoracic artery</u>
- In the **left upper extremity**, there is an anomalous origin of the **lateral thoracic artery** off the **subscapular artery**
- The **right middle suprarenal and right inferior phrenic** bifurcate from a <u>common trunk</u> that comes off the abdominal aorta
- In the **left internal iliac**, the orientation of the anterior and posterior trunks is flipped so that the posterior division is more anteriorly oriented
- In the **left internal iliac**, there is a <u>common stem for the superior and inferior gluteal arteries</u>

- In the **right lower extremity**, there is a <u>common stem for the lateral circumflex femoral artery and its descending branch</u> off the femoral artery

Detailed Overview:

ARCH OF THE AORTA

Brachiocephalic trunk is normal, bifurcates into right subclavian and right common carotid normally. The left common carotid is normal. The left subclavian is normal.

HEART

The left coronary artery is normal. The LAD is normal, descends with the diagonal branch. The left marginal is normal. The left circumflex is normal. The right coronary artery is normal. The right circumflex is normal. The posterior interventricular comes off the right coronary and is normal.

FOREGUT

Celiac trunk only has 2 branches: the splenic and the common hepatic. Left gastric comes off the abdominal aorta. The left gastric is normal and can match its lumen to the one on the abdominal aorta. The splenic artery is normal. Gives rise to the left gastro-omental artery, which can be seen along the greater curvature of the stomach, but it gets cut before it originates from the splenic so do not fully know where it came from. The other branches of the splenic are cut. The common hepatic is normal and gives off the gastroduodenal artery normally. The gastroduodenal artery is normal. The supraduodenal is cut. Gives off the right gastro-omental normally and the superior pancreaticoduodenal normally. The anterior superior pancreaticoduodenal is cut but the posterior is normal. The proper hepatic is normal. Divides into the left and right hepatic arteries. The right hepatic gives off a branch that looks like the cystic artery, but there is no gallbladder. The right gastric is cut but can still see it along the lesser curvature of the stomach.

MIDGUT

The SMA is normal. The IPD is normal. The ileal and jejunal arteries are normal. The SMA only has 2 branches supplying the large intestine. **There is a common trunk for the middle and right colic arteries.** The ileocolic is normal.

HINDGUT

IMA is normal. The left colic and its ascending and descending branches are normal. The sigmoid arteries are normal. The superior rectal artery is cut.

RIGHT KIDNEY

Have 2 renal arteries off the abdominal aorta going to the kidney. The superior renal artery bifurcates into 2 thick trunks that branch as they reach kidney. The inferior renal artery also bifurcates, but 1 branch is thick, and the other is skinny. **The middle suprarenal and inferior phrenic bifurcate from a common trunk on aorta.** The inferior phrenic is cut but can match its lumen to one found on the inferior surface of the diaphragm. Cannot find the inferior suprarenal artery or the testicular artery.

LEFT KIDNEY

Have 2 renal arteries coming off abdominal aorta to kidney. The superior one bifurcates as it reaches the kidney, the inferior one does not. The inferior phrenic artery is normal and gives off superior suprarenal branches normally. The testicular artery is normal. Cannot find the inferior suprarenal artery or the middle suprarenal artery.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebrals are normal. The anterior communicating is normal, but the posterior communicating got torn. The superior cerebellar arteries are normal. The basilar artery is normal.

RIGHT CAROTID

The common carotid bifurcates normally into the internal and external carotids. The internal carotid is normal but cut shortly after bifurcation point. The external is normal but cut before it gives off its terminal branches. The superior thyroid is normal and gives off the superior laryngeal normally. The lingual and ascending pharyngeal are normal. The external is cut before we can see branch point of facial. The facial artery is normal. Gives off the submental, superior and inferior labial branches, and the angular branch normally.

LEFT CAROTID

The common carotid bifurcates normally into the internal and external carotids. The internal carotid is normal but cut shortly after bifurcation point. The external is normal but cut before it gives off its terminal branches. The superior thyroid is normal and gives off the superior laryngeal normally. The lingual, facial, and occipital are normal. The facial artery is normal. Gives off the superior and inferior labial branches before it gets cut. The ophthalmic artery from the internal carotid is normal.

RIGHT SUBCLAVIAN

The internal thoracic is ok. The artery is cut in so many places that the branches got lost in that. Have a lumen for the vertebral artery.

LEFT SUBCLAVIAN

Vertebral is normal. **Thyrocervical trunk and internal thoracic come from a common trunk**. The inferior thyroid and transverse cervical are normal, the suprascapular is cut. Cannot find the costocervical trunk. The dorsal scapular is normal and comes off the subclavian artery

RIGHT UPPER EXTREMITY

The thoracoacromial artery and its branches are normal. Cannot find the lateral thoracic artery. The subscapular artery and its branches are normal. The anterior and posterior circumflex humeral arteries are cut, but you can see the lumens and it looks like they were normal. The axillary artery continues normally as the brachial artery and gives off the deep brachial artery. The ulnar and radial arteries are normal and bifurcate at the cubital fossa. The common interosseous artery is normal and comes off the ulnar artery. The anterior interosseous artery is also normal but cannot see the posterior interosseous artery. The ulnar artery continues normally to the wrist but is cut there. Can see the superficial palmar arch and the lumen that connected it to the ulnar artery and is normal. Cannot see ulnar collateral arteries or radial recurrent artery.

LEFT UPPER EXTREMITY

Thoracoacromial artery and its branches are normal. The subscapular artery, circumflex scapular, and thoracodorsal arteries are normal. **The lateral thoracic comes off the subscapular**. The anterior and posterior circumflex humeral arteries are normal. The axillary artery continues normally as the brachial artery. The deep brachial artery is normal and comes off the brachial artery. The ulnar and radial arteries are normal and bifurcate in the cubital fossa. The radial recurrent artery is normal. The common interosseous artery comes off the ulnar artery and is normal. The anterior and posterior interosseous arteries are also normal. The superficial palmar arch is normal. Cannot find any ulnar collateral arteries.

RIGHT PELVIC VESSELS

The common iliac bifurcates normally into the internal and external iliacs. The internal iliac divides normally into anterior and posterior divisions.

Anterior division: the inferior gluteal, internal pudendal, and inferior vesicle all come off a common trunk and go to their destinations normally. The inferior gluteal gives off a middle rectal branch. No obturator or umbilical arteries.

Posterior: iliolumbar and lateral sacral come off a common trunk. The superior gluteal is normal.

The external iliac is normal. The inferior epigastric is normal, bifurcates and the other branch goes down the obturator canal. Cannot find deep circumflex iliac.

LEFT PELVIC VESSELS

Common iliac bifurcates normally into internal and external iliacs. The internal iliac divides normally into anterior and posterior divisions. The anterior and posterior divisions are flipped in orientation so that the posterior division is more anterior.

Anterior division: has 2 major divisions. The first branch includes the umbilical, superior and inferior vesicle, and middle rectal arteries. The second branch is the internal pudendal artery.

Posterior division: lateral sacral comes off right as it divides into the posterior division. **There is a common trunk for the superior and inferior gluteal arteries.**

Iliolumbar comes off the common iliac

External iliac is normal. Inferior epigastric is normal, bifurcates and another branch goes down the adductor canal. Cannot find the deep circumflex iliac.

RIGHT LOWER EXTREMITY

Femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery posteriorly. The lateral circumflex femoral artery comes off the femoral artery. There is a common trunk for the descending branch of the lateral circumflex femoral and the lateral circumflex femoral artery. The medial circumflex artery comes off the deep femoral, inferior to the branch point of the lateral circumflex femoral. The femoral artery continues through the adductor hiatus. The anterior tibial artery is normal. Cannot see posterior tibial, fibular, or dorsalis pedis.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery posteriorly. The lateral circumflex femoral artery is normal and comes off the deep femoral artery. The medial circumflex femoral artery comes off the deep femoral normally, superior to the branch point of the lateral circumflex femoral. The femoral artery continues normally through the adductor hiatus. The anterior and posterior tibial arteries are normal. Cannot see the fibular artery.

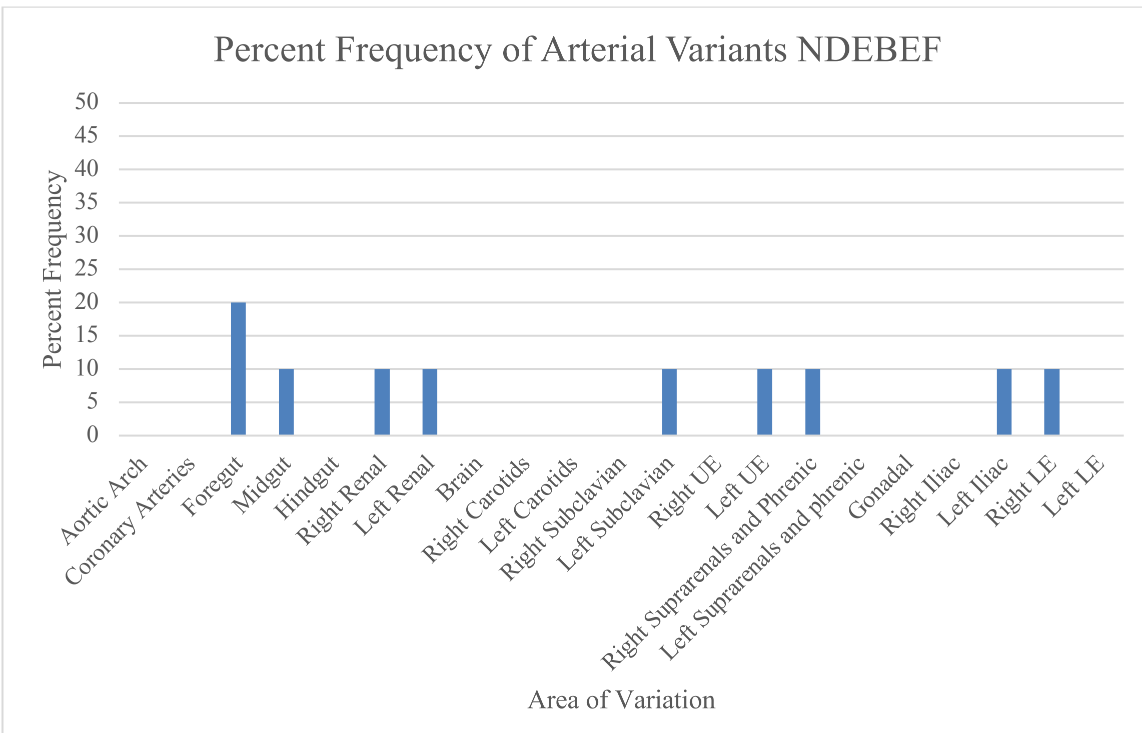

Figure 35: Percent frequency of arterial variants observed in body donor, NDEBEF.

NDEBEF

Key
TCTr = thyrocervical trunk
ITA = internal thoracic artery
SubA = subscapular artery
LGA = left gastric artery
L_RA = left renal artery
R_RA = right renal artery
R_MSRA = right middle suprarenal artery
R_IPHA = right inferior phrenic artery
MCA = middle colic artery
RCA = right colic artery
LCFA = lateral circumflex femoral artery
SGA = superior gluteal artery
IGA = inferior gluteal artery

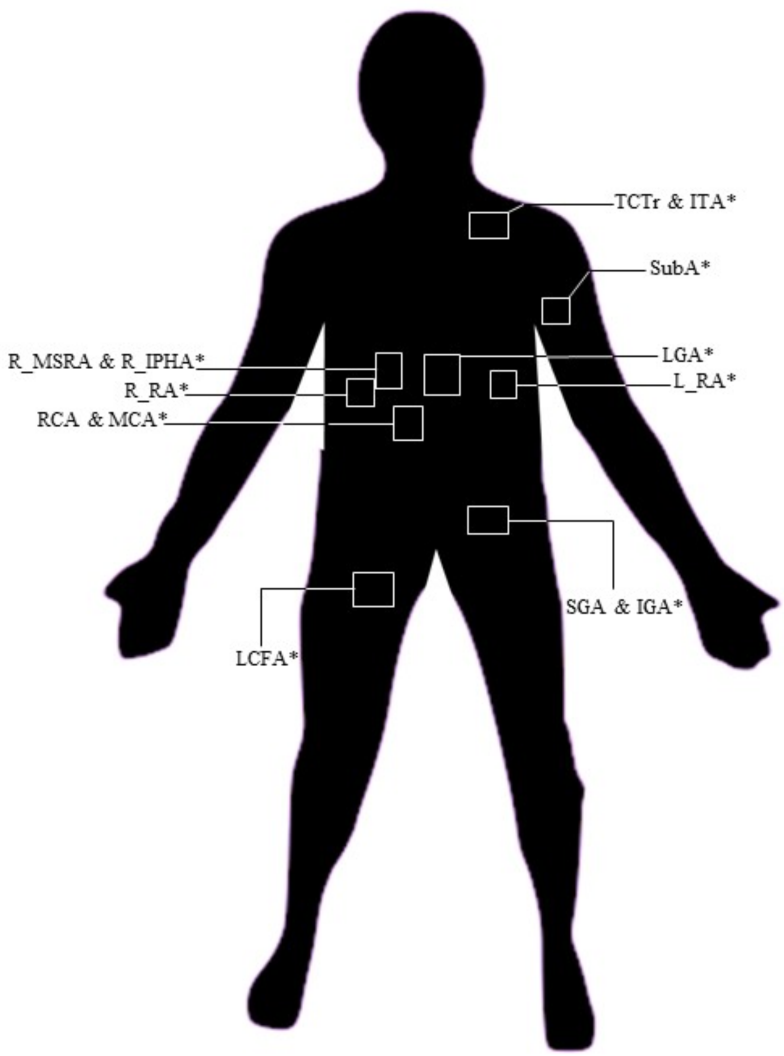

Figure 36: A schematic of the location and number of arterial variants found in body donor, NDEBEF.

IPEHETPO

Sex: F

Age: 87

COD: Adult failure to thrive/dementia/bronchiectasis

Summary of variants seen (Figures 37–38)

- **Celiac trunk has 5 branches**, the main three branches plus (1.) **another common hepatic artery** and (2) an unknown branch that got cut
- The **two common hepatic** arteries come back together to form one artery after the gastroduodenal is given off by the inferior common hepatic (Figure 39)
- There is **a common stem for the middle colic and right colic arteries**
- On the **right subclavian**, there is a common stem for the thyrocervical trunk and internal thoracic artery
- On the **left subclavian**, there is a common stem for the thyrocervical trunk and internal thoracic artery
- In the **right upper extremity**, the brachial artery bifurcates early, about an inch after the subscapular artery. Both branches that were given off bifurcate again in the cubital fossa.
- The medial branch bifurcates at the elbow, giving off the anterior and posterior interosseous arteries.

- The lateral branch bifurcates at the elbow, giving off the radial and ulnar arteries
- In the **right internal iliac**, there is an anomalous origin of the **inferior gluteal artery** from the **superior gluteal artery**
- In the **right lower extremity**, the ascending branch of the lateral circumflex femoral artery comes off the deep femoral artery
- In the **left lower extremity**, there is a <u>common stem for the lateral circumflex femoral and the deep femoral</u> arteries off the femoral artery

Detailed Overview:

ARCH OF THE AORTA

The brachiocephalic trunk is normal and bifurcates into the right subclavian and right common carotid normally. The left common carotid is normal. The left subclavian is normal.

HEART

The left coronary artery is normal. The left anterior descending artery is normal. The left marginal artery is normal. The left circumflex artery is normal. The right coronary artery is normal and gives off the posterior interventricular artery normally. The right marginal artery is normal.

FOREGUT

Celiac trunk has 5 branches: splenic, left gastric, 2 common hepatics, and one artery that got cut, so do not know what it is (Figure 39). The cut branch bifurcates shortly after branching from celiac trunk, but both branches are cut. The splenic artery is normal. Gives off the greater pancreatic artery and the left gastro-omental arteries normally. The dorsal pancreatic artery was cut. The left gastric is normal. **The 2 common hepatic arteries come back together** (Figure 39). The gastroduodenal artery is given off by the inferior common hepatic artery before they join. The gastroduodenal artery is cut but can still match the lumens. Gives off the right gastro-omental, and the anterior and posterior SPD normally. Cannot find the supraduodenal. The proper hepatic artery is normal. Bifurcates into cystic artery and a branch for the right and left hepatics. The left and right hepatics do not bifurcate until really close to the liver. Cannot find the right gastric artery but may have a lumen for it on the proper hepatic.

MIDGUT

SMA is normal. Inferior pancreaticoduodenal is normal. Ileal and jejunal branches are normal. Ileocolic and cecal branches are normal. **There is a common stem for the middle and right colic arteries.**

HINDGUT

IMA is normal. The left colic and its ascending and descending branches are normal. It may have been that the sigmoid arteries and the left colic came from a common trunk, but the sigmoid arteries are cut. Superior rectal is cut.

RIGHT RENAL

There is one renal artery coming off the abdominal aorta normally. It bifurcates as it reaches the kidney and then each of those branches divides again. The inferior suprarenal artery comes off the renal artery normally. The inferior phrenic artery is present, but it is cut off the aorta and cannot find the lumen for it on the aorta so do not know where it came from. The inferior phrenic artery gives off the superior suprarenal artery normally. Cannot find the middle suprarenal artery or the ovarian artery.

LEFT RENAL

There is one renal artery coming off the abdominal aorta normally. It bifurcates as it reaches the kidney. The inferior suprarenal artery comes off the renal artery normally. The middle suprarenal artery came off the abdominal aorta normally, but it got cut before it reached the adrenal gland. The inferior phrenic artery is present off the diaphragm, but it got cut before it could be traced back to its point of origin. Cannot find the ovarian artery.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal. The anterior and posterior communicating arteries are normal, but the left posterior communicating artery is cut. The basilar artery is normal. The superior cerebellar arteries are normal.

RIGHT CAROTIDS

The common carotid bifurcates normally into the internal and external carotids. The internal carotid is normal but cut shortly after it originates. The external carotid is normal but cut before it gives off its terminal branches. The superior thyroid, lingual, and facial arteries are normal. The facial artery gives off the inferior and superior labial arteries normally before it gets cut.

LEFT CAROTIDS

The common carotid bifurcates normally into the internal and external carotids. The internal carotid is normal but cut shortly after it originates. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal, originates before the common carotid bifurcates. Gives rise to the superior laryngeal artery normally. The lingual and facial arteries are normal. The external carotid gives off the ascending pharyngeal and occipital arteries normally, but they are cut before they reach their targets. The facial artery is normal and gives off the submental and angular branches normally. Cannot find the inferior or superior labial branches. The maxillary artery is normal.

RIGHT SUBCLAVIAN

The vertebral artery is normal. **The thyrocervical trunk and the internal thoracic artery come from a common trunk**. The branches of the thyrocervical trunk are cut, except for the suprascapular artery, which is normal. Cannot find the dorsal scapular artery or the costocervical trunk.

LEFT SUBCLAVIAN

The vertebral artery is normal. **The thyrocervical trunk and the internal thoracic artery come from a common trunk**. The branches of the thyrocervical trunk are cut, except for the inferior thyroid artery, which is normal. The dorsal scapular artery is normal and comes off the subclavian artery. cannot find the costocervical trunk

RIGHT UPPER EXTREMITY

The thoracoacromial trunk and its branches are normal. Cannot find the lateral thoracic artery. The subscapular artery and its branches are normal. Cannot find the anterior and posterior circumflex humeral arteries. **The brachial artery bifurcates early, about an inch after the subscapular artery. The brachial artery continues down to the cubital fossa and bifurcates there as well, where the normal bifurcation point of the ulnar and radial arteries is. The arteries that result from the second bifurcation at the cubital fossa take the normal paths of the ulnar and radial arteries. The other fork of the brachial artery (back at its original bifurcation after the subscapular artery) also bifurcates at the cubital fossa. The arteries from that bifurcation are the anterior and posterior interosseous arteries.**

LEFT UPPER EXTREMITY

The thoracoacromial trunk is normal, but its branches are cut except for the pectoral branches which are normal. Cannot find the lateral thoracic artery. The subscapular artery and its branches, the circumflex scapular and thoracodorsal arteries, are normal. The anterior and posterior circumflex humeral arteries are normal. The axillary artery continues normally as the brachial artery. The deep brachial artery is normal and comes off the brachial artery. The superior ulnar collateral artery is normal. The ulnar and radial arteries are normal and bifurcate in the cubital fossa. The common interosseous artery and the anterior interosseous arteries are normal. Cannot find the posterior interosseous artery. The superficial palmar arch is normal. Cannot find radial recurrent artery.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac bifurcates normally into the anterior and posterior divisions.

Anterior division is normal and looks like one large trunk that terminates by giving off all the pelvic branches. The uterine, umbilical, and superior vesicle arteries are normal. One of the branches given off, bifurcates into the internal pudendal artery and inferior vesicle artery, both of which are normal.

Posterior division is normal. Gives off the lateral sacral artery which trifurcates. The obturator artery comes off the posterior division and is normal. **The superior gluteal artery gives off the inferior gluteal artery**.

The iliolumbar artery is an independent branch that comes off the internal iliac before it bifurcates

The external iliac is normal. The inferior epigastric is normal. Cannot find the deep circumflex iliac artery.

LEFT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac bifurcates normally into anterior and posterior divisions.

Anterior division is normal and looks like one main trunk that everything divides off. The uterine artery branches off first and is normal. Gives off a lateral sacral branch at the same level as the uterine artery. the umbilical artery is normal and gives off multiple superior vesicle arteries. Terminates with the inferior gluteal artery. The internal pudendal artery branches off the inferior gluteal artery after it passes through the greater sciatic foramen.

Posterior division is normal. Gives off the lateral sacral artery and the obturator artery normally. Terminates with the superior gluteal artery normally.

The iliolumbar artery is an independent branch that comes off before the internal iliac divides.

The external iliac is normal. The inferior epigastric and deep circumflex iliac arteries are normal.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and branches off the femoral artery postero-laterally. The lateral circumflex femoral artery is normal and branches from the deep femoral artery. **The ascending branch of the lateral circumflex femoral artery is also coming off the deep femoral artery**. Cannot find the medial circumflex femoral artery. The femoral artery continues normally to the adductor hiatus. The anterior tibial artery is normal. Cannot find the posterior tibial or fibular arteries.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery branches off the femoral artery postero-laterally. **The deep femoral artery and lateral circumflex femoral artery come off a common trunk.** The medial circumflex femoral branches off the deep femoral, inferior to the branch point of the lateral circumflex femoral. The femoral artery continues normally through the adductor hiatus. The anterior tibial artery is normal. The dorsalis pedis artery is normal. Cannot see the posterior tibial or fibular arteries.

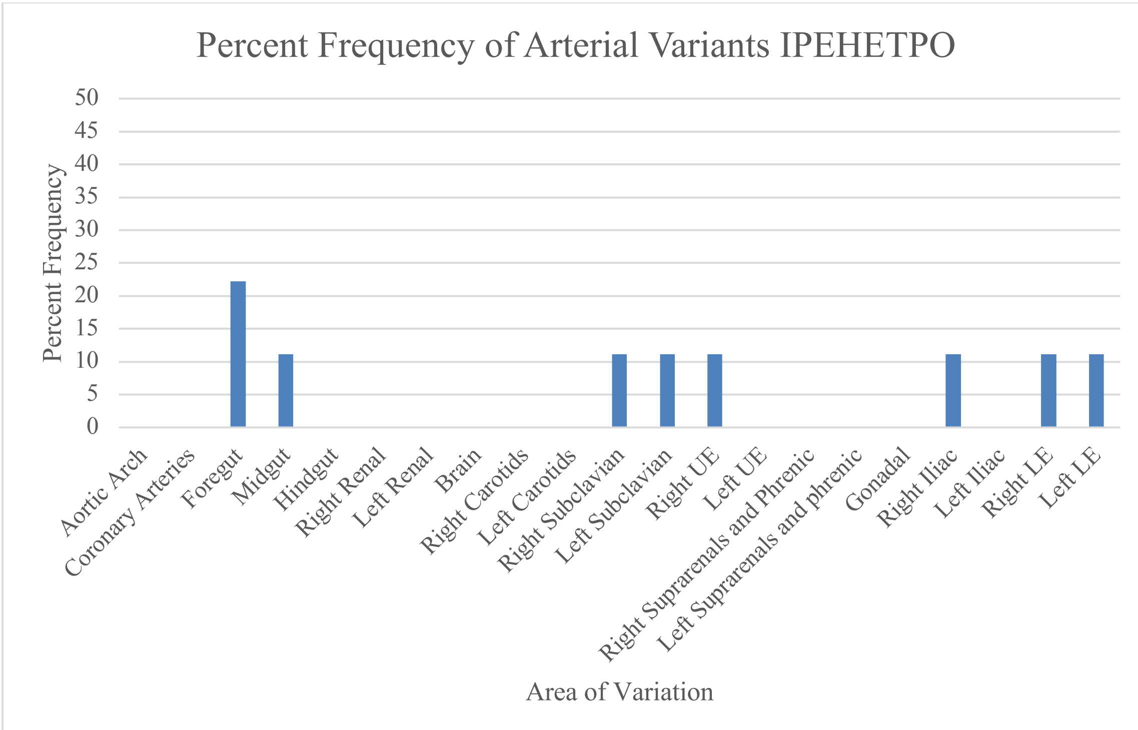

Figure 37: Percent frequency of arterial variants observed in body donor, IPEHETPO.

IPEHETPO

Key
TCTr = thyrocervical trunk
ITA = internal thoracic artery
BrA = brachial artery
CTr = celiac trunk
CHA = common hepatic artery
MCA = middle colic artery
RCA = right colic artery
SGA = superior gluteal artery
DFA = deep femoral artery
LCFA = lateral circumflex femoral artery

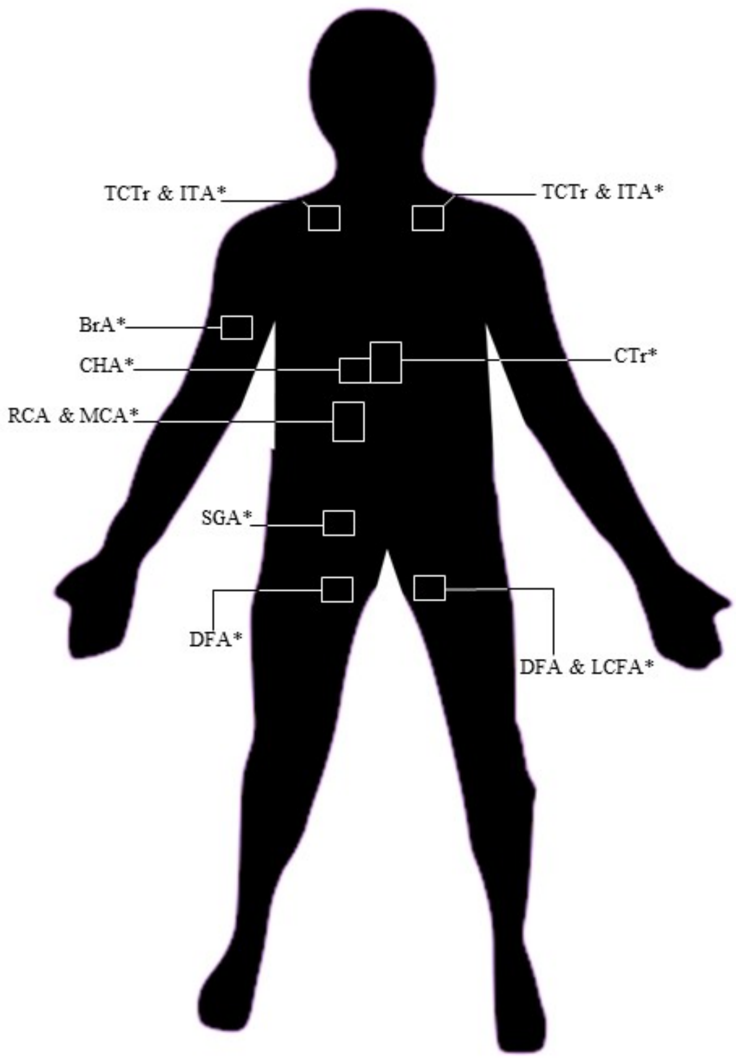

Figure 38: A schematic of the location and number of arterial variants found in body donor, IPEHETPO.

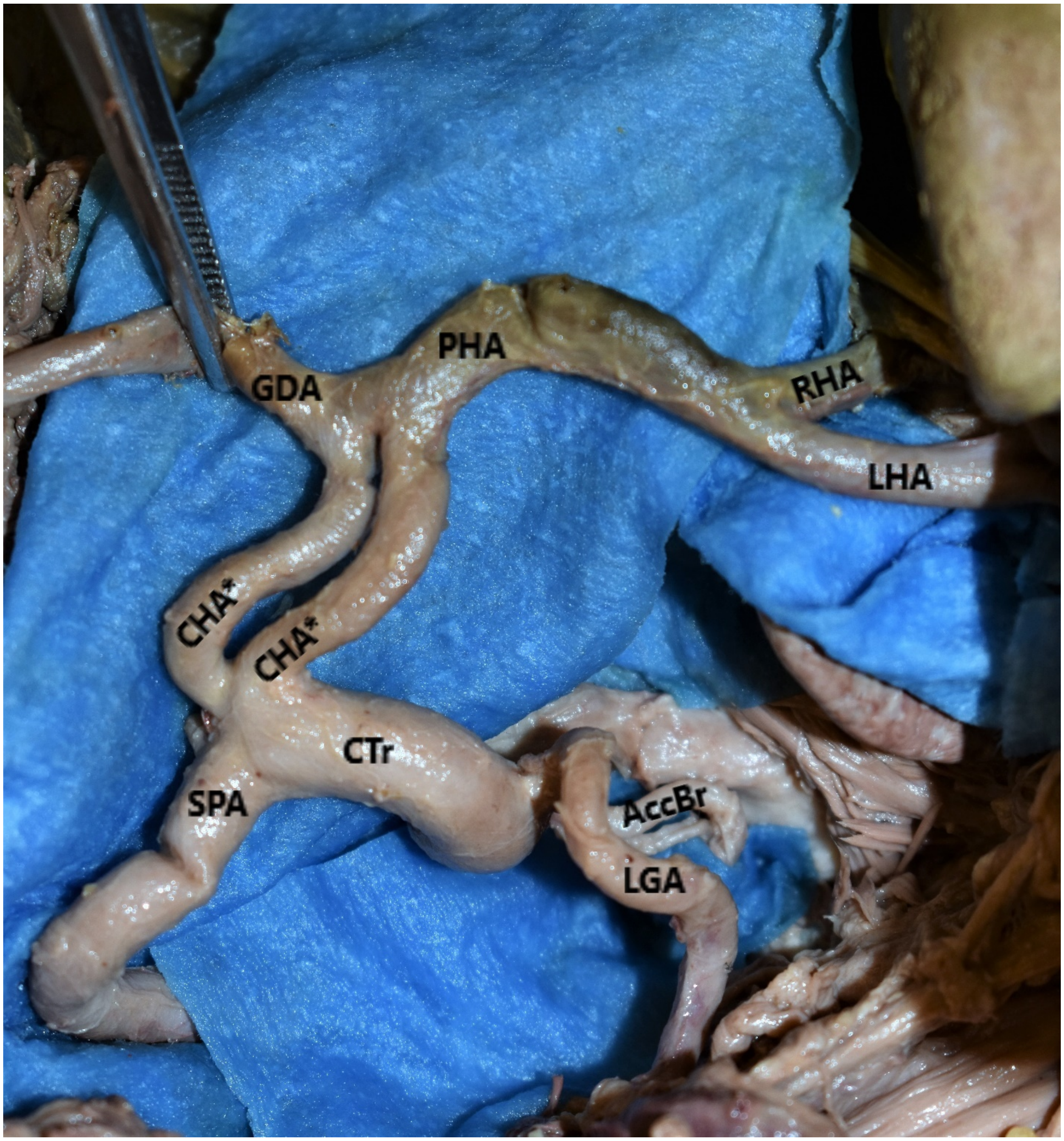

Figure 39: Multiple common hepatic arteries originating from the celiac trunk and then merging back together in body donor, IPEHETPO. Also pictured is the other anomalous branch coming off the celiac trunk.

CTr = celiac trunk, LGA = left gastric artery, AccBr = accessory branch off the celiac trunk, SPA = splenic artery, CHA = common hepatic artery, GDA = gastroduodenal artery, PHA = proper hepatic artery, RHA = right hepatic artery, LHA = left hepatic artery, * = variant.

EBSTU

Sex: M

Age: 76

COD: Pancreatic cancer

Summary of variants seen (Figures 40-41)

- The **right coronary artery** continues to the posterior aspect of the heart and trifurcates into the posterior interventricular arteries. One of those branches then bifurcates so that there are **4 posterior interventricular arteries**
- Abdominal and renal viscera is altered by tumors
- In the **right internal iliac**, there are **2 inferior gluteal artery** branches
- In the **right internal iliac**, the orientation of the anterior and posterior divisions is flipped so that the posterior division is more anterior
- In the **left internal iliac**, there are **2 internal pudendal arteries**
- In the **left lower extremity**, there is an anomalous origin of the **medial circumflex femoral artery** from the **femoral artery**

Detailed Overview:

ARCH OF THE AORTA

Brachiocephalic trunk is normal and divides into the right subclavian and right common carotid normally. The left common carotid is normal. The left subclavian is normal.

HEART

The left coronary artery is normal. The left anterior descending artery is normal and gives rise to the diagonal branch normally. The left marginal is normal. The left circumflex is normal. The right coronary artery is normal. The right marginal is normal. **The right coronary artery continues to the posterior aspect of the heart and trifurcates into the posterior interventricular branches. One of those branches then bifurcates so that there are 4 posterior interventricular arteries.**

FOREGUT

Tumors are enclosing all the vessels, so cannot tell where any of the arteries are. Can see a lumen for the celiac trunk on the abdominal aorta and it is very muscular. Can find a splenic artery, but it does not trace back to a common trunk.

MIDGUT

SMA is normal and not effected by tumors as much. The inferior pancreaticoduodenal is normal. The ileal and jejunal branches are normal. The right colic and middle colic arteries got cut but can see lumens for them on the SMA. The ileocolic artery is normal.

HINDGUT

Cannot find lumen for it or any of the branches of it. Cannot even find a lumen for it off the abdominal aorta.

RIGHT RENAL

Cannot find the renal vessels because tumors are enclosing all the vessels off the abdominal aorta.

LEFT RENAL

Cannot find the renal vessels because tumors are enclosing all the vessels off the abdominal aorta.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal. The anterior and posterior communicating arteries are normal. The basilar artery is normal. The superior cerebellar arteries are normal.

RIGHT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid and lingual arteries are normal. The facial artery is normal and gives off the superior and inferior labial and angular arteries normally.

LEFT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The lingual and facial arteries are normal. The occipital artery is given off normally but cut before it reaches its target. The facial artery gives off the submental artery normally but is cut before it gives off any other branches.

RIGHT SUBCLAVIAN

The vertebral artery is normal. The thyrocervical trunk is normal, but all its branches are cut except for the inferior thyroid artery, which is normal. The internal thoracic artery is normal. The dorsal scapular artery is normal and originates from the subclavian artery. Cannot find the costocervical trunk.

LEFT SUBCLAVIAN

Artery is completely ripped up. The vertebral artery is normal, but all the other branches are lost.

RIGHT UPPER EXTREMITY

The branches of the thoracoacromial artery are cut but can see a small portion of the trunk coming off the axillary artery. Cannot find the lateral thoracic artery. Cannot find the anterior and posterior circumflex humeral arteries. The subscapular artery, the circumflex scapular artery, and the thoracodorsal arteries are normal. The axillary artery continues normally as the brachial artery. The deep brachial artery is normal and comes off the brachial artery. The radial and ulnar arteries are normal and bifurcate in the cubital fossa. The common interosseous artery is normal and branches from the ulnar artery. The anterior and posterior interosseous arteries are normal. Cannot find the superficial palmar arch, radial recurrent artery, or ulnar collateral arteries.

LEFT UPPER EXTREMITY

The axillary artery is cut so it is difficult to see the branch point of the early segment arteries. Thoracoacromial trunk is cut. Cannot find the lateral thoracic artery. The subscapular artery and its branches, the circumflex scapular artery and thoracodorsal artery, are all normal. The anterior and posterior circumflex humeral arteries were cut but can see the lumens for them. The axillary artery continues normally as the brachial artery. The deep brachial artery is normal and comes off the brachial artery. The radial and ulnar arteries are normal and bifurcate in the cubital fossa. The common, anterior, and posterior interosseous arteries are normal. The superficial palmar arch is normal. Cannot see the ulnar collateral arteries or the radial recurrent artery.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac bifurcates into the anterior and posterior divisions. The orientation of the anterior and posterior divisions is reversed so that the posterior division is more anterior.

Anterior division is shaped like a common trunk that everything comes off. The obturator artery is normal and branches at the same level as the branch that gives off the inferior gluteal and internal pudendal arteries. The umbilical artery is normal and gives off superior vesicle arteries normally. The internal pudendal artery and inferior gluteal arteries bifurcate from a common branch and are normal. **There is also another inferior gluteal branch so that there are two inferior gluteal arteries**.

Posterior division gives off the lateral sacral arteries normally. The superior gluteal artery is oriented more anteriorly than normal, it makes an arcing path, swinging away from the posterior division towards the anterior division.

The iliolumbar artery comes off the internal iliac before it bifurcates.

The external iliac is normal. The inferior epigastric and deep circumflex iliac arteries are normal.

LEFT ILIAC

The common iliac is normal and bifurcates into the internal and external iliacs normally. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division is normal and has two major bifurcations. The first branch is the umbilical artery which is normal and gives off superior vesicle arteries normally. The second branch also bifurcates. It gives off the inferior vesicle artery normally and a branch that trifurcates into the inferior gluteal and two internal pudendal arteries normally. **That means that there is a double internal pudendal artery.** Cannot find the obturator artery.

Posterior division is normal. Gives off two lateral sacral arteries normally. The superior gluteal artery is normal.

The iliolumbar artery is an independent branch that comes off the internal iliac before it bifurcates.

The external iliac is normal. The inferior epigastric artery is normal but bifurcates and the other branch goes down the obturator canal. The deep circumflex iliac artery is normal.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery postero-laterally. The lateral circumflex femoral artery is normal and comes off the deep femoral artery. The medial circumflex femoral is normal and comes off the deep femoral inferior to the branch point of the lateral circumflex femoral. The anterior tibial artery is normal but cut at the ankle before it can continue as dorsalis pedis. Cannot find the posterior tibial or fibular arteries.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery posteriorly. The lateral circumflex femoral artery is normal and comes off the deep femoral. **The medial circumflex femoral artery comes off the femoral artery**, superior to the branch point of the deep femoral artery. The femoral artery continues normally through the adductor hiatus. The anterior tibial artery is normal and continues as dorsalis pedis normally. Cannot see the posterior tibial or fibular arteries.

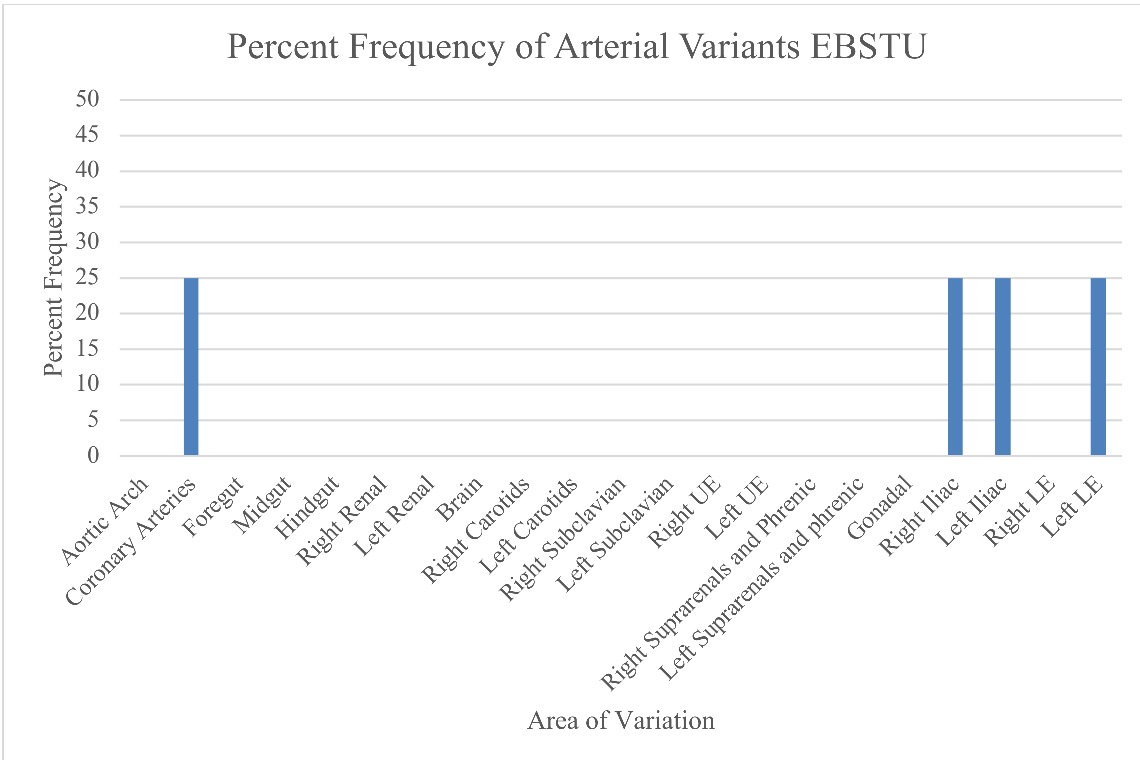

Figure 40: Percent frequency of arterial variants observed in body donor, EBSTU.

EBSTU

Key
PIVA = posterior interventricular artery
IPA = internal pudendal artery
IGA = inferior gluteal artery
FA = femoral artery

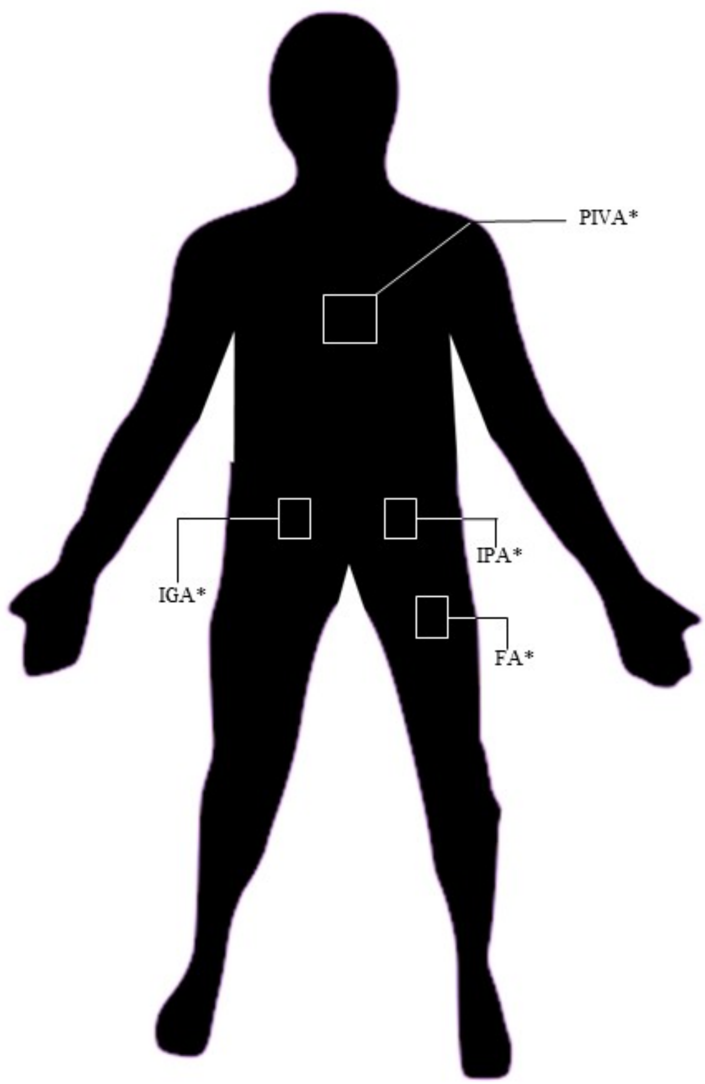

Figure 41: A schematic of the location and number of arterial variants found in body donor, EBSTU.

LFGBVWFS

Sex: F

Age: 81

COD: Cardiopulmonary arrest/adult failure to thrive/small bowel obstruction/metastatic fallopian tube neoplasm/diabetes/urinary retention

Summary of variants seen (Figures 42–43)

- **Celiac trunk gives off 4 branches**, the 3 main ones plus (1) a **branch that goes to the** liver and gives off the cystic artery
- **The left hepatic artery originates from the left gastric artery**
- The **right upper extremity**, appears to have a <u>common trunk for the subscapular and posterior circumflex humeral artery</u>, but the posterior circumflex humeral is cut, so it cannot be certain
- The **inferior phrenic arteries** come off a <u>common trunk with each other</u>, with an origin at the abdominal aorta
- In the **left internal iliac**, there is an anomalous origin of the **inferior gluteal artery** from the **superior gluteal artery**
- In the **left lower extremity**, there is an anomalous origin of the **lateral circumflex femoral artery** from the **femoral artery**
- In the **left lower extremity**, the **deep femoral** artery gives off a descending branch that would normally be coming off the lateral circumflex femoral artery

Detailed Overview:

ARCH OF THE AORTA

The brachiocephalic trunk is normal and bifurcates into the right common carotid and right subclavian normally. The left common carotid is normal. The left subclavian is normal.

HEART

The left coronary artery is normal. The left anterior descending is normal and gives off the diagonal branch normally. The left marginal is normal. The left circumflex is normal. An artificial left coronary artery was added (bypass surgery). The right coronary artery is normal but has surgical remnants on it. Cannot find the right marginal artery because of the surgical alterations. The right coronary artery still gives off the posterior interventricular artery normally.

FOREGUT

The celiac trunk has 4 branches; the left gastric, the splenic, the common hepatic, and a fourth branch that goes to the liver and gives off the cystic artery. The splenic artery is normal and gives off the dorsal pancreatic artery normally. Cannot find the left gastro-omental artery off the splenic. **The left gastric gives off the left hepatic artery** but is otherwise normal. The common hepatic artery is normal. It dives straight down and becomes the superior pancreaticoduodenal artery which divides normally into its anterior and posterior divisions. Cannot find the supraduodenal or right gastro-omental arteries off the gastroduodenal. The proper hepatic artery is normal. It gives off the right gastric artery and the right hepatic artery normally.

MIDGUT

The SMA is normal. The inferior pancreaticoduodenal artery is normal. The middle colic, right colic, and ileocolic arteries are normal. The ileal and jejunal branches are normal.

HINDGUT

The IMA is normal. The left colic is normal and gives off its ascending and descending branches normally. Have branches for the sigmoid and superior rectal arteries, but they are cut before reaching their targets.

RIGHT RENAL

The renal artery comes off the abdominal aorta normally and bifurcates as it reaches the kidney. The inferior suprarenal artery comes off the renal artery normally. **The inferior phrenic artery comes off a common trunk with the other side inferior phrenic artery**. The common trunk still comes off the abdominal aorta and the inferior phrenic artery still travels to the diaphragm normally and gives off superior suprarenal arteries. Cannot find the middle suprarenal artery or the ovarian artery.

LEFT RENAL

Renal artery comes off the abdominal aorta normally and bifurcates as it reaches the kidney. The inferior phrenic gives off superior suprarenal arteries normally. Cannot find middle or inferior suprarenal arteries or the ovarian artery.

BRAIN

The Circle of Willis is normal. The anterior communicating artery and the anterior cerebral arteries were torn out when the brain was removed but can see lumens for them. The middle and posterior cerebral arteries are normal. The posterior communicating arteries are normal. The basilar artery is normal. The superior cerebellar arteries are normal.

RIGHT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid, lingual and facial arteries are normal. The facial artery gives off the submental, superior and inferior labial, and angular branches normally.

LEFT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The lingual and facial arteries are normal. The facial artery gives off the superior and inferior labial, lateral nasal, and angular arteries normally. The maxillary artery is normal. The ophthalmic branch of the internal carotid is normal.

RIGHT SUBCLAVIAN

The vertebral artery is normal. The subclavian gets cut up very badly after the vertebral is given off. The thyrocervical trunk was lost when the artery got cut up. The internal thoracic artery is normal. The costocervical trunk is normal. The dorsal scapular artery is normal and comes off the subclavian.

LEFT SUBCLAVIAN

The vertebral artery is normal. The thyrocervical trunk is normal, but its branches are cut. The internal thoracic is normal. The costocervical trunk is normal. The dorsal scapular artery is normal and comes off the subclavian.

RIGHT UPPER EXTREMITY

The thoracoacromial trunk is normal. Cannot find the lateral thoracic artery. It appears that there was a common trunk for the subscapular artery and the posterior circumflex humeral artery, but the posterior circumflex humeral artery was cut, so it is uncertain. The anterior circumflex humeral artery is normal. The axillary artery continues normally as the brachial artery. The deep brachial artery is normal and comes from the brachial artery. The ulnar and radial arteries are normal and bifurcate in the cubital fossa. The common, anterior, and posterior interosseous arteries are normal. Cannot find the radial recurrent artery or the ulnar collateral arteries.

LEFT UPPER EXTREMITY

The axillary artery is cut from the subclavian artery. The thoracoacromial artery is cut. Cannot find the lateral thoracic artery. The subscapular artery is normal, and its branches, the circumflex scapular artery and the thoracodorsal artery are normal. Anterior and posterior circumflex humeral arteries are cut, but their lumens are present. The axillary artery continues normally as the brachial artery. The deep brachial artery is normal and comes off the brachial artery. The ulnar and radial arteries are normal and bifurcate in the cubital fossa. The common interosseous artery is normal and branches from the ulnar artery. The anterior interosseous artery is normal but cannot see the posterior interosseous artery. The superficial palmar arch is normal. Cannot find the radial recurrent artery or the ulnar collateral arteries.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliacs. The internal iliac bifurcates normally into the anterior and posterior divisions.

Anterior division is a major branch that everything comes off. The umbilical artery is normal and gives off superior vesicle arteries. The obturator artery is normal. There is a common branch that gives off the inferior gluteal and internal pudendal arteries normally. The internal pudendal artery gives off the middle rectal artery. Cannot find vaginal or uterine arteries, but the body had the uterus and ovaries removed so that probably explains it.

Posterior division is normal. Gives off the lateral sacral artery normally. The superior gluteal artery is normal.

Have an independent lateral sacral artery as well coming off the internal iliac before it bifurcates. Could not find the iliolumbar artery.

The external iliac is normal. The inferior epigastric and deep circumflex iliac arteries are normal.

LEFT PELVIC VESSELS

The common iliac bifurcates normally into the internal and external iliacs. The internal iliac bifurcates normally into the anterior and posterior divisions.

Anterior division has a common trunk that everything branches off. The umbilical artery is normal and gives off superior vesicle arteries. The obturator artery is normal. The internal pudendal artery is normal and gives off the middle rectal artery.

Posterior division gives off the lateral sacral artery normally. **The superior gluteal artery gives off the inferior gluteal artery.**

Could not find the iliolumbar artery.

The external iliac is normal. The inferior epigastric artery is normal. Could not find the deep circumflex iliac.

RIGHT LOWER EXTREMITY

Femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery postero-laterally. The lateral circumflex femoral is normal and comes off the deep femoral artery. Cannot find the medial circumflex femoral artery. The femoral artery continues normally through the adductor hiatus. The anterior tibial artery is normal and continues normally as dorsalis pedis. Cannot find the posterior tibial or fibular arteries.

LEFT LOWER EXTREMITY

The femoral artery is normal. The lateral circumflex femoral artery comes off the femoral artery. The deep femoral artery comes off the femoral artery posteriorly. The deep femoral artery has a descending branch that would normally be coming off the lateral circumflex femoral artery. The medial circumflex femoral artery is normal and comes off the deep femoral, inferior to the branch point of the lateral circumflex femoral. The femoral continues normally through the adductor hiatus. The anterior tibial artery is normal. Cannot find the posterior tibial or fibular arteries.

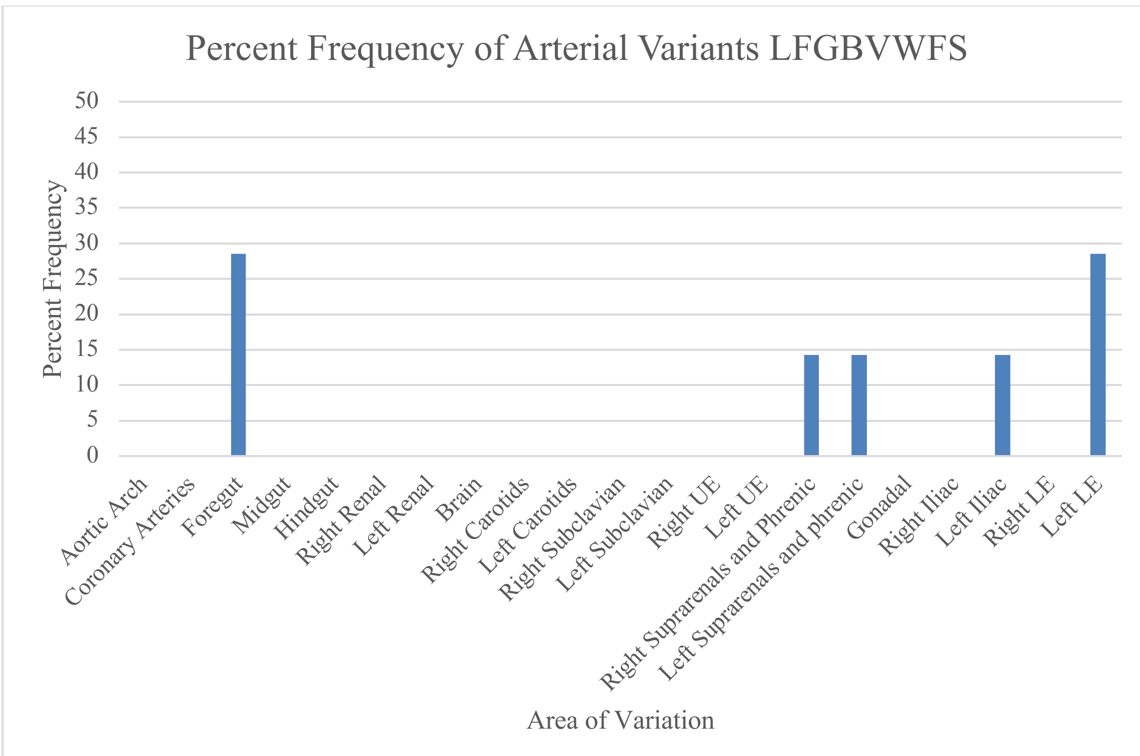

Figure 42: Percent frequency of arterial variants observed in body donor, LFGBVWFS.

LFGBVWFS

Key
LGA = left gastric artery
CTr = celiac trunk
AccHA = accessory hepatic artery
IPHA = inferior phrenic artery
SGA = superior gluteal artery
FA = femoral artery
DFA = deep femoral artery

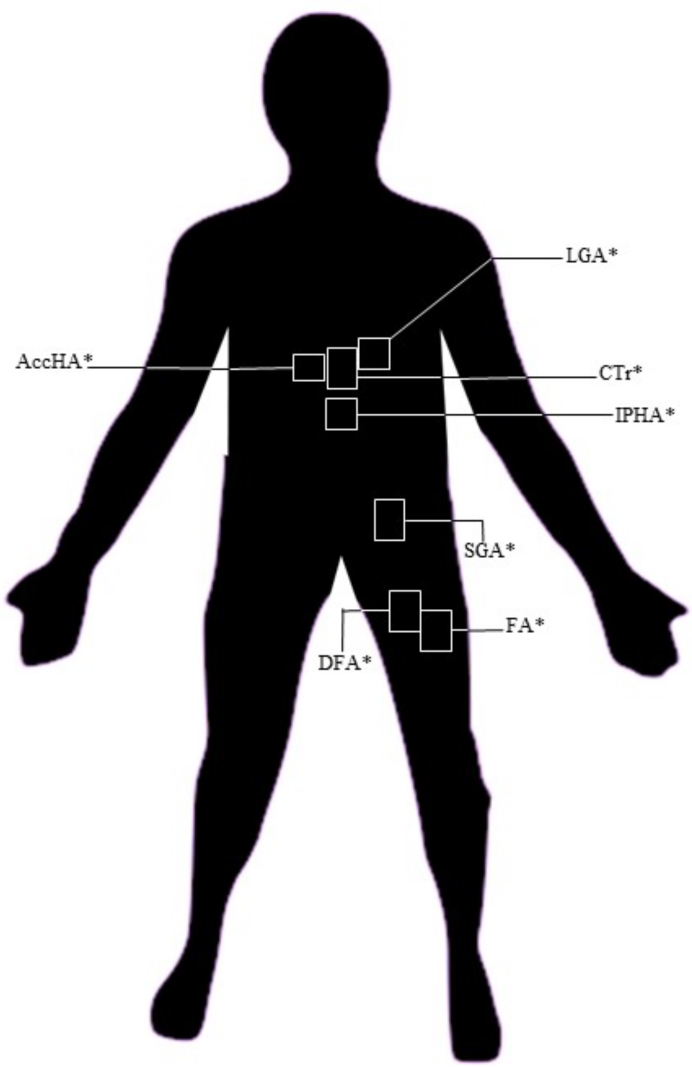

Figure 43: A schematic of the location and number of arterial variants found in body donor, LFGBVWFS.

NBJO

Sex: M

Age: 89

COD: Acute myocardial infarction/hypertension/angina/Alzheimer’s and dementia

Summary of variants seen (Figures 44-45)

- **Celiac trunk has 4 branches**, the three main ones plus (1) **dorsal pancreatic artery**
- There is **a common stem for the middle colic and right colic arteries**
- The ascending and descending branches of the **left colic artery** bifurcate again
- There are **two right accessory renal arteries** going to the **right kidney**
- There is a **left accessory renal artery** going to the inferior pole of the **left kidney**
- In the **right subclavian**, the suprascapular artery trifurcates into the suprascapular artery, the dorsal scapular artery, and a third branch that got cut
- In the **right upper extremity**, there is a common stem for the posterior circumflex humeral, deep brachial, and subscapular arteries
- In the **right upper extremity**, the radial and ulnar arteries bifurcate at a low point, just inferior to the cubital fossa
- In the **left upper extremity**, the ulnar artery branches high up, between the thoracoacromial and the subscapular arteries. The brachial artery bifurcates again in the cubital fossa to the radial artery and the anterior interosseous artery

Detailed Overview:

ARCH OF THE AORTA

The brachiocephalic trunk is normal and bifurcates normally into the right common carotid and right subclavian. The left common carotid is normal. The left subclavian is normal.

HEART

The left coronary artery is normal, but there was a bypass surgery done on it. The left anterior descending artery is normal and gives off the diagonal branch. The left marginal and left circumflex arteries are normal. The right coronary artery is normal and gives off the posterior interventricular artery normally. The right marginal is normal.

FOREGUT

The celiac trunk has four branches; the splenic, left gastric, common hepatic, and the dorsal pancreatic artery. The splenic artery is normal and gives off the left gastro-omental artery normally. The left gastric artery is normal. The common hepatic artery is normal and gives gastro-omental. Superior pancreaticoduodenal, and the supraduodenal arteries normally. The proper hepatic artery is normal. It divides into the left/right hepatic arteries normally. The right hepatic artery gives off the cystic artery normally. Cannot find the right gastric artery.

MIDGUT

The SMA is normal. The inferior pancreaticoduodenal artery is normal. **There is common stem for the middle and right colic arteries**. The ileocolic is normal. The jejunal and ileal branches are normal.

HINDGUT

The IMA is normal. **The left colic gives off branches normally, but both the ascending and descending branches bifurcate again**. The sigmoid branches are normal. The superior rectal artery is normal.

RIGHT RENAL

There is one renal artery coming off the abdominal aorta normally. **There are also two accessory renal arteries coming off the abdominal aorta.** One goes to the superior pole of the kidney and the other bifurcates and goes to both poles of the kidney. Could not find the inferior, middle, or superior suprarenal arteries, the inferior phrenic artery, or the testicular artery.

LEFT RENAL

There is one renal artery coming off the abdominal aorta normally, bifurcates as it reaches the kidney. **There is also an accessory renal artery coming off the abdominal aorta and going to the inferior pole of the kidney**. The accessory renal artery is inferior to the renal artery. Cannot find the inferior, middle, or superior suprarenal arteries or the inferior phrenic artery. The testicular artery is normal.

BRAIN

The brain did not preserve well and was too mushy to look at.

RIGHT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is cut but can match it to the lumen on the external carotid. The lingual artery is cut, but can match its lumen, gives off the suprahyoid artery normally. The facial artery is normal and gives off the superior labial and angular branches normally.

LEFT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but gets cut up very badly after it was given off. Can see the lingual artery coming off it normally. The facial artery is normal and gives off the superior and inferior labial branches and the angular branches normally. The maxillary artery is normal.

RIGHT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal. The inferior thyroid and transverse cervical branches are cut. **The suprascapular branch trifurcates into the suprascapular branch, the dorsal scapular artery, and a third branch that got cut.** Cannot find the costocervical trunk.

LEFT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal. The inferior thyroid is cut. The ascending cervical and suprascapular branches are normal. Cannot find the costocervical trunk or the dorsal scapular artery.

RIGHT UPPER EXTREMITY

The axillary artery is cut, but the lumens still match. The thoracoacromial trunk and its branches are normal. The lateral thoracic artery is normal. **There is a common trunk for the posterior circumflex humeral artery, deep brachial artery, and subscapular artery.** The branches of the subscapular artery are cut. Cannot find the anterior circumflex humeral artery. The axillary artery continues normally as the brachial artery. **The ulnar and radial arteries are normal, but bifurcate at a low point, just inferior to the cubital fossa.** The ulnar artery gives off the common interosseous artery normally and the anterior and posterior interosseous arteries are normal. The radial recurrent artery is normal. Cannot find the ulnar collateral arteries.

LEFT UPPER EXTREMITY

The thoracoacromial trunk and its branches are normal. The lateral thoracic artery is cut. The anterior and posterior circumflex humeral arteries are normal. The subscapular artery is normal and its branches, the thoracodorsal artery and the circumflex scapular artery, are normal. The deep brachial artery is normal. **The axillary artery divides early with the ulnar artery branching off between the thoracoacromial artery and the subscapular artery. The brachial artery then bifurcates again in the cubital fossa**

into the radial artery and the anterior interosseous artery. The radial recurrent artery is normal and comes off the radial artery. The superficial palmar arch is normal and still comes off the ulnar artery. The superior ulnar collateral artery is normal.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliacs. The internal iliac is normal but does not really have an anterior and posterior division, everything just kind of branches off a common trunk.

Approximate anterior division; umbilical artery is normal and gives off the superior vesicle arteries. The internal pudendal artery and inferior gluteal artery bifurcate from a common trunk and are normal.

Approximate posterior division: the obturator artery comes off this division and is normal. The iliolumbar and lateral sacral arteries bifurcate from a common trunk but are otherwise normal. Another lateral sacral artery is given off. The superior gluteal artery is normal.

External iliac artery is normal. The inferior epigastric is normal, bifurcates and has branch that goes through the obturator canal. The deep circumflex iliac is normal.

LEFT ILIAC

The common iliac bifurcates normally into the internal and external iliac. The internal iliac bifurcates normally into the anterior and posterior divisions.

Anterior division looks like a terminal bifurcation with two major branches. The first branch is the umbilical artery which gives rise to the superior vesicle arteries normally. The second branch is a common trunk that bifurcates into the internal pudendal artery and the inferior gluteal artery normally. Cannot find the obturator artery

Posterior division is normal and gives off the lateral sacral artery normally. The iliolumbar artery is normal and comes off the posterior division. The superior gluteal artery is normal.

The external iliac is normal. The inferior epigastric and deep circumflex iliac arteries are normal. Gives rise to an independent branch that goes through the obturator canal.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery postero-laterally. The lateral circumflex femoral artery is normal and comes off the deep femoral artery. The medial circumflex femoral artery is normal and comes off the deep femoral superior to the adductor hiatus. The anterior tibial artery is normal. Cannot find the posterior tibial, fibular, or dorsalis pedis arteries.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery posteriorly. The lateral circumflex femoral artery is normal and comes off the deep femoral artery. The medial circumflex femoral artery is normal and comes off the deep femoral inferior to the branch point of the lateral circumflex femoral. The femoral artery continues normally through the adductor hiatus. The anterior and posterior tibial arteries are normal. Cannot find the fibular artery or dorsalis pedis.

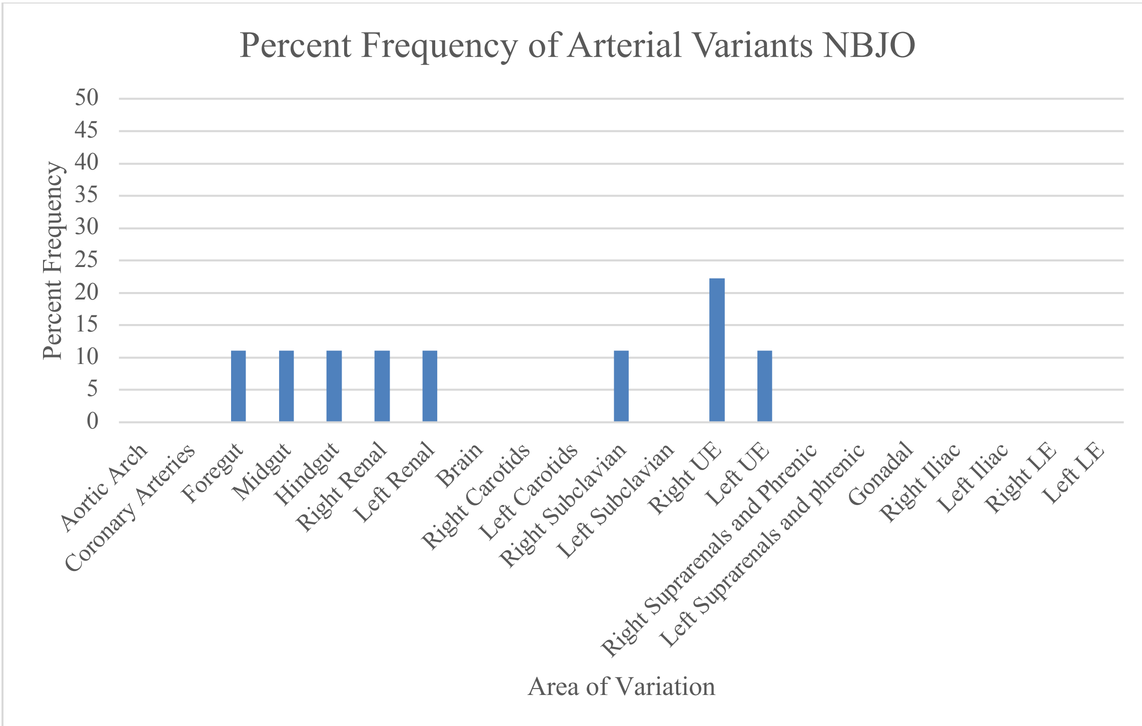

Figure 44: Percent frequency of arterial variants observed in body donor, NBJO.

NBJO

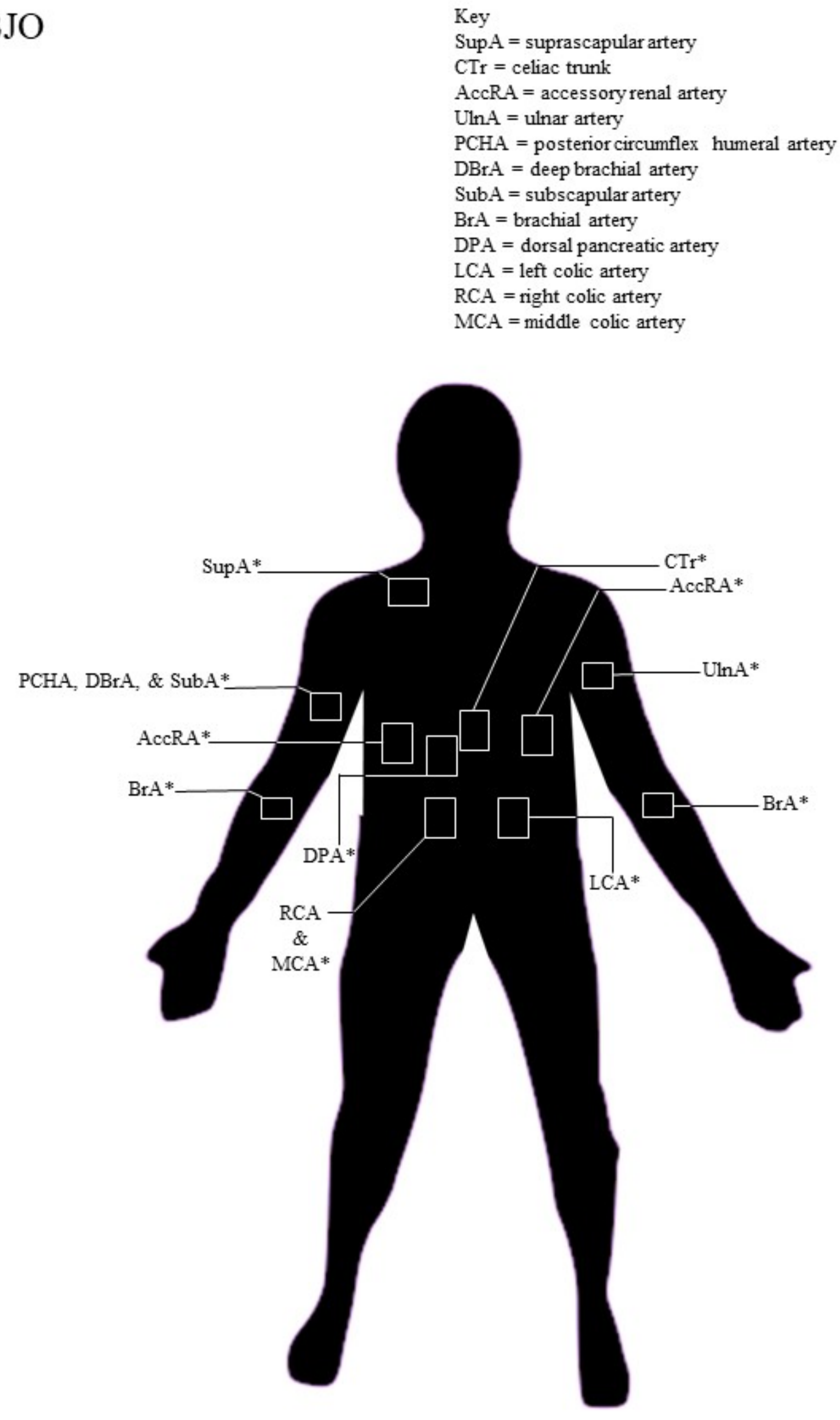

Figure 45: A schematic of the location and number of arterial variants found in body donor, NBJO.

NBSUJO

Sex: F

Age: 90

COD: Dementia/failure to thrive/congestive heart failure

Summary of variants seen (Figures 46-47)

- In the **right subclavian**, there is a common stem for the thyrocervical trunk and internal thoracic artery
- In the **right upper extremity**, there is a high branch point of the radial and ulnar arteries, about halfway down the arm
- There is a trifurcation coming off the **abdominal aorta** close to the bifurcation of the common iliacs. **Trifurcates into the 2 ovarian arteries and the median sacral artery**

Detailed Overview:

ARCH OF THE AORTA

The brachiocephalic trunk is normal and bifurcates into the right common carotid and the right subclavian normally. The left common carotid is normal. The left subclavian is normal.

HEART

The left coronary artery is normal. The left anterior descending is normal and gives off the diagonal branch normally. The left marginal is normal. The left circumflex is normal. The right coronary artery is normal and gives off the posterior interventricular artery normally. The right marginal is cut but can see the lumen where is was given off.

FOREGUT

The celiac trunk gives off the splenic, left gastric, and common hepatic arteries normally. The celiac trunk was cut after it gave off the left gastric artery, so it makes the left gastric artery look like an independent branch, but it is not. The splenic artery is normal and gives off the left gastro-omental artery normally. The left gastric artery is normal. The common hepatic artery is normal and gives off the gastroduodenal artery normally. The gastroduodenal artery is normal and gives off the supraduodenal, right gastro-omental, and superior pancreaticoduodenal arteries normally. The proper hepatic artery is normal. Cannot see it bifurcate into the left/right hepatic arteries. No cystic artery because the gallbladder was removed. Cannot find the right gastric artery.

MIDGUT

The SMA is normal. Gives off the inferior pancreaticoduodenal artery normally, but it got cut, but can still match the lumens. The ileal and jejunal branches are normal. The ileocolic artery is normal. The right colic and middle colic arteries were cut off the SMA but can still match the lumens and see that they are normal.

HINDGUT

The IMA is normal. All the branches were cut off it.

RIGHT RENAL

Have one renal artery coming off the abdominal aorta normally, bifurcates as it reaches the kidney. The inferior suprarenal artery comes off the renal artery normally. The inferior phrenic is normal on the diaphragm and gives off superior suprarenal branches but is cut before its branch point from the abdominal aorta can be seen. Cannot find the middle suprarenal artery. **There is a trunk coming off the abdominal aorta, close to the bifurcation point of the common iliacs. The trunk trifurcates into the ovarian arteries and the median sacral artery.**

LEFT RENAL

Have one renal artery coming off the abdominal aorta normally, bifurcates as it reaches the kidney. The inferior suprarenal artery comes off the renal artery normally. There is an artery coming off the abdominal aorta that could be the middle suprarenal artery, but it comes off inferior to the renal artery and is cut before reaching its target. Cannot find the inferior phrenic artery.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal. The anterior communicating arteries are normal. The posterior communicating arteries were torn when the brain was removed. The basilar artery is normal. The superior cerebellar arteries are normal.

RIGHT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid, lingual and facial arteries are normal. The facial artery gives off superior and inferior labial arteries and the angular artery normally. The maxillary artery is normal. The sphenopalatine artery is normal. The ophthalmic artery from the internal carotid is normal.

LEFT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery and the lingual artery are normal. The facial artery gives off the superior and inferior labial arteries and the angular artery normally.

RIGHT SUBCLAVIAN

The right vertebral artery is normal. **The thyrocervical trunk and the internal thoracic artery come off a common trunk.** The branches of the thyrocervical trunk are cut, except for the suprascapular artery, which is normal. Cannot find the costocervical trunk or the dorsal scapular artery.

LEFT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal, but its branches are cut. Cannot find the costocervical trunk or the dorsal scapular arteries.

RIGHT UPPER EXTREMITY

The thoracoacromial trunk is ok, but there is a lumen right next to it so it could be that the pectoral branches come directly off the axillary artery. The lateral thoracic artery is normal. The subscapular artery and its branches, the circumflex scapular and the thoracodorsal arteries, are normal. The anterior and posterior circumflex humeral arteries may have come from a common trunk, but it was cut and there are lumens that could have been for the anterior circumflex humeral artery on both the posterior circumflex humeral artery and the axillary artery. The deep brachial artery is normal. **There is a high branch point of the radial and ulnar arteries, about halfway down the arm.** The ulnar artery still bifurcates in the cubital fossa into the common interosseous artery. The anterior and posterior interosseous arteries are normal. Cannot find ulnar collateral arteries or the radial recurrent artery. The superficial palmar arch is cut.

LEFT UPPER EXTREMITY

The axillary artery is normal. The thoracoacromial trunk and its branches are normal. The lateral thoracic artery is cut. The subscapular artery is cut. The anterior circumflex humeral artery is cut, but the posterior circumflex humeral artery is normal. The axillary artery continues normally as the brachial artery. The deep brachial artery branches off the brachial artery normally. The radial and ulnar arteries bifurcate normally in the cubital fossa. The radial artery is cut in the fossa but can still match the lumens and see it reach the wrist normally. The ulnar artery is cut when it re-emerges from the muscles close to the wrist but can match the lumens for it. The superficial palmar arch is normal. Cannot find the ulnar collateral arteries or the radial recurrent artery.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliacs. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division has two main bifurcations. The first branch gives off the umbilical and uterine arteries normally. The second branch gives off the internal pudendal artery and the inferior gluteal arteries normally. The obturator artery branches off the internal pudendal artery.

Posterior division is gives off the iliolumbar artery normally. Cannot find the lateral sacral artery. The superior gluteal artery is normal.

The external iliac is normal. The inferior epigastric and the deep circumflex iliac are normal.

LEFT ILIAC

The common iliac bifurcates normally into the internal and external iliacs. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division is one long trunk that everything branches off. The umbilical and uterine arteries are normal. The inferior gluteal and internal pudendal arteries are normal. The obturator artery branches off the inferior gluteal and is normal.

Posterior division gives off the lateral sacral artery normally. The superior gluteal artery is normal.

The iliolumbar artery is cut but came off the internal iliac before it divided.

The external iliac is normal. The inferior epigastric and the deep circumflex iliac arteries are normal.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery branches off the femoral artery and is normal, comes off the femoral postero-laterally. The medial and lateral circumflex femoral arteries come off the deep femoral artery normally. The lateral circumflex femoral artery has a shorter trunk before branching. The medial circumflex femoral branches off the deep femoral just inferior to the lateral circumflex femoral. The femoral artery continues normally through the adductor hiatus. The anterior tibial and posterior tibial arteries are normal. Dorsalis pedis is normal. Cannot find the fibular artery.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal, it is cut at its branch point off the femoral, but the lumens of each end match each other so can still see the path of it. The deep femoral came off the femoral posteriorly. The lateral circumflex femoral artery is normal and comes off the deep femoral. The medial circumflex femoral artery is normal and comes off the deep femoral artery just inferior to the branch point of the lateral circumflex femoral. The femoral artery continues normally through the adductor hiatus. The anterior tibial artery is normal and continues to dorsalis pedis normally. The posterior tibial artery is normal. Cannot find the fibular artery.

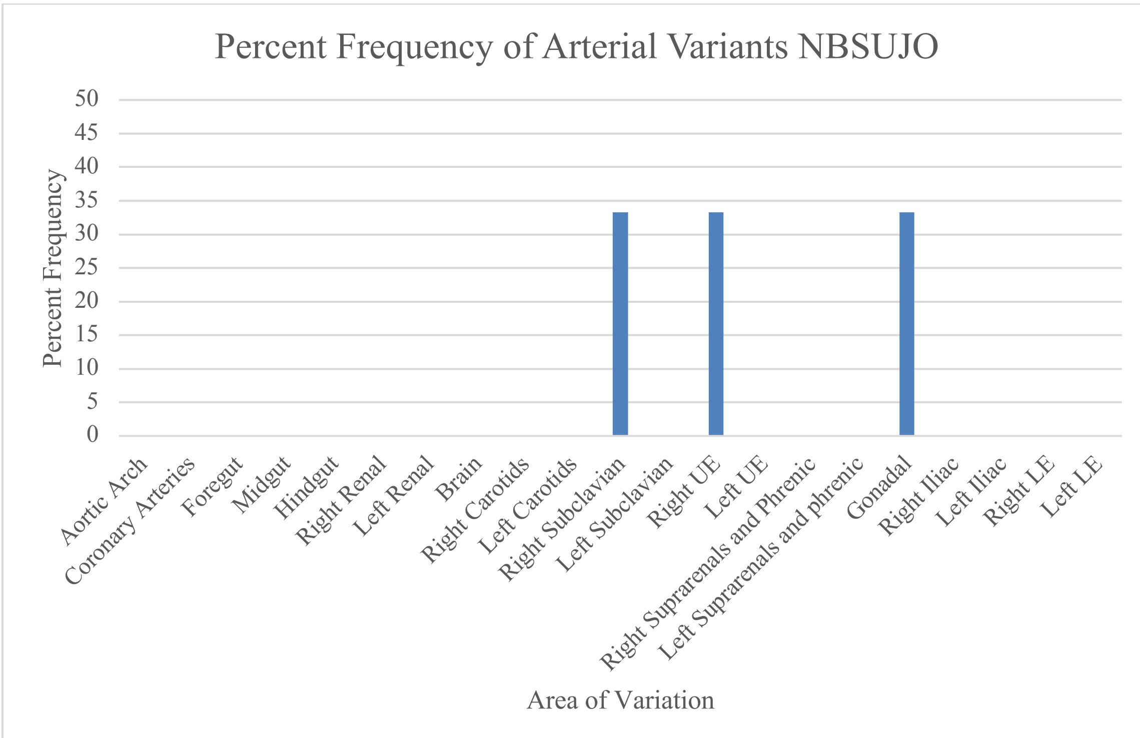

Figure 46: Percent frequency of arterial variants observed in body donor, NBSUJO.

NBSUJO

Key
TCTr = thyrocervical trunk
ITA = internal thoracic artery
BrA = brachial artery
MedSA = median sacral artery
OVA = ovarian artery

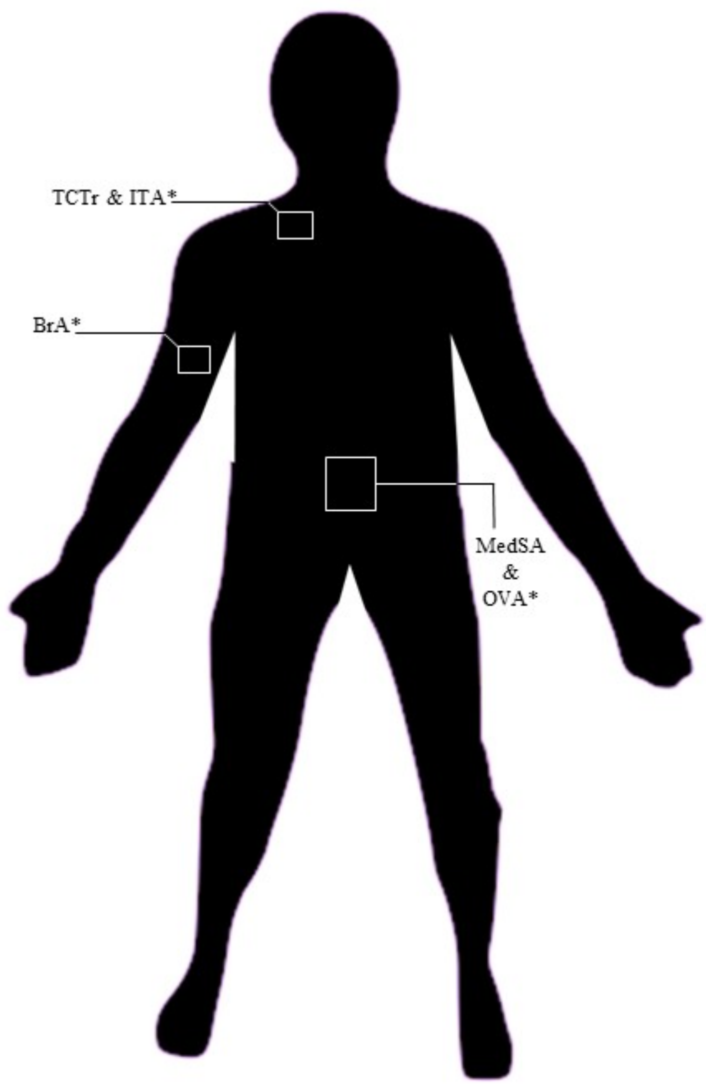

Figure 47: A schematic of the location and number of arterial variants found in body donor, NBSUJO.

DBTUSP

Sex: M

Age: 88

COD: Cardiopulmonary arrest/diabetes mellitus/vascular dementia

Summary of variants seen (Figures 48-49)

- There is an **extra branch off the celiac trunk** where it is coming off the abdominal aorta. The branch is cut, so do not know what it was
- There is **no middle colic artery** off the SMA, instead the right colic artery supplies the ascending and transverse colons. The **right colic artery makes an anastomosis with the left colic artery** of the IMA, so that it is supplying the entire colon
- There are **2 right renal arteries** off the abdominal aorta
- In the **right upper extremity**, the <u>bifurcation of the ulnar and radial arteries is high</u>, about halfway down the arm
- In the **left upper extremity**, the <u>bifurcation of the radial and ulnar arteries is high</u>, about halfway down the arm. The radial artery crosses the ulnar artery at the wrist
- The **inferior phrenic arteries** for both sides come from a <u>common trunk off the abdominal aorta</u>
- In the **right internal iliac,** there is an anomalous origin of the **inferior gluteal artery** from the **superior gluteal artery**

- In the **right lower extremity**, there is an anomalous origin of the **medial and lateral circumflex femoral arteries** from the **femoral artery**

Detailed Overview:

ARCH OF THE AORTA

The brachiocephalic trunk is normal and bifurcates into the right common carotid and the right subclavian normally. The left common carotid is normal. The left subclavian is normal.

HEART

The left coronary artery is normal. The left anterior descending is normal and gives off the diagonal branch normally. Cannot find the left marginal artery. the left circumflex is normal. The right coronary artery is normal. The right marginal and posterior interventricular arteries got cut, but there are lumens for them

FOREGUT

The celiac trunk only has two branches; the left gastric and the common hepatic. There is no splenic artery because the spleen was removed. **There is an extra branch off the celiac trunk where the trunk is coming off the abdominal aorta, but it is cut so do not know what it was.** The left gastric was cut but can match its lumen to the one on the stomach and it is normal. The common hepatic artery is normal and gives off the gastroduodenal artery normally. The gastroduodenal artery is normal and gives off the supraduodenal and superior pancreaticoduodenal arteries normally. Also gives off the right gastro-omental artery normally, though the right gastro-omental artery is very long and wraps all the way to the other side of the stomach. The proper hepatic artery is normal and gives off the left/right hepatic arteries normally. No cystic artery because the gallbladder was removed. Cannot find the right gastric artery.

MIDGUT

The SMA is normal. Cannot find the inferior pancreaticoduodenal artery. The ileal and jejunal branches are normal. The ileocolic artery is normal. **There is no middle colic artery. The right colic forms an anastomosis with the left colic artery of the IMA and is supplying the entire large intestine.**

HINDGUT

The IMA is normal. The left colic is normal and still gives off the ascending and descending branches, just has that anastomosis with the right colic artery. The sigmoid arteries are normal. The superior rectal artery is normal.

RIGHT RENAL

Have two renal arteries coming off the abdominal aorta. They are oriented one on top of the other, both bifurcate as they reach the kidney. The inferior suprarenal artery comes off the more posterior renal artery. **The inferior phrenic artery comes off a common trunk with the other side inferior phrenic.** Still gives off superior suprarenal branches normally. The testicular artery is normal. Cannot find the middle suprarenal artery.

LEFT RENAL

Have one renal artery coming off the abdominal aorta normally, bifurcates as it reaches the kidney. The inferior phrenic artery comes off the common trunk, still gives off the superior suprarenal branches normally. Cannot find the middle or inferior suprarenal arteries or the testicular artery.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal. The anterior and posterior communicating arteries are normal. The basilar artery is normal. The superior cerebellar arteries are normal.

RIGHT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The lingual and facial arteries are normal. The external carotid gives off the occipital artery normally, but it gets cut before it reaches its target. The facial artery gives off the submental and superior and inferior labial arteries normally. The maxillary artery is normal.

LEFT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches.

The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The lingual and facial arteries are normal. The external carotid artery gives off the occipital artery normally, but it is cut before it reaches its destination. The facial artery gives off the superior and inferior labial arteries normally, before it gets cut.

RIGHT SUBCLAVIAN

The right subclavian is cut right after is comes off the brachiocephalic trunk. Cannot find the branches of it. The dorsal scapular artery is normal and can see it coming off the subclavian.

LEFT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal, but its branches are cut, except for the suprascapular, which is normal. The dorsal scapular artery is normal and comes off the subclavian. Cannot find the costocervical trunk.

RIGHT UPPER EXTREMITY

The thoracoacromial trunk is normal. The lateral thoracic artery is normal. The subscapular artery and its branches, the circumflex scapular and the thoracodorsal arteries, are normal. The anterior and posterior circumflex humeral arteries may have come from a common trunk, but the branch point off the axillary artery is cut and only being held together by fascia. The deep brachial artery is normal. **There is a high branch point of the radial and ulnar arteries, about halfway down the arm.** The ulnar artery still bifurcates in the cubital fossa into the common interosseous artery. The anterior and posterior interosseous arteries are normal. The radial artery continues normally to the wrist. The superficial palmar arch is normal. Cannot find ulnar collateral arteries or the radial recurrent artery.

LEFT UPPER EXTREMITY

The axillary artery is normal. The thoracoacromial trunk and its branches are normal. The lateral thoracic artery is normal. The subscapular artery and its branches, the circumflex scapular and thoracodorsal arteries, are normal. The anterior circumflex humeral artery is cut, but the posterior circumflex humeral artery is normal. The axillary artery continues normally as the brachial artery. The deep brachial artery branches off the brachial artery normally. **The bifurcation of the radial and ulnar arteries occurs early, about halfway down the arm.** The ulnar artery still bifurcates in the cubital fossa into the common interosseous artery. The anterior and posterior interosseous arteries are normal. **The radial artery is normal but crosses the ulnar artery by the wrist.** Cannot find the ulnar collateral arteries, the radial recurrent artery, or the superficial palmar arch.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliacs. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division looks like a common ganglion that everything branches off. The umbilical artery is normal and gives off the obturator and inferior vesicle arteries normally. The internal pudendal artery is normal and gives off the middle rectal artery.

Posterior division gives off the lateral sacral artery normally. The superior gluteal artery is normal. **The superior gluteal artery gives off the inferior gluteal artery.** Cannot find the iliolumbar artery.

The external iliac is normal. The inferior epigastric is normal. Cannot find the deep circumflex iliac.

LEFT ILIAC

The common iliac bifurcates normally into the internal and external iliacs. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division is like two major bifurcations. The first division gives off the umbilical artery and the obturator artery, both of which are normal. The second division gives off the inferior gluteal artery and the internal pudendal arteries normally. The internal pudendal artery gives off the inferior vesicle artery.

Posterior division gives off the lateral sacral artery normally. The superior gluteal artery is normal. Cannot find the iliolumbar artery.

The external iliac is normal. The inferior epigastric artery if normal. Cannot find the deep circumflex iliac artery.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The lateral circumflex femoral artery branches off the femoral artery. The medial circumflex femoral artery branches off the femoral artery, inferior to the branch point of the lateral circumflex femoral. The deep femoral artery is normal and comes off the deep femoral artery posteriorly. The femoral artery continues normally through the adductor hiatus. The anterior tibial and posterior tibial arteries are normal. Dorsalis pedis is normal. Cannot find the fibular artery.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and branches off the femoral artery posteriorly. The lateral circumflex femoral artery is normal and comes off the deep femoral. Cannot find the medial circumflex femoral artery. The femoral artery continues normally through the adductor hiatus. The anterior tibial artery is normal and continues as dorsalis pedis normally. Cannot find the fibular artery or the posterior tibial artery.

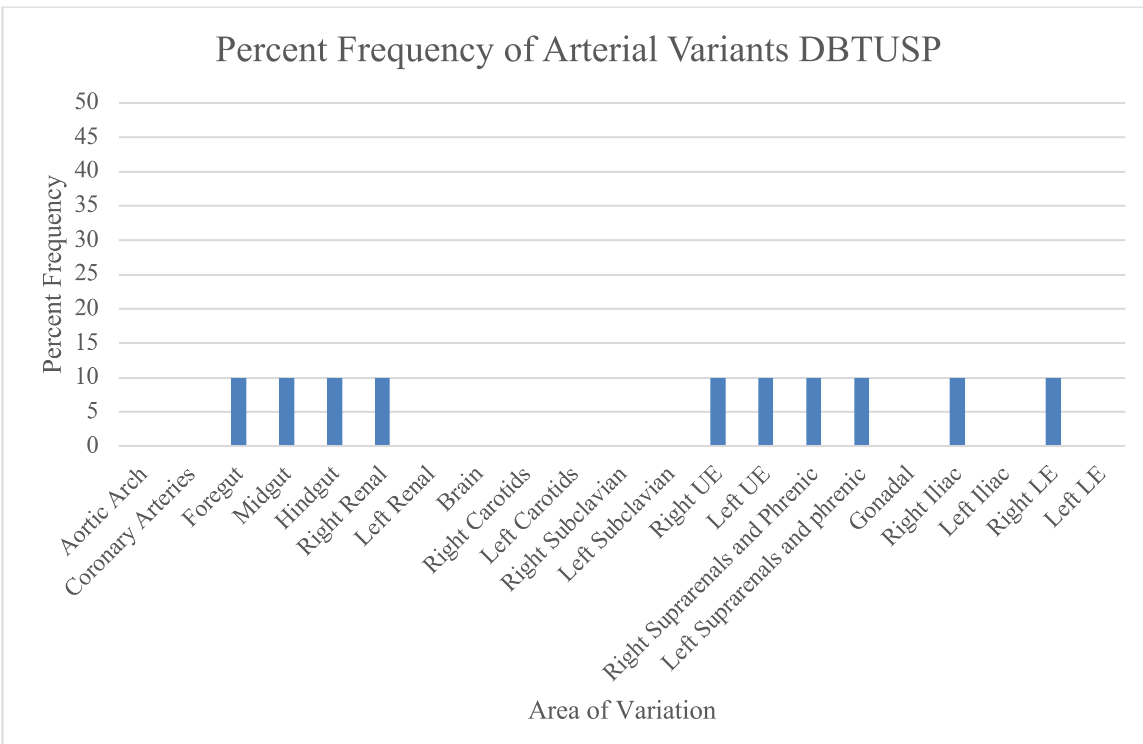

Figure 48: Percent frequency of arterial variants observed in body donor, DBTUSP.

DBTUSP

Key
CTr = celiac trunk
BrA = brachial artery
RA = renal artery
IPHA = inferior phrenic artery
MCA = middle colic artery
RCA = right colic artery
LCA = left colic artery
SGA = superior gluteal artery
FA = femoral artery

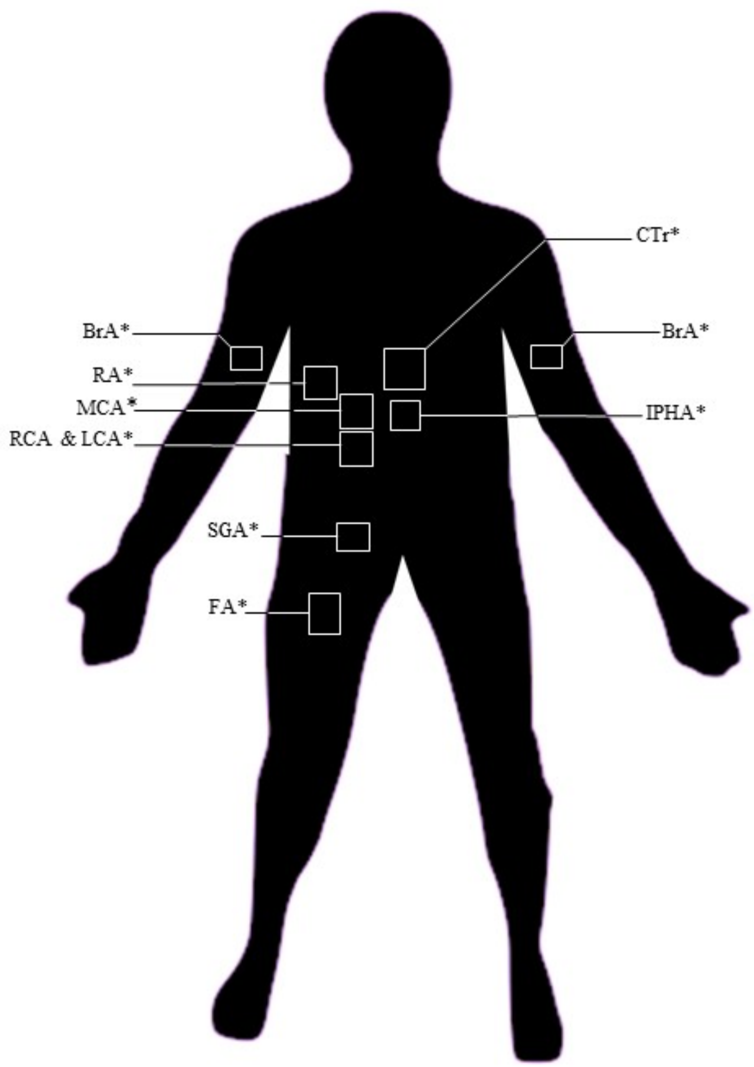

Figure 49: A schematic of the location and number of arterial variants found in body donor, DBTUSP.

DMPVHI

Sex: F

Age: 82

COD: Failure to thrive/dementia with behavioral disturbances/hypertension depression

Summary of variants seen (Figures 50-51)

- **The left hepatic artery gives off the right gastric artery**
- There are 2 left renal arteries coming off the abdominal aorta
- On the **right subclavian artery**, all the branches come off very close to one another. The **transverse cervical artery** is an <u>independent branch</u> in between the vertebral and thyrocervical trunk. The **costocervical trunk** <u>comes off next to the vertebral artery</u>
- On the **left subclavian**, there is a <u>common stem for the thyrocervical trunk and internal thoracic artery</u>
- In the **right internal iliac**, there are **2 internal pudendal arteries**, one comes from a bifurcation off the inferior gluteal and one originates as its own branch
- In the **left internal iliac**, the orientation of the anterior and posterior divisions is reversed such that the posterior division is anterior

Detailed Overview:

ARCH OF THE AORTA

The brachiocephalic trunk is normal and bifurcates into the right common carotid and the right subclavian normally. The left common carotid is normal. The subclavian is normal.

HEART

The left coronary artery is normal. The left anterior descending is normal and gives off the diagonal branch normally. The left marginal artery is normal. The left circumflex is normal. The right coronary artery is normal. The right marginal artery is normal. The right coronary artery gives off the posterior interventricular artery normally.

FOREGUT

The celiac trunk is normal and gives off the splenic, left gastric, and common hepatic arteries normally. The splenic artery is normal and gives off the posterior gastric and left gastro-omental arteries normally. The left gastric artery is normal. The common hepatic artery is normal and gives off the gastroduodenal artery normally. The gastroduodenal artery is normal and gives off the supraduodenal, the superior pancreaticoduodenal, and the right gastro-omental arteries normally. The proper hepatic artery is normal. The proper hepatic artery bifurcates normally into the left and right hepatic arteries. The right hepatic artery gives off the cystic artery normally. **The right gastric artery comes off the left hepatic artery.**

MIDGUT

The SMA is normal. The inferior pancreaticoduodenal artery is normal. The ileal and jejunal branches are normal. The middle colic, right colic, and ileocolic arteries are all normal.

HINDGUT

The IMA is normal. The left colic is normal and still gives off the ascending and descending branches normally. The sigmoid arteries are normal. The superior rectal artery is normal.

RIGHT RENAL

Have one renal artery coming off the abdominal aorta, bifurcates as it reaches the kidney. The renal artery has a branch that goes straight to the superior pole of the kidney. The inferior suprarenal artery comes off the renal artery normally. Cannot find the middle suprarenal artery, inferior phrenic artery, or the ovarian artery.

LEFT RENAL

Have two renal arteries coming off the abdominal aorta. One is oriented superiorly and twists down to the inferior pole of the kidney. The inferior artery is larger and bifurcates as it reaches the kidney. Have the superior suprarenal artery but cannot find the inferior phrenic artery off the abdominal aorta. The middle suprarenal artery is normal and comes off the abdominal aorta. Cannot find the inferior suprarenal or ovarian arteries.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal. The anterior and posterior communicating arteries are normal. The basilar artery is normal. The superior cerebellar arteries are normal.

RIGHT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The lingual and facial arteries are normal. The external carotid gives off the occipital artery normally, but it gets cut before it reaches its target. The facial artery gives off the submental and superior and inferior labial arteries normally.

LEFT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The lingual and facial arteries are normal. The external carotid artery gives off the occipital artery normally, but it is cut before it reaches its destination. The facial artery gives off the superior and inferior labial arteries normally, before it gets cut. The maxillary artery is normal.

RIGHT SUBCLAVIAN

The branches come off very close to one another. The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal. The inferior thyroid and suprascapular branches of the thyrocervical trunk are normal. **The transverse cervical artery is an independent branch between the vertebral artery and the thyrocervical trunk. The costocervical trunk branches next to the vertebral artery.** The dorsal scapular artery is normal and comes off the subclavian.

LEFT SUBCLAVIAN

The vertebral artery is normal. Have a branch directly behind the vertebral artery. The internal thoracic artery and the thyrocervical trunk come off a common trunk. The branches of the thyrocervical trunk are cut. The costocervical trunk is normal. The dorsal scapular artery is normal and comes off the subclavian.

RIGHT UPPER EXTREMITY

The thoracoacromial trunk is cut. The lateral thoracic artery is cut, but it is cut closer to the body so there is a large amount of the artery hanging off the axillary artery and it was normal. The subscapular artery and its branches, the circumflex scapular and the thoracodorsal arteries, are normal. The anterior and posterior circumflex humeral arteries are normal, but they branch at the same level as the subscapular artery. The axillary artery continues normally as the brachial artery. The deep brachial artery is normal and comes off the brachial artery. The ulnar and radial arteries are normal and bifurcate at the cubital fossa. The ulnar artery gives off the common interosseous artery normally. The anterior and posterior interosseous arteries are normal. The superficial palmar arch is normal. Cannot find the ulnar collateral arteries or the radial recurrent artery.

LEFT UPPER EXTREMITY

Thoracoacromial trunk is cut. The lateral thoracic artery is cut, but it is cut closer to the body so there is still a long amount of the artery hanging off the axillary artery. The subscapular artery and its branches, the circumflex scapular and thoracodorsal arteries, are normal. The posterior circumflex humeral artery is good, but the anterior circumflex humeral artery is cut. The axillary artery continues normally as the brachial artery. The deep brachial artery is normal and comes off the brachial artery. The ulnar and radial arteries are normal and bifurcate in the cubital fossa. The ulnar artery gives off the common interosseous artery normally. The anterior and posterior interosseous arteries are normal. The superficial palmar arch is cut. Cannot find ulnar collaterals or the radial recurrent artery.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal, does not have the anterior/posterior divisions, but more like a giant nucleus that everything branches from.

Anterior division (approximately): The internal pudendal artery is normal and comes off a common trunk with the middle rectal artery. The obturator artery is normal. The uterine, vaginal, and superior vesicle arteries come off a common trunk. All are normal. Cannot find the umbilical artery.

Posterior division (approximately): The superior gluteal artery and the inferior gluteal artery bifurcate from a common stem and that is what makes up the posterior division. The inferior gluteal artery is normal, but it gives off a second internal pudendal artery. Have two lateral sacral arteries, both are normal. Gives off the iliolumbar artery normally

The external iliac is normal. The inferior epigastric is normal. The deep circumflex iliac is normal.

LEFT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division is like one long trunk that everything branches from. The obturator artery is normal. The umbilical artery is normal. The vaginal and uterine arteries come off a common trunk and are normal. The inferior gluteal and internal pudendal arteries are normal, and both give off middle rectal artery branches.

Posterior division gives off two lateral sacral arteries normally. The superior gluteal artery is normal.

The iliolumbar artery is an independent branch that comes off before the internal iliac bifurcates.

The external iliac is normal. The inferior epigastric artery if normal. The deep circumflex iliac artery is normal.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and branches off the femoral artery postero-laterally. The lateral circumflex femoral artery is normal and comes off the deep brachial artery. The medial circumflex femoral artery comes off the deep femoral artery superior to the branch point of the lateral circumflex scapular artery. The femoral artery continues normally through the adductor hiatus. The lower leg is poorly preserved, so it is difficult to see the arteries of the lower leg. The anterior tibial artery is normal. Cannot see the posterior tibial, fibular artery, or dorsalis pedis.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery laterally. The lateral circumflex femoral artery is normal and comes off the deep femoral artery. Cannot find the medial circumflex femoral artery. The femoral artery continues normally through the adductor hiatus. The lower leg is poorly preserved here also. Cannot find the anterior tibial, posterior tibial, dorsalis pedis and fibular arteries.

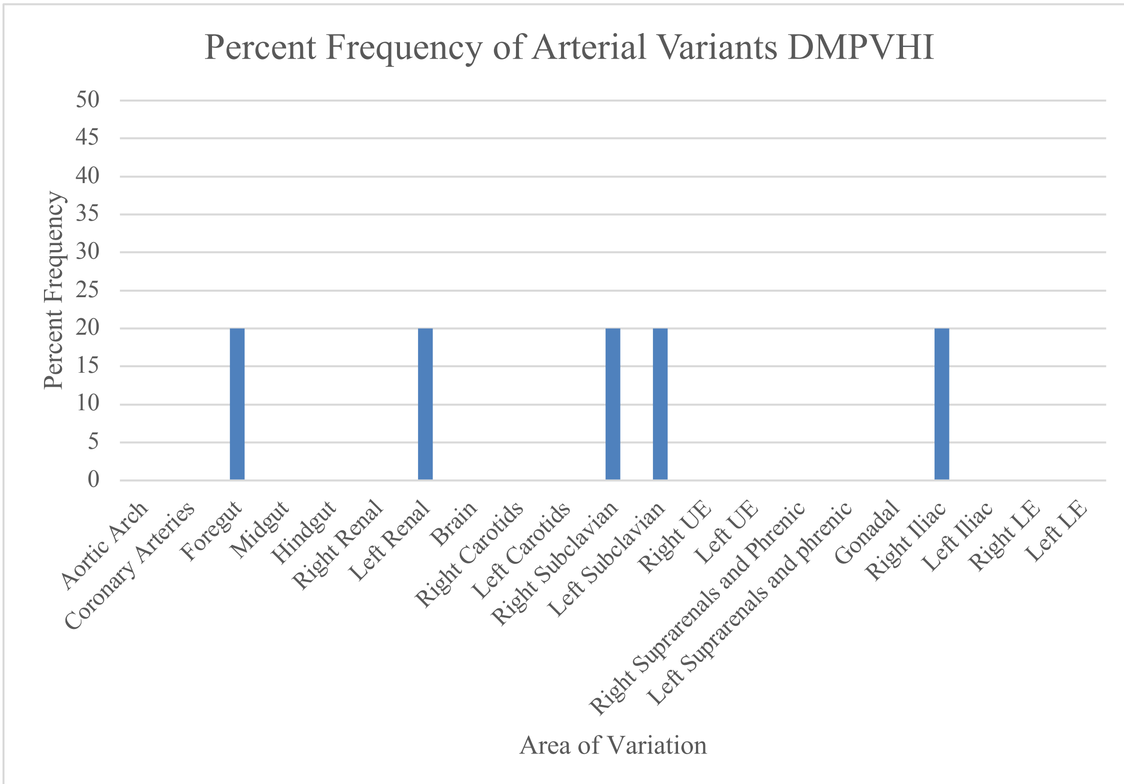

Figure 50: Percent frequency of arterial variants observed in body donor, DMPVHI.

DMPVHI

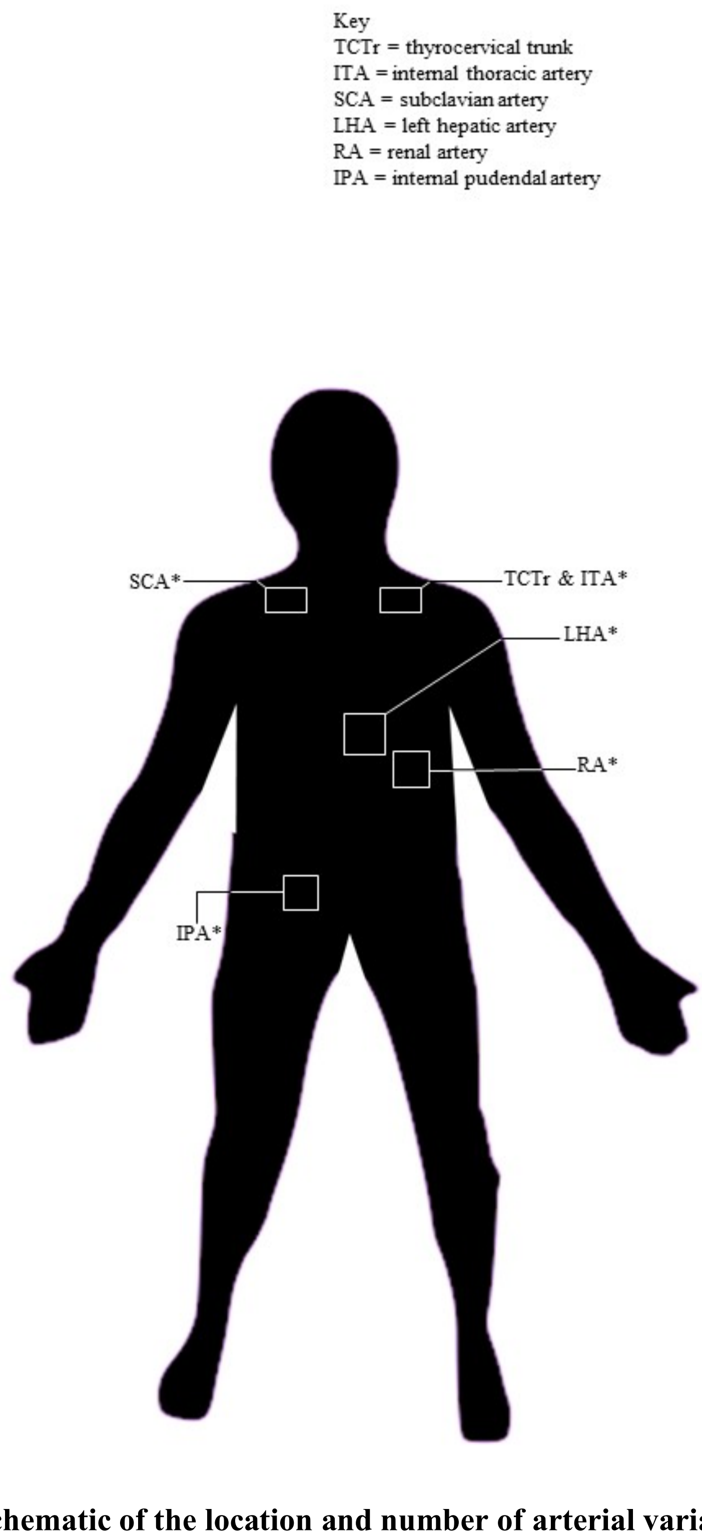

Figure 51: A schematic of the location and number of arterial variants found in body donor, DMPVHI.

CFSOTUFJO

Sex: F

Age: 97

COD: Aspiration pneumonia

Overview of variants seen (Figures 52-53)

- **Bovine aortic arch** where brachiocephalic and left common carotid come from the same origin (Figure 54)
- **The celiac trunk has 7 branches**. It has 3 typical branches plus (1.) the dorsal pancreatic artery (2.) left inferior phrenic, (3.) right inferior phrenic, (4.) common stem for middle suprarenal and esophageal branch (Figures 55-56)
- The **proper hepatic artery** bifurcates into the cystic and left hepatic arteries. The cystic artery gives off the right hepatic artery (Figure 56)
- On the **left subclavian**, there is a common stem for the thyrocervical trunk and internal thoracic artery
- In the **right upper extremity**, there are **2 circumflex scapular** branches from a common trunk
- In the **right internal iliac**, there are **2 internal pudendal arteries**, one comes from the bifurcation of the inferior gluteal and internal pudendal arteries and the other is a branch off the inferior gluteal

- In the **left internal iliac**, the anterior and posterior trunks are reversed so that the branches of the posterior trunk are oriented anteriorly. Make the superior and inferior gluteal arteries leave the greater sciatic foramen at a more anterior angle than normal. The superior gluteal is shifted so far anteriorly, that it is almost parallel to the external iliac artery
- In the **right lower extremity**, there is an anomalous origin of the **descending branches of the lateral circumflex femoral artery** from the **deep femoral artery**
- In the **left lower extremity**, there is a <u>common stem for the deep femoral and lateral circumflex femoral artery</u>
- In the **left lower extremity**, there is an anomalous origin of the **descending branches of the lateral circumflex femoral artery** from the **femoral artery**

Detailed Overview:

ARCH OF THE AORTA

Have a bovine aortic arch where the brachiocephalic trunk and the left common carotid artery originate from a common stem (Figure 54). The left subclavian is normal.

HEART

The left coronary artery is normal. The left anterior descending is normal and gives off the diagonal branch normally. The left marginal artery is normal. The left circumflex is normal. The right coronary artery is normal. The right marginal artery is normal. The right coronary artery gives off the posterior interventricular artery normally.

FOREGUT

The celiac trunk has 7 branches. It has 3 typical branches plus (1.) the dorsal pancreatic artery (2.) left inferior phrenic, (3.) right inferior phrenic, (4.) common stem for middle suprarenal and esophageal branch (Figures 55-56). The splenic artery is normal and gives off the posterior gastric and left gastro-omental arteries normally. The left gastric artery is normal. The common hepatic artery is normal and gives off the gastroduodenal artery normally. The gastroduodenal artery is normal and gives off the supraduodenal, the superior pancreaticoduodenal, and the right gastro-omental arteries normally. The proper hepatic artery is normal. **The proper hepatic artery bifurcates into the cystic artery and the left hepatic artery** (Figure 56). **The cystic artery gives off the right hepatic artery**. Cannot find the right gastric artery.

MIDGUT

The SMA is normal. Cannot find the inferior pancreaticoduodenal artery. The ileal and jejunal branches are normal. The middle colic, right colic, and ileocolic arteries are all normal.

HINDGUT

The IMA is normal. The left colic is normal but does not have clear ascending and descending branches. The sigmoid arteries are normal. The superior rectal artery is normal.

RIGHT RENAL

Have one renal artery coming off the abdominal aorta, bifurcates as it reaches the kidney. The middle suprarenal artery comes off the abdominal aorta normally. **The inferior phrenic artery comes off the celiac trunk** (Figure 55). Cannot find the, superior suprarenal, inferior suprarenal, or ovarian artery.

LEFT RENAL

Have one renal artery coming off the abdominal aorta, bifurcates as it reaches the kidney. **The middle suprarenal artery and the inferior phrenic artery come from a common stem off the celiac trunk** (Figure 55). The inferior phrenic artery gives off the superior suprarenal arteries normally. Cannot find the inferior suprarenal or ovarian arteries.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal. The anterior communicating artery is normal, but the posterior communicating arteries got torn as the brain was removed. The basilar artery is normal. The superior cerebellar arteries are normal.

RIGHT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The lingual and facial arteries are normal. The external carotid gives off the occipital artery normally, but it gets cut before it reaches its target. The facial artery gives off the submental, superior and inferior labial arteries, and the angular branch normally. The maxillary artery is normal. The ophthalmic artery off the internal carotid is normal.

LEFT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The lingual and facial arteries are normal. The external carotid artery gives off the occipital artery normally, but it is cut before it reaches its destination. The facial artery gives off the superior and inferior labial arteries and the angular branch normally.

RIGHT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal. The inferior thyroid, ascending cervical, and suprascapular branches of the thyrocervical trunk are normal. The transverse cervical artery got cut. Cannot find the costocervical trunk. The dorsal scapular artery is normal and comes off the subclavian.

LEFT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery and the thyrocervical trunk come off a common trunk. The ascending cervical and suprascapular arteries are normal. The other branches of the thyrocervical trunk are cut. Cannot find the costocervical trunk. The dorsal scapular artery is normal and comes off the subclavian.

RIGHT UPPER EXTREMITY

The thoracoacromial trunk is normal. The lateral thoracic artery is cut. The subscapular artery and its branches, the circumflex scapular and thoracodorsal arteries, are normal. **There are two circumflex scapular branches coming from a common trunk.** The anterior and posterior circumflex humeral arteries are normal. The axillary artery continues normally as the brachial artery. The deep brachial artery comes off the brachial artery normally. The ulnar and radial arteries are normal and bifurcate in the cubital fossa. The superficial palmar arch is normal. Cannot find the interosseous arteries, ulnar collateral arteries, or the radial recurrent artery.

LEFT UPPER EXTREMITY

The thoracoacromial trunk is normal. The lateral thoracic artery is cut. The subscapular artery and its branches, the circumflex scapular and the thoracodorsal arteries, are normal. The anterior and posterior circumflex humeral arteries are normal. The axillary artery continues normally as the brachial artery. The deep brachial artery is normal and branches off the brachial. The arm has some type of pathology at the elbow making it difficult to determine what's happening with the branching of the brachial artery. The ulnar and radial arteries bifurcate normally. The paths of the radial and ulnar arteries are normal down to the wrist. The superficial palmar arch is normal. Cannot find the interosseous arteries, ulnar collateral arteries, or the radial recurrent artery.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division is a long branch that everything comes off from. The obturator artery is normal. The umbilical artery is normal and gives off superior vesicle arteries normally. The uterine artery is normal. The internal pudendal artery is normal. **The inferior gluteal artery is normal but gives off another inferior gluteal artery so that there are two internal pudendal arteries**.

Posterior division gives off the lateral sacral artery normally. The superior gluteal artery is normal.

The iliolumbar artery is an independent branch that comes off the common iliac artery.

The external iliac is normal. The inferior epigastric is normal. The deep circumflex iliac is normal.

LEFT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally. **The orientation of the anterior and posterior divisions is flipped so that the posterior division is more anterior.**

Anterior division is like one long trunk that ends with a trifurcation. The first branch is the umbilical artery giving off the superior vesicle arteries normally. The second branch is the internal pudendal artery, which gives off the uterine artery. Both are normal. The third division is the inferior gluteal artery which gives off the lateral sacral artery and the middle rectal artery. All are normal, though the inferior gluteal artery exits the pelvis more anteriorly. Cannot find the obturator artery.

Posterior division gives off the superior gluteal artery. The superior gluteal artery is shifted so far anteriorly that it is almost parallel to the external iliac artery.

The iliolumbar artery is an independent branch that comes off before the internal iliac bifurcates.

The external iliac is normal. The inferior epigastric artery if normal but bifurcates and the other branch goes through the obturator canal. The deep circumflex iliac artery is normal.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery postero-laterally. The lateral circumflex femoral artery comes off the deep femoral artery normally. **Some of the descending branches of the lateral circumflex femoral artery come off the deep femoral artery.** Cannot find the medial circumflex femoral artery. The femoral artery continues normally through the adductor hiatus. The anterior tibial artery is normal and continues to dorsalis pedis normally. The posterior tibial artery is normal. Cannot see the fibular arteries.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery posteriorly. The lateral circumflex femoral artery comes off the deep femoral artery normally. The trunk of the deep femoral artery before giving off the lateral circumflex femoral artery is very short. **According to the literature, there is a common trunk for the deep femoral artery and the lateral circumflex femoral artery. There are descending branches of the lateral circumflex femoral artery coming off the femoral artery.** The medial circumflex femoral artery comes off the deep femoral artery just superior to the branch point of the lateral circumflex femoral artery. The anterior tibial artery is normal and continues to dorsalis pedis normally. The posterior tibial artery is normal. Cannot find the fibular artery.

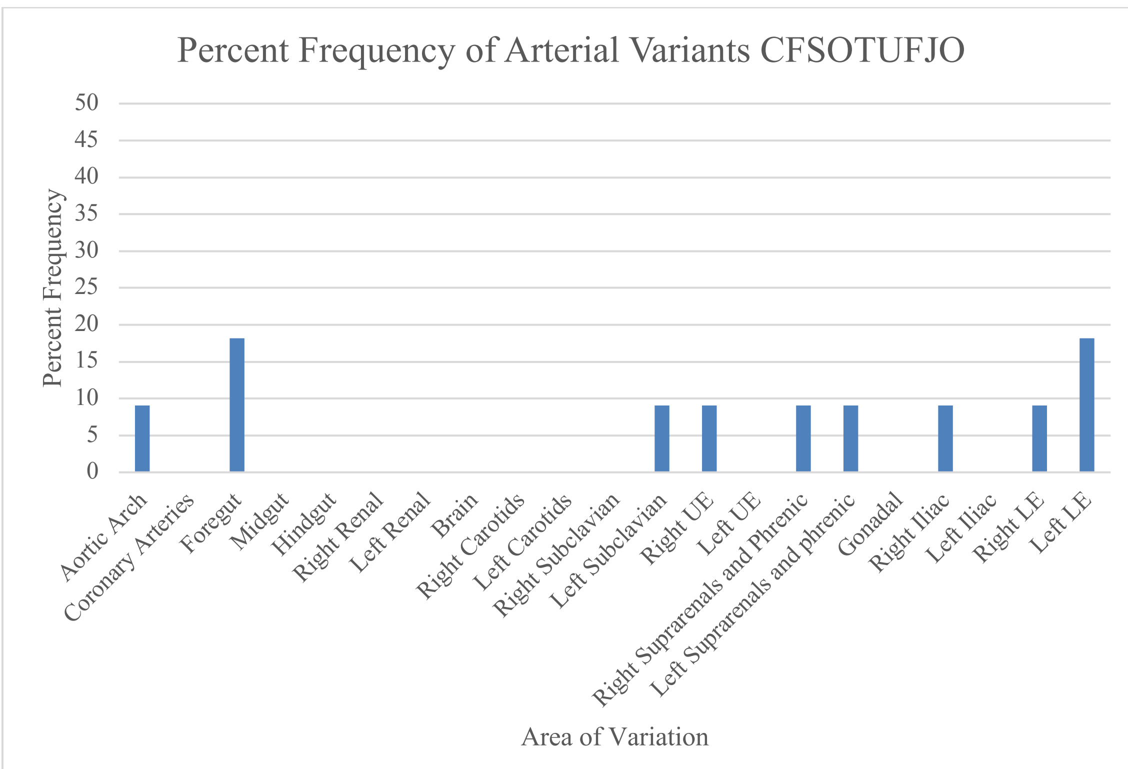

Figure 52: Percent frequency of arterial variants observed in body donor, CFSOTUFJO.

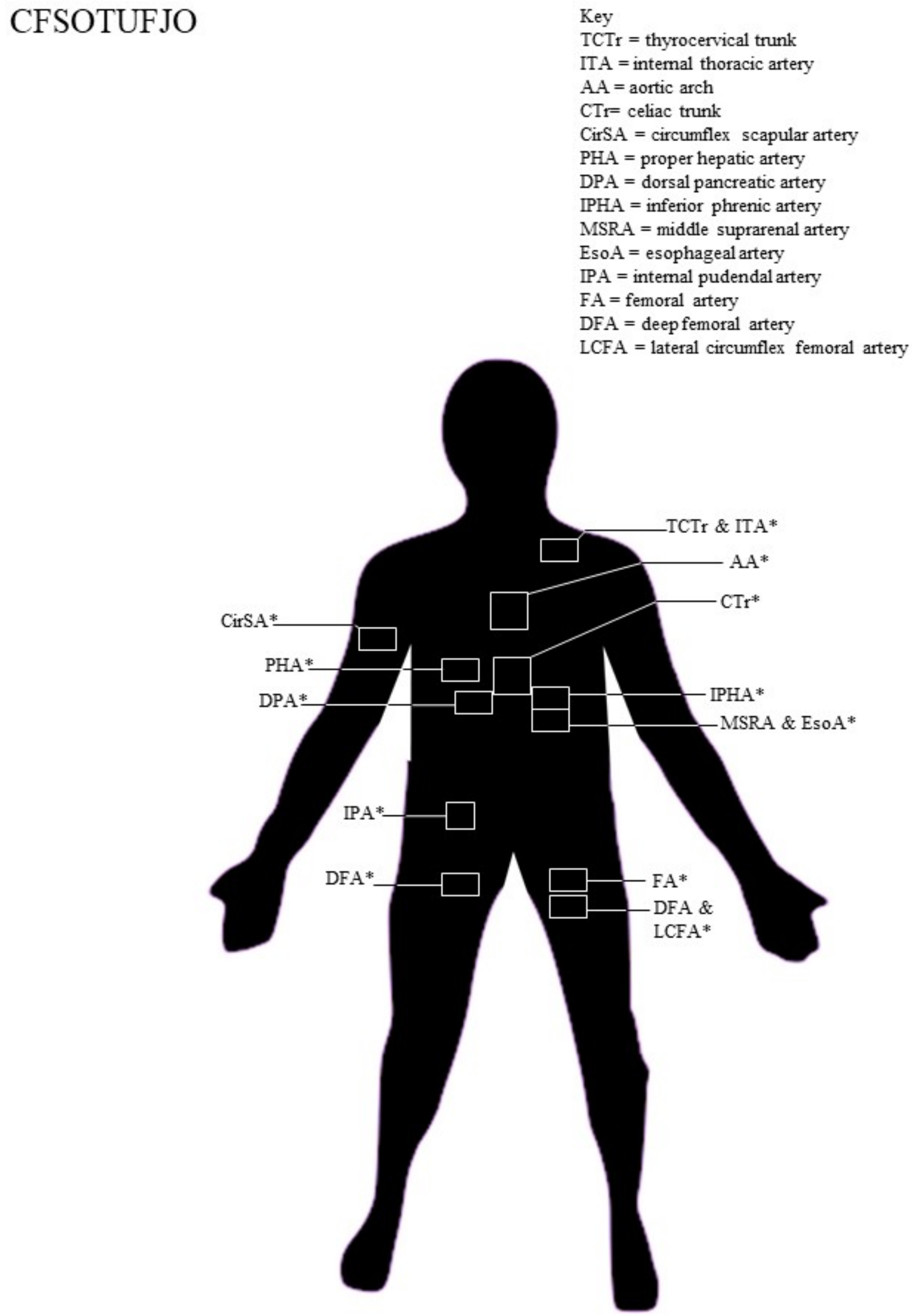

Figure 53: A schematic of the location and number of arterial variants found in body donor, CFSOTUFJO.

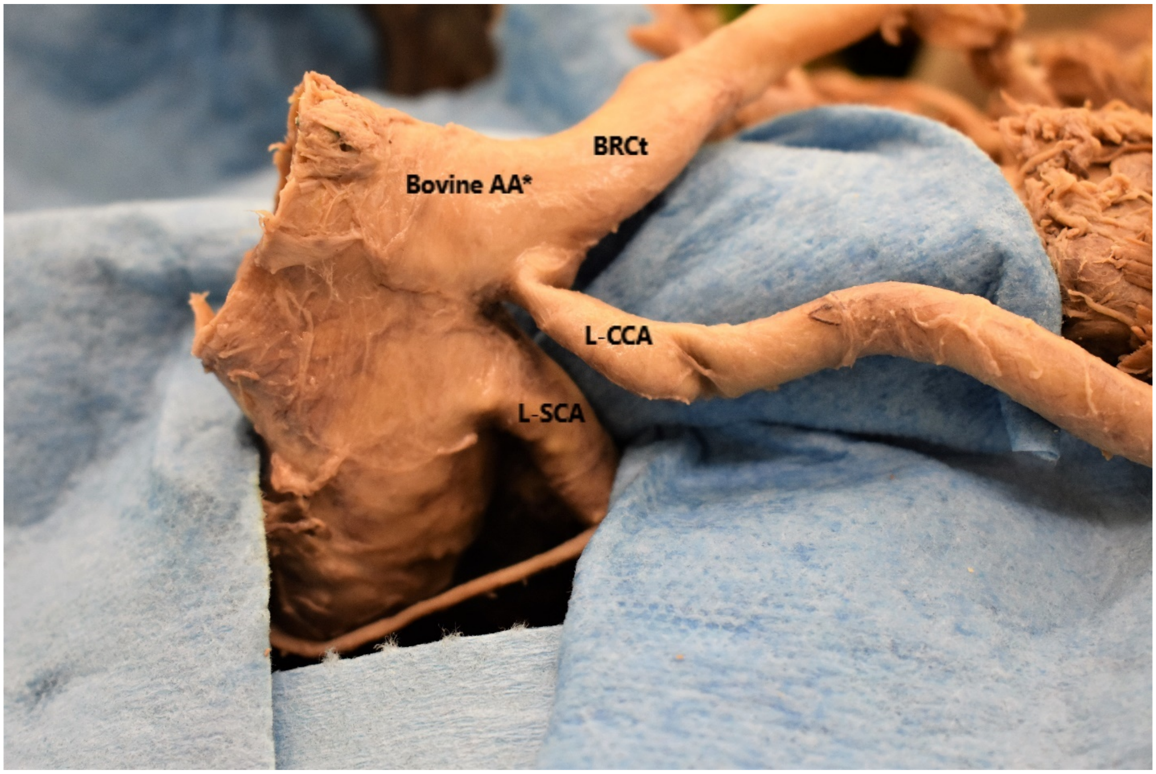

Figure 54: The bovine aortic arch in which the brachiocephalic trunk and left common carotid artery originate from the same stem in body donor, CFSOTUFJO.

AA = aortic arch, BRCt = brachiocephalic trunk, L-CCA = left common carotid artery, L-SCA = left subclavian artery, * = variant.

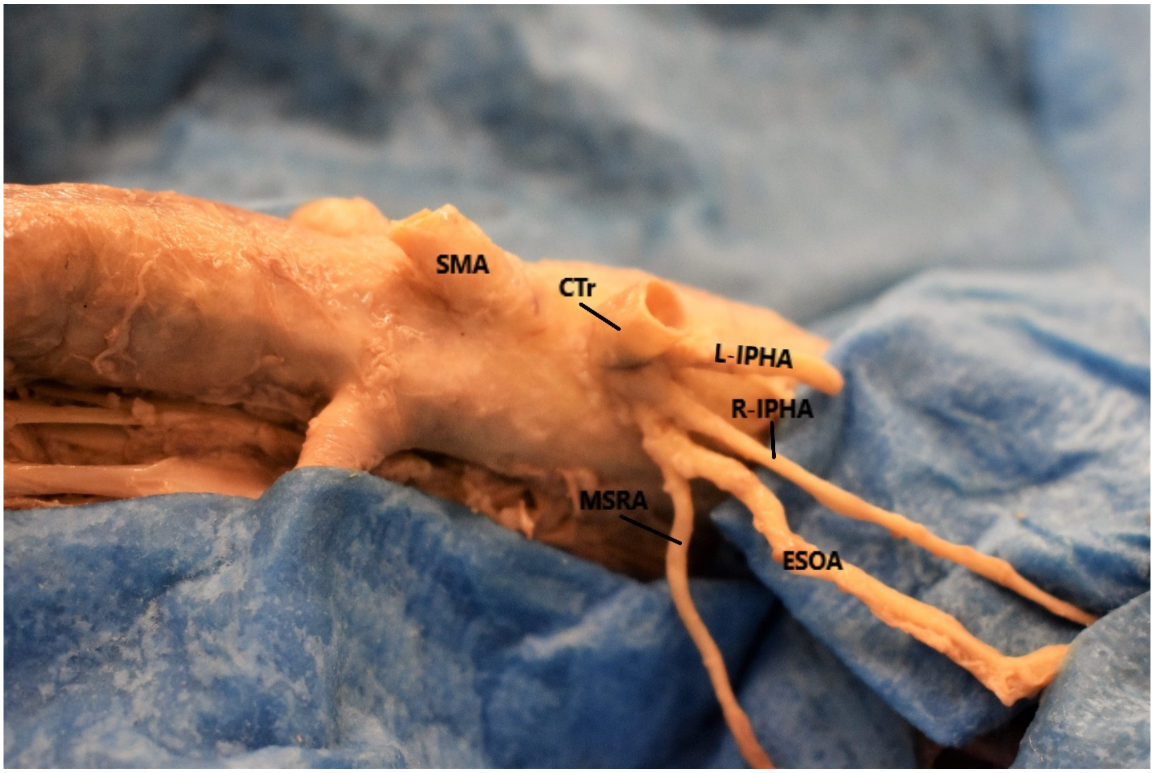

Figure 55: A variant of the celiac trunk in which the right and left inferior phrenic arteries and a common stem for an esophageal artery and the middle suprarenal artery originate from it in body donor, CFSOTUFJO.
SMA = superior mesenteric artery, CTr = celiac trunk, L-IPHA = left inferior phrenic artery, R-IPHA = right inferior phrenic artery, ESOA = esophageal artery, MSRA = middle suprarenal artery, * = variant.

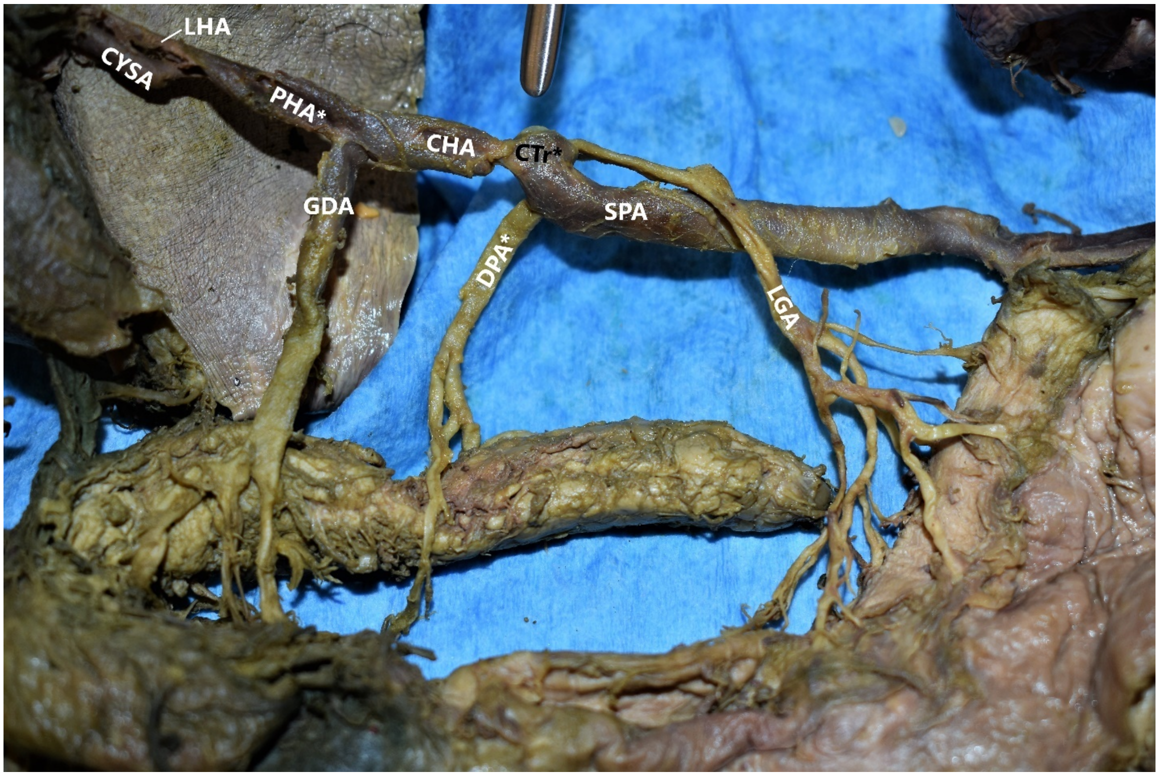

Figure 56: A variant of the celiac trunk in which the dorsal pancreatic artery originates from it in body donor, CFSOTUFJO. Also pictured is the proper hepatic artery bifurcating into the cystic and left hepatic arteries.

CTr = celiac trunk, SPA = splenic artery, LGA = left gastric artery, DPA = dorsal pancreatic artery, CHA = common hepatic artery, GDA = gastroduodenal artery, PHA = proper hepatic artery, CYSA = cystic artery, LHA = left hepatic artery, * = variant.

NBJMMPVY

Sex: M

Age: 64

COD: Anoxic brain injury/cardiac arrest/coronary artery disease

Summary of variants seen (Figures 57-58)

- The **celiac trunk has 4 branches**; it has 3 typical branches plus (1.) **the dorsal pancreatic artery**
- There is no **right colic artery**, the middle colic and ileocolic supply the ascending colon
- The **middle colic** artery has an **anastomosis with the left colic artery** of the IMA, **Arc of Riolan**
- In the **right upper extremity**, there is an anomalous origin of the **lateral thoracic artery** from the **subscapular artery**
- In the **right upper extremity**, there is a <u>common stem for 2 anterior circumflex arteries and the posterior circumflex humeral artery</u>
- In the **right upper extremity**, the <u>branching of the ulnar and radial arteries is lower</u> in the cubital fossa, branches just below the fossa
- In the **right upper extremity**, the <u>radial artery gives rise to the common interosseous artery</u>

- In the **left upper extremity**, the branching of the ulnar and radial arteries is lower in the cubital fossa, branches just below the fossa and the radial artery seems small and poorly developed

- The **right and left inferior phrenic arteries** come off a **common trunk** from the abdominal aorta

- In the **left internal iliac**, the orientation of the anterior and posterior branches is reversed so that the posterior vessels are more anterior. The superior gluteal artery exits the pelvis at a more anterior orientation than normal and gives off branches to the anterior pelvic wall

- In the **left lower extremity**, there is an anomalous origin of the **lateral circumflex femoral artery** from the **femoral artery** and it branches off further down than normal, about an inch away from the branch point of the deep femoral and 2.5 inches away from the ilioinguinal ligament

Detailed Overview:

ARCH OF THE AORTA

The brachiocephalic trunk is normal and bifurcates into the right common carotid and right subclavian arteries normally. The left common carotid is normal. The left subclavian is normal.

HEART

The left coronary artery is normal, but there was a bypass on it. The left anterior descending is normal and gives off the diagonal branch normally. Cannot find the left circumflex or left marginal arteries because of the surgery. Cannot find the right coronary artery because of the surgery.

FOREGUT

The celiac trunk has 4 branches. It has 3 typical branches plus (1.) the **dorsal pancreatic artery**. The splenic artery is normal and gives off the posterior gastric and left gastro-omental arteries normally. The left gastric artery is normal. The common hepatic artery is normal and gives off the gastroduodenal artery normally. The gastroduodenal artery is normal and gives off the superior pancreaticoduodenal and the right gastro-omental arteries normally. Cannot find the supraduodenal artery. The proper hepatic artery is normal. The proper hepatic artery bifurcates into the right hepatic artery the left hepatic artery. The right hepatic artery gives off the cystic artery normally. Cannot find the right gastric artery.

MIDGUT

The SMA is normal. The inferior pancreaticoduodenal artery is normal. The ileal and jejunal branches are normal. **There is no right colic artery**. The middle colic and ileocolic artery help supply the ascending colon. The middle colic and ileocolic arteries are otherwise normal.

HINDGUT

The IMA is normal. The left colic is normal and gives off the ascending and descending branches normally. **The left colic artery has an anastomosis with the middle colic artery.** The sigmoid arteries are normal. The superior rectal artery is normal.

RIGHT RENAL

Have one renal artery coming off the abdominal aorta, bifurcates as it reaches the kidney. The middle suprarenal artery comes off the abdominal aorta normally. **The inferior phrenic artery comes off the abdominal aorta from a common stem with the left inferior phrenic artery.** The inferior phrenic artery gives off the superior suprarenal arteries normally. Cannot find the middle suprarenal, or testicular arteries.

LEFT RENAL

Have one renal artery coming off the abdominal aorta, bifurcates as it reaches the kidney. **The inferior phrenic artery comes off a common stem with the other side inferior phrenic artery**. The inferior phrenic artery gives off the superior suprarenal arteries normally. Cannot find the inferior suprarenal, middle suprarenal, or testicular arteries.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal. The anterior and posterior communicating arteries are normal. The basilar artery is normal. The superior cerebellar arteries are normal.

RIGHT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The lingual and facial arteries are normal. The facial artery gives off the submental, superior and inferior labial arteries, and the angular branch normally.

LEFT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid, lingual, and facial arteries are normal. The facial artery gives off the superior and inferior labial arteries normally, before it gets cut. The maxillary artery is normal.

RIGHT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal, but its branches were cut. Cannot find the costocervical trunk. The dorsal scapular artery is normal and comes off the subclavian.

LEFT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal, but its branches were cut. The costocervical trunk is normal. Cannot find the dorsal scapular artery.

RIGHT UPPER EXTREMITY

The thoracoacromial trunk is normal, but its branches are cut. **The lateral thoracic artery comes off the subscapular artery.** The other branches of the subscapular artery; the thoracodorsal and circumflex scapular arteries, are normal. **The anterior and posterior circumflex humeral arteries come off a common trunk and there are 2 anterior circumflex humeral branches.** The axillary artery continues normally as the brachial artery. The deep brachial artery comes off the brachial artery normally. **The bifurcation of the radial and ulnar arteries is lower in the cubital fossa, bifurcates just inferior to the fossa**. The ulnar artery branches off posteriorly and dives deep, under the muscles. It continues to the wrist normally. The radial artery continues to the wrist normally. **The anterior and posterior interosseous arteries come off the radial instead of the ulnar.** The superficial palmar arch is normal. Cannot find the radial recurrent artery or the ulnar collateral arteries.

LEFT UPPER EXTREMITY

The thoracoacromial trunk is normal. The lateral thoracic artery is normal. The subscapular artery and its branches, the thoracodorsal and circumflex scapular arteries, are normal. The anterior and posterior circumflex humeral arteries are normal. The axillary artery continues normally as the brachial artery. The deep brachial artery comes off the brachial artery normally. **The branch point of the ulnar and radial arteries is lower in the cubital fossa than normal. The radial artery is smaller in width than normal and seems poorly developed.** The radial artery is cut at the wrist and has a lumen there. There were staples in the artery or something, but it was trapped in fascia that was keeping it together. The ulnar artery is normal but does not have a branch point for the common interosseous artery. The superficial palmar arch is normal. Cannot find the ulnar collateral arteries or the radial recurrent artery.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division is a long branch that everything comes off from. The umbilical artery is normal and gives off superior vesicle arteries normally. The inferior vesicle artery is normal. Terminates with a branch that bifurcates into the inferior gluteal artery and the internal pudendal artery. Both are normal.

Posterior division gives off the obturator artery and the iliolumbar artery. The superior gluteal artery is normal.

The lateral sacral artery is an independent branch that comes off the internal iliac artery before it bifurcates.

The external iliac is normal. The inferior epigastric is normal. Cannot find the deep circumflex iliac artery.

LEFT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally. The orientation of the anterior and posterior divisions is flipped so that the posterior division is more anterior.

Anterior division is like one ganglion that everything comes from. The umbilical artery is normal and gives off superior vesicle arteries and inferior vesicle arteries. Cannot find the obturator artery. The inferior gluteal artery comes from a common trunk with the middle rectal artery and an inferior vesicle artery. All are normal, though oriented more anteriorly. The internal pudendal artery is normal. The lateral sacral artery comes from the anterior division and is normal.

Posterior division gives off the superior gluteal artery. The superior gluteal artery is shifted anteriorly. Superior gluteal artery gives off a branch to the pubic symphysis.

The iliolumbar artery is an independent branch that comes off before the internal iliac bifurcates.

The external iliac is normal. The inferior epigastric artery if normal. Cannot find the deep circumflex iliac artery.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery comes off the femoral artery postero-medially but is smaller in width than normal. The lateral circumflex femoral artery is normal and comes off the deep femoral artery. Cannot find the medial circumflex femoral artery. The femoral artery continues through the adductor hiatus normally. The posterior tibial artery is normal. Cannot find the anterior tibial, dorsalis pedis, or fibular arteries.

LEFT LOWER EXTREMITY

The femoral artery is normal. **The lateral circumflex femoral artery branches off the femoral artery and the branch point is further down than normal, about an**

inch away from the branch point of the deep femoral and 2.5 inches from the ilioinguinal ligament. The deep femoral is normal and branches off the femoral artery postero-medially. The medial circumflex femoral artery is normal and comes off the deep femoral. The femoral artery continues through the adductor hiatus normally. The posterior tibial artery is normal. Cannot find the anterior tibial, dorsalis pedis, or fibular arteries.

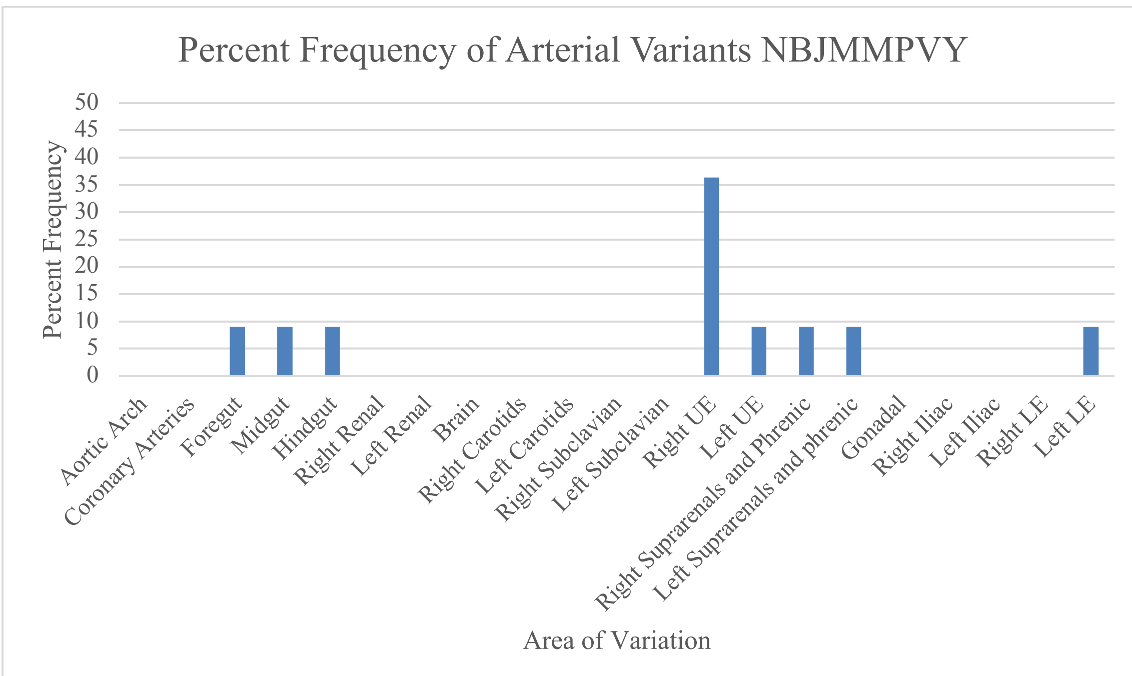

Figure 57: Percent frequency of arterial variants observed in body donor, NBJMMPVY.

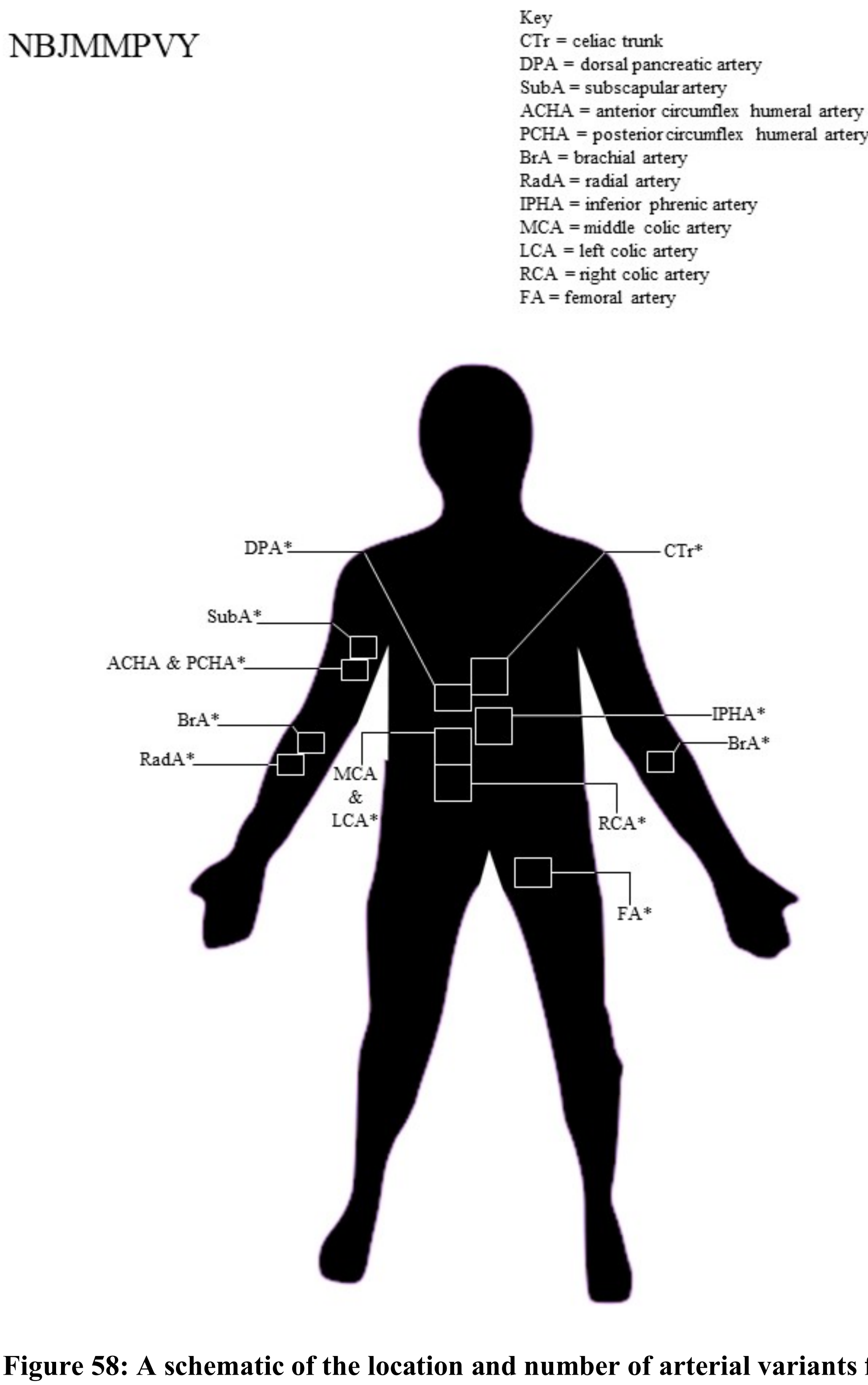

Figure 58: A schematic of the location and number of arterial variants found in body donor, NBJMMPVY.

TJMWB

Sex: F

Age: 90

COD: COPD

Summary of variants seen (Figures 59-60)

- **The left gastric artery gives off 2 branches that go to the lesser curvature of the stomach and an accessory left hepatic artery** (Figure 61)
- There is **a common stem for the middle colic and right colic artery** (Figures 62–63)
- The <u>middle colic artery forms an anastomosis with the IMA</u> via the left colic artery, **Arc of Riolan** (Figure 62–63)
- Have **2 left renal arteries** and an **accessory left renal artery** coming off the abdominal aorta for the inferior pole of the kidney (Figure 64)
- In the **brain**, the **left vertebral artery** gives off a branch that ends up rejoining the basilar artery, makes a mug handle shape (Figure 65)
- In the **right subclavian**, there is an anomalous origin of the **dorsal scapular artery** from the **thyrocervical trunk**
- In the **left subclavian**, there is a common stem for the suprascapular and dorsal scapular arteries
- The **right inferior phrenic and right middle suprarenal** come off a <u>common trunk</u> off the abdominal aorta

- In the **left internal iliac**, there are **2 inferior gluteal arteries**. One is given off by the bifurcation of the inferior gluteal and internal pudendal arteries and the other is a branch off the internal pudendal artery

Detailed Overview:

ARCH OF THE AORTA

The brachiocephalic trunk is normal and bifurcates into the right common carotid and the right subclavian arteries normally. The left common carotid artery is normal. The left subclavian is normal.

HEART

The left coronary artery is normal. The left anterior descending is normal and gives off the diagonal branch normally. The left marginal artery is normal. The left circumflex is normal. The right coronary artery is normal. The right marginal artery is normal. The right coronary artery gives off the posterior interventricular artery normally.

FOREGUT

The celiac trunk gives off the splenic, left gastric, and common hepatic arteries normally. The splenic artery is normal. Cannot find the left gastro-duodenal. **The left gastric artery gives off two branches that go to the stomach and an accessory left hepatic artery** (Figure 61). The common hepatic artery is normal and gives off the gastroduodenal artery normally. The gastroduodenal artery is normal and gives off the superior pancreaticoduodenal and the right gastro-omental arteries normally. Cannot find the supraduodenal artery. The proper hepatic artery is normal. It gives off the right gastric artery normally and terminates by bifurcating into the right and left hepatic arteries normally. The right hepatic artery gives off the cystic artery normally.

MIDGUT

The SMA is normal. The inferior pancreaticoduodenal artery is normal. The ileal and jejunal branches are normal. The ileocolic artery is normal and supplies the ascending colon. **There is a common trunk of the right colic and middle colic arteries** (Figures 62-63). **The middle colic artery forms an anastomosis with the IMA via the left colic artery: Arc of Riolan** (Figures 62-63).

HINDGUT

The IMA is normal. The left colic is normal but does have that anastomosis with the SMA (Figures 62-63). The sigmoid arteries are normal. The superior rectal artery is cut.

RIGHT RENAL

Have one renal artery coming off the abdominal aorta, bifurcates as it reaches the kidney. **The middle suprarenal artery and the inferior phrenic artery come from a common stem off the abdominal aorta.** The inferior phrenic gives off the superior suprarenal arteries normally. Cannot find the inferior suprarenal or ovarian arteries.

LEFT RENAL

Have two renal arteries coming off the abdominal aorta (Figure 64)**, and one accessory renal artery coming off the abdominal aorta that goes to the inferior pole**

of the kidney. The width of the accessory renal artery was very narrow. The renal arteries are oriented one on top of the other and one is more anterior, and one is more posterior. The superior, anterior renal artery is smaller in width than the other renal artery. The middle suprarenal artery comes off the abdominal aorta normally. The inferior phrenic artery is normal on the diaphragm but is cut before it reaches its origination point. The inferior phrenic artery gives off superior suprarenal arteries normally. Cannot find the inferior suprarenal or ovarian arteries.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal. The anterior and posterior communicating arteries are normal. **The left vertebral artery gives off a branch that rejoins the basilar artery, creates a mug handle shape** (Figure 65). The basilar artery is otherwise normal. The superior cerebellar arteries are normal.

RIGHT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The lingual and facial arteries are normal. The facial artery gets cut very quickly, so cannot find any of its branches in the face.

LEFT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid, lingual, and facial arteries are normal. The facial artery gives off the superior and inferior labial arteries, the lateral nasal artery, and the angular branch normally. The maxillary artery is normal.

RIGHT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal. The inferior thyroid and ascending cervical branches are cut. The suprascapular branch is normal. **The dorsal scapular artery comes off the thyrocervical trunk**. Cannot find the costocervical trunk.

LEFT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal.
The thyrocervical trunk is normal. The ascending cervical artery is normal, but the inferior thyroid artery is cut. **The suprascapular and dorsal scapular arteries bifurcate from a common stem**, continue to their targets normally. Cannot find the costocervical trunk.

RIGHT UPPER EXTREMITY

The thoracoacromial trunk and its branches are normal. The lateral thoracic artery is cut. The subscapular artery and its branches, the circumflex scapular and thoracodorsal arteries, are normal. The anterior and posterior circumflex humeral arteries are normal.

The axillary artery continues normally as the brachial artery. The deep brachial artery comes off the brachial artery normally. The radial and ulnar arteries are normal and bifurcate at the cubital fossa. The radial recurrent artery joins the radial artery after it bifurcates from the brachial artery, making it look like a trifurcation. The common interosseous artery comes off the ulnar artery normally. The anterior and posterior interosseous arteries are normal. The superficial palmar arch is normal. Cannot find the ulnar collateral arteries.

LEFT UPPER EXTREMITY

The thoracoacromial trunk and its branches are normal. The lateral thoracic is normal. The subscapular artery and its branches, the thoracodorsal artery and the circumflex scapular artery, are normal. The anterior circumflex humeral artery is cut. The posterior circumflex humeral artery is normal. The axillary artery continues normally as the brachial artery. The deep brachial artery branches normally from the brachial artery. The ulnar and radial arteries are normal and bifurcate in the cubital fossa. The common interosseous artery is normal and comes off the ulnar artery. The anterior interosseous artery is cut, and the posterior cannot be found. The superficial palmar arch is normal. Cannot find the radial recurrent artery or the ulnar collateral arteries.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division is a long branch that everything comes off from. The umbilical artery is normal and gives off superior vesicle arteries normally. The obturator artery and the internal pudendal artery come off the same branch, both are normal. The inferior gluteal artery is normal.

Posterior division gives off the lateral sacral artery and the iliolumbar artery at the same level, both are otherwise normal. Gives off another lateral sacral artery. The superior gluteal artery is normal.

The iliolumbar artery is an independent branch that comes off the common iliac artery.

The external iliac is normal. The inferior epigastric is normal. The deep circumflex iliac is normal.

LEFT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division is like one long trunk that everything branches from. The umbilical and obturator arteries are normal. Terminates with a bifurcation into **two inferior gluteal arteries**. The second inferior gluteal artery gives off the internal pudendal artery and the middle rectal artery.

Posterior division gives off the lateral sacral artery normally. The superior gluteal artery is normal.

The iliolumbar artery cannot be found.

The external iliac is normal. The inferior epigastric artery if normal. Cannot find the deep circumflex iliac artery.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery postero-laterally. The medial and lateral circumflex femoral arteries are normal and come off the deep femoral. The femoral artery continues normally through the adductor hiatus. The anterior and posterior tibial arteries are normal. Cannot see the fibular artery or dorsalis pedis.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery postero-laterally. The lateral circumflex femoral artery is normal and comes off the deep femoral artery. Cannot find the medial femoral artery. The femoral artery continues normally through the adductor hiatus. The anterior tibial artery is normal and continues normally to dorsalis pedis. The posterior tibial artery is normal. Cannot see the fibular artery.

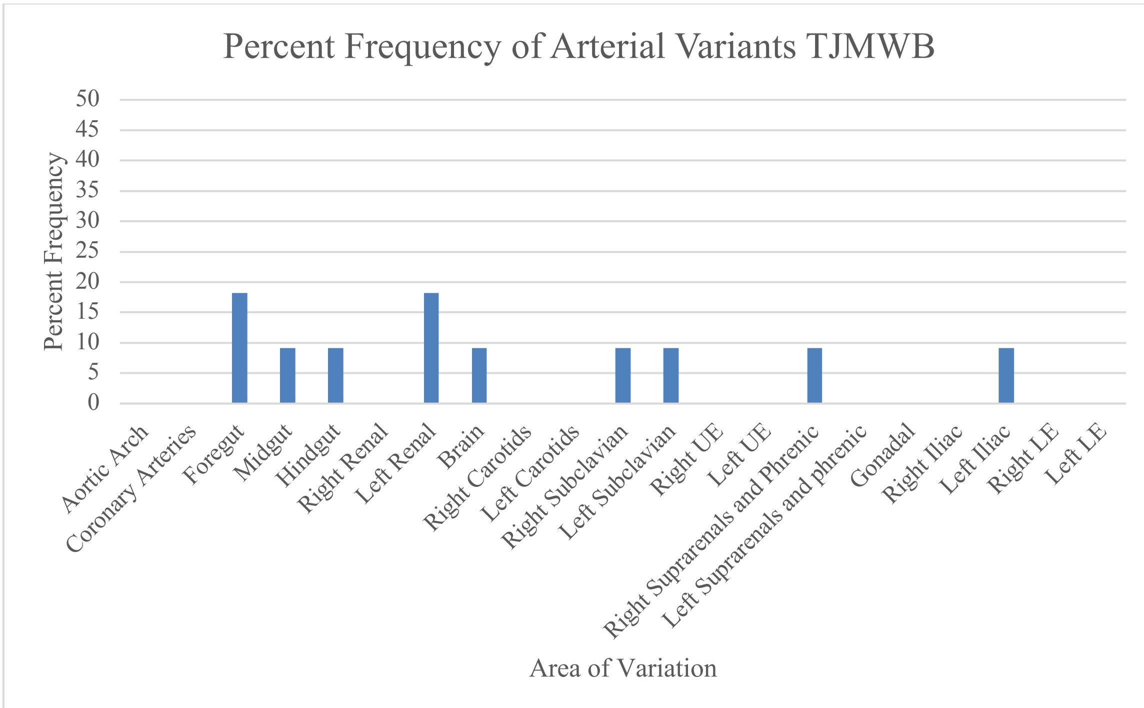

Figure 59: Percent frequency of arterial variants observed in body donor, TJMWB.

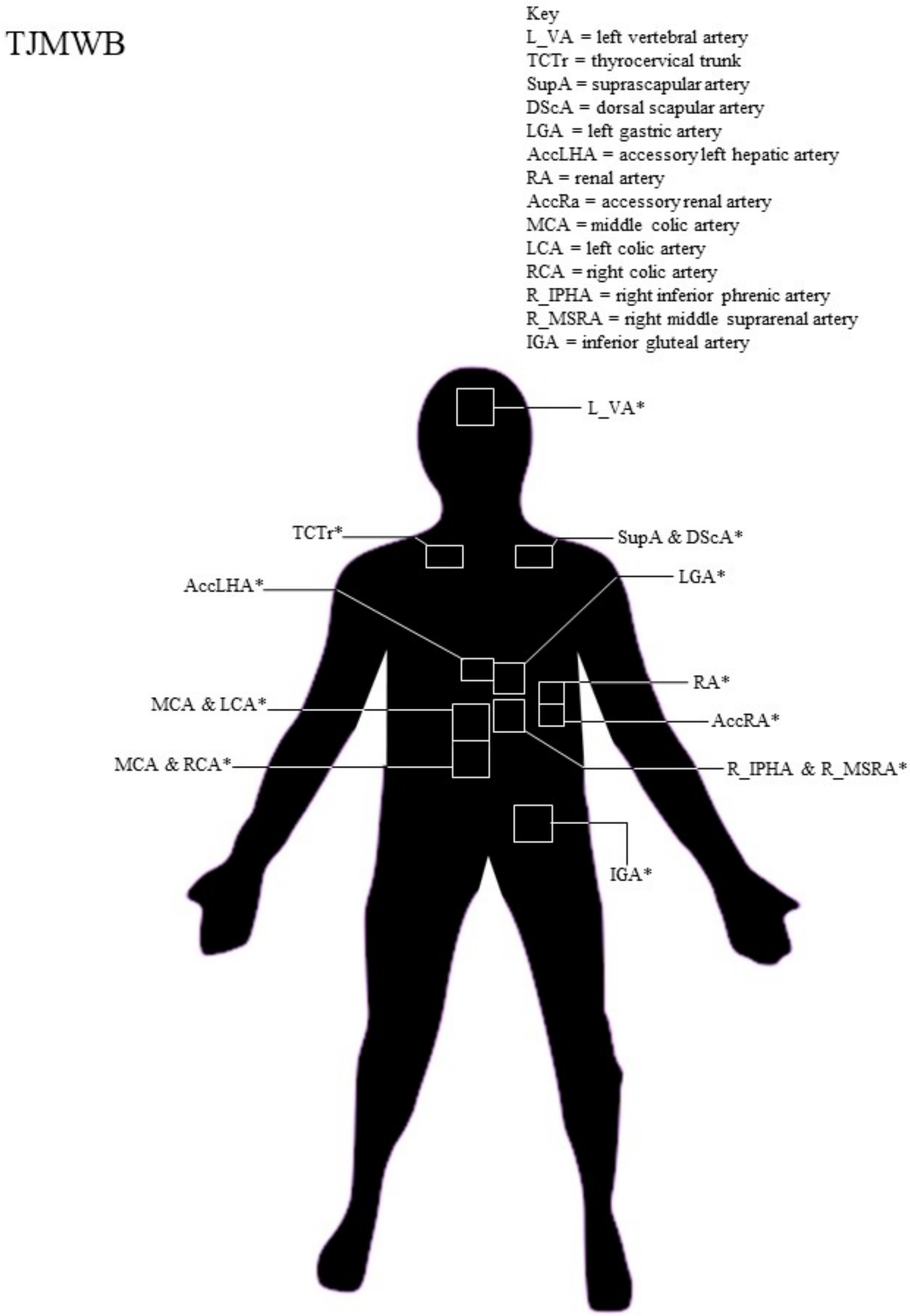

Figure 60: A schematic of the location and number of arterial variants found in body donor, TJMWB.

Figure 61: A variant of the left gastric artery in which it gives off an accessory left hepatic artery as well as two branches that supply the lesser curvature of the stomach in body donor, TJMWB.

CTr = celiac trunk, LGA = left gastric artery, SA = stomach arteries, AccLHA = accessory left hepatic artery, CHA = common hepatic artery, GDA = gastroduodenal artery, PHA = proper hepatic artery, LHA = left hepatic artery, RHA = right hepatic artery, * = area of variant.

Figure 62: The common stem for the right colic artery and the middle colic artery off the SMA in body donor, TJMWB. The Arc of Riolan can also be seen between the middle colic artery and the left colic artery.

SMA = superior mesenteric artery, RCA = right colic artery, MCA = middle colic artery, IlCA = ileocolic artery, LCA = left colic artery, IMA = inferior mesenteric artery, * = area of variant.

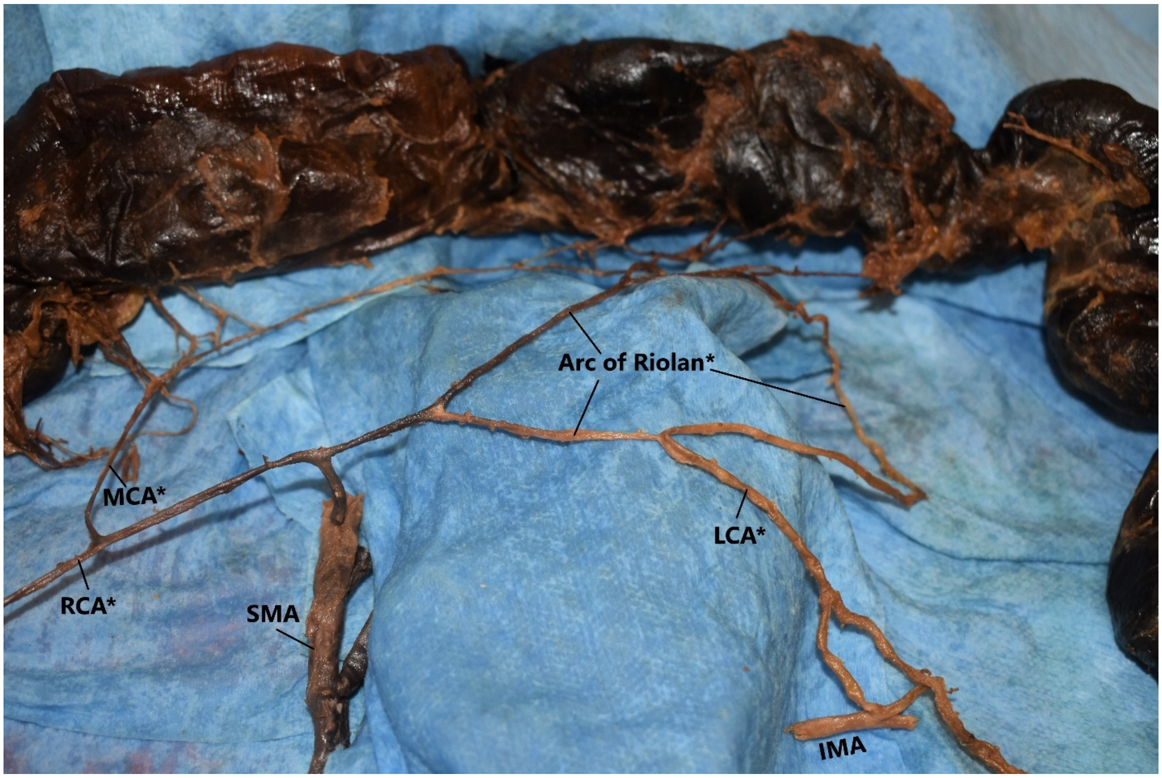

Figure 63: The Arc of Riolan formed between the middle colic artery of the SMA and the left colic artery of the IMA in body donor, TJMWB. The common stem for the right colic artery and the middle colic artery off the SMA can also be seen.

SMA = superior mesenteric artery, RCA = right colic artery, MCA = middle colic artery, LCA = left colic artery, IMA = inferior mesenteric artery, * = variant.

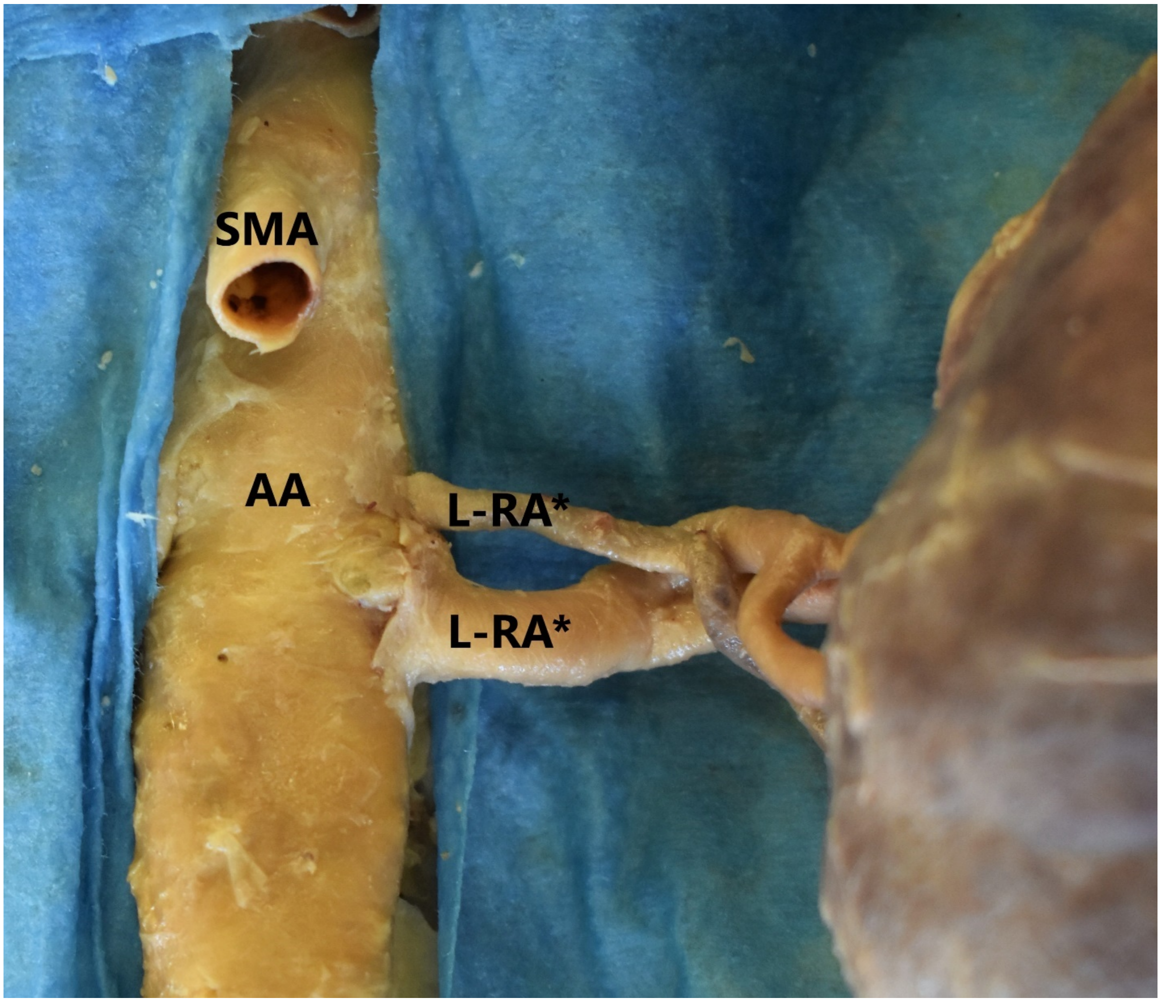

Figure 64: Multiple left renal arteries coming off the abdominal aorta in body donor, TJMWB.
AA = abdominal aorta, SMA = superior mesenteric artery, L-RA = left renal artery, * = variant.

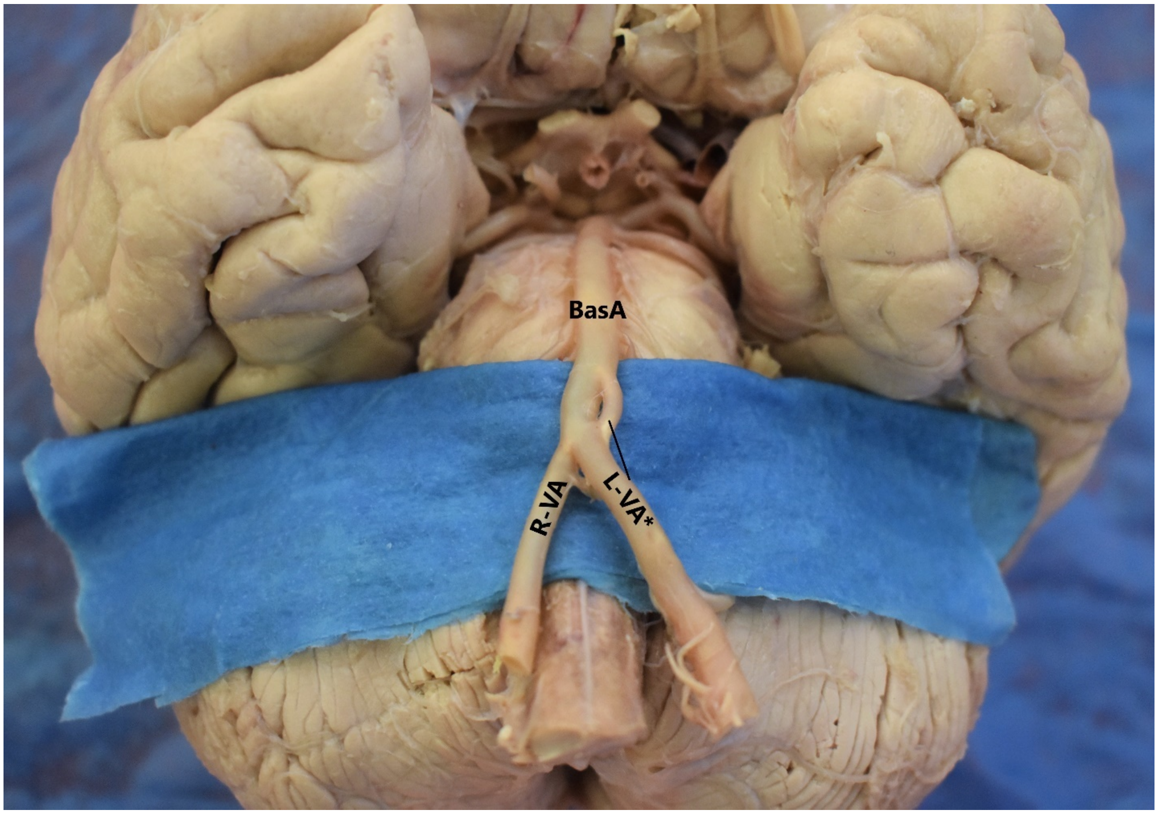

Figure 65: A variant of the left vertebral artery in which a small arterial branch is given off that rejoins the basilar artery in body donor, TJMWB.

R-VA = right vertebral artery, L-VA = left vertebral artery, BasA = basilar artery, * = variant.

HSFFO.N

Sex: M

Age: 90

COD: Squamous cell carcinoma of tongue/dementia

Summary of variants seen (Figures 66-67)

- **Left dominant heart**, the left coronary artery gives off the posterior interventricular artery
- **The celiac trunk has 4 branches,** the 3 main ones plus (1.) the **left inferior phrenic** artery
- There is **a common stem for the middle and right colic arteries** off the **SMA**
- Have a **right accessory renal artery** off the abdominal aorta going to the inferior pole of the kidney
- Have **2 left renal arteries** and an **accessory left renal artery** off the abdominal aorta going to the inferior pole of the kidney
- On the **right carotid artery**, there is a common stem for the lingual and facial arteries
- On the **left subclavian**, there is a common stem for the thyrocervical trunk and internal thoracic artery
- In the **right lower extremity**, there is an anomalous origin of the **medial circumflex femoral artery** off the **femoral artery**

Detailed Overview:

ARCH OF THE AORTA

The brachiocephalic trunk is normal and bifurcates into the left common carotid and the left subclavian normally. The left subclavian is normal. The left common carotid is normal.

HEART

The left coronary artery is normal. The left anterior descending is normal and gives off the diagonal branch normally. The left marginal artery is normal. The left circumflex is normal. The left circumflex artery keeps going to the posterior aspect of the heart and gives rise to the posterior interventricular artery, meaning **this is a left-dominant heart**. The right coronary artery is normal. The right marginal artery is normal.

FOREGUT

The celiac trunk has 4 branches. It has 3 typical branches plus the **right inferior phrenic**. The splenic artery is normal and gives off the left gastro-omental artery normally. The left gastric artery is normal. The common hepatic artery is normal and gives off the gastroduodenal artery normally. The gastroduodenal artery is normal and gives off the supraduodenal, the superior pancreaticoduodenal, and the right gastro-omental arteries normally. The proper hepatic artery is normal. The proper hepatic artery bifurcates into the right hepatic artery and the left hepatic artery normally. The right hepatic artery gives off the cystic artery normally. Cannot find the right gastric artery.

MIDGUT

The SMA is normal. The inferior pancreaticoduodenal artery is normal. The ileal and jejunal branches are normal. The middle colic and ileocolic arteries are normal**.** **There is a common stem for the middle colic and right colic arteries.**

HINDGUT

The IMA is normal. The left colic is normal and bifurcates into the ascending and descending branches normally. The sigmoid arteries are normal. The superior rectal is cut.

RIGHT RENAL

Have one renal artery coming off the abdominal aorta, bifurcates as it reaches the kidney. **Also have an accessory renal artery coming off the abdominal aorta and going to the inferior pole of the kidney**. The inferior suprarenal artery came off the renal artery normally. Have a lumen on the abdominal aorta where the middle suprarenal artery was. The inferior phrenic artery was cut but can match its lumen to one of the abdominal aorta, it came off right before the base of the celiac trunk. The inferior phrenic artery continues to the diaphragm normally and gives off the superior suprarenal arteries. Cannot find the testicular artery.

LEFT RENAL

Have two renal arteries coming off the abdominal aorta and one accessory renal artery coming off the abdominal aorta and going to the inferior pole of the kidney. The renal arteries are oriented anterior and posterior to one another, both bifurcate as they reach the kidney. **The inferior phrenic artery comes off the celiac trunk**. Cannot find the middle or inferior suprarenal arteries or the testicular artery.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal. The anterior and posterior communicating arteries are normal. The brain stem got torn from the brain when it was removed so cannot see the basilar or superior cerebellar arteries.

RIGHT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal. **The lingual and facial arteries come off a common stem**. The external carotid gives off the occipital artery normally, but it gets cut before it reaches its target. The facial artery gives off the submental and superior and inferior labial arteries normally. The ophthalmic artery off the internal carotid is normal.

LEFT CAROTID

The common carotid ascends the neck normally, but there is a mass in the neck covering the carotid artery so cannot see it bifurcate into the internal and external carotids. The lingual artery is normal as it reaches the tongue. The facial artery is normal and gives off the superior and inferior labial arteries normally before it gets cut. The maxillary artery is normal.

RIGHT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal, but its branches got cut. Cannot find the costocervical trunk. The dorsal scapular artery is normal and comes off the subclavian.

LEFT SUBCLAVIAN

The vertebral artery is normal. **The internal thoracic artery and the thyrocervical trunk come off a common trunk.** The branches of the thyrocervical trunk are normal. Cannot find the costocervical trunk. The dorsal scapular artery is normal and comes off the subclavian.

RIGHT UPPER EXTREMITY

The thoracoacromial trunk is normal. The lateral thoracic artery is cut but can see the lumens that match the branch to its branch point off the artery. The subscapular artery and its branches, the circumflex scapular and thoracodorsal arteries, are normal. The anterior and posterior circumflex humeral arteries are normal. The axillary artery continues normally as the brachial artery. The deep brachial artery is normal and comes off the brachial artery. The radial and ulnar arteries are normal and bifurcate at the cubital fossa. The common interosseous artery is normal and comes off the ulnar artery. The anterior interosseous artery is normal but cannot see the posterior interosseous artery. Cannot find the ulnar collateral arteries, the radial recurrent artery, or the superficial palmar arch.

LEFT UPPER EXTREMITY

The thoracoacromial trunk is normal and so are its branches. The lateral thoracic artery is normal. The subscapular artery and its branches, the circumflex scapular artery and the thoracodorsal artery, are normal. The anterior and posterior circumflex humeral arteries are normal. The axillary artery continues normally as the brachial artery. The deep brachial artery is normal and comes off the brachial artery. The ulnar and radial arteries are normal and bifurcate in the cubital fossa. The common interosseous artery comes off the ulnar artery normally. The anterior interosseous artery is normal but cannot see the posterior interosseous artery. The superficial palmar arch is good. Cannot find the radial recurrent artery or the ulnar collateral arteries.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division is a long branch that everything comes off from. The obturator artery is normal, branches off at the same time as several superior vesicle arteries. Terminates with a trifurcation into the middle rectal artery, inferior gluteal artery, and internal pudendal artery, all of which are normal.

Posterior division gives off the lateral sacral artery normally. The superior gluteal artery is normal.

Cannot find the iliolumbar artery.

The external iliac is normal. The inferior epigastric is normal. Cannot find the deep circumflex iliac.

LEFT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division is like one long trunk that everything branches from. The umbilical and obturator arteries are normal. The internal pudendal artery is normal. The inferior gluteal artery is normal, gives off a branch to the sacrum.

Posterior division gives off the superior gluteal artery normally.

The iliolumbar artery and the lateral sacral artery come from a common stem off the internal iliac before it bifurcates.

The external iliac is normal. The inferior epigastric artery if normal. Cannot find the deep circumflex iliac artery.

RIGHT LOWER EXTREMITY

The femoral artery is normal. **The medial circumflex femoral artery comes off the femoral artery, superior to the branch point of the lateral femoral artery.** The deep femoral artery is normal and comes off the femoral artery posteriorly. The lateral circumflex femoral artery is normal and comes off the deep femoral artery. The femoral artery continues normally through the adductor hiatus. The anterior and posterior tibial arteries are normal. Dorsalis pedis is normal. Cannot see the fibular artery.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery postero-laterally. The lateral circumflex femoral artery is normal and comes off the deep femoral artery. The medial circumflex femoral artery comes off the deep femoral at the same level as the lateral circumflex femoral artery but is cut. The femoral artery continues through the adductor hiatus normally. The anterior and posterior tibial arteries are normal. Cannot see dorsalis pedis or the fibular artery.

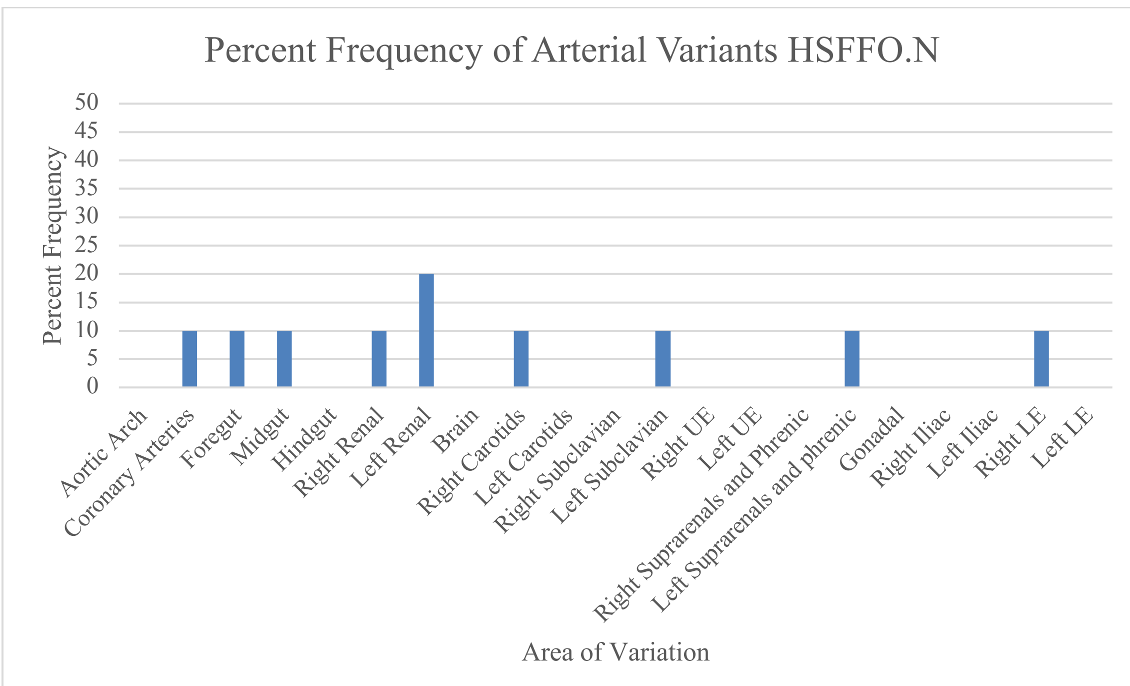

Figure 66: Percent frequency of arterial variants observed in body donor, HSFFO.N.

HSFFO.N

Key
LngA = lingual artery
FacA = facial artery
Left Dom. Heart = left dominant heart
TCTr = thyrocervical trunk
ITA = internal thoracic artery
CTr = celiac trunk
L_IPHA = left inferior phrenic artery
RA = renal artery
AccRA = accessory renal artery
MCA = middle colic artery
RCA = right colic artery
FA = femoral artery

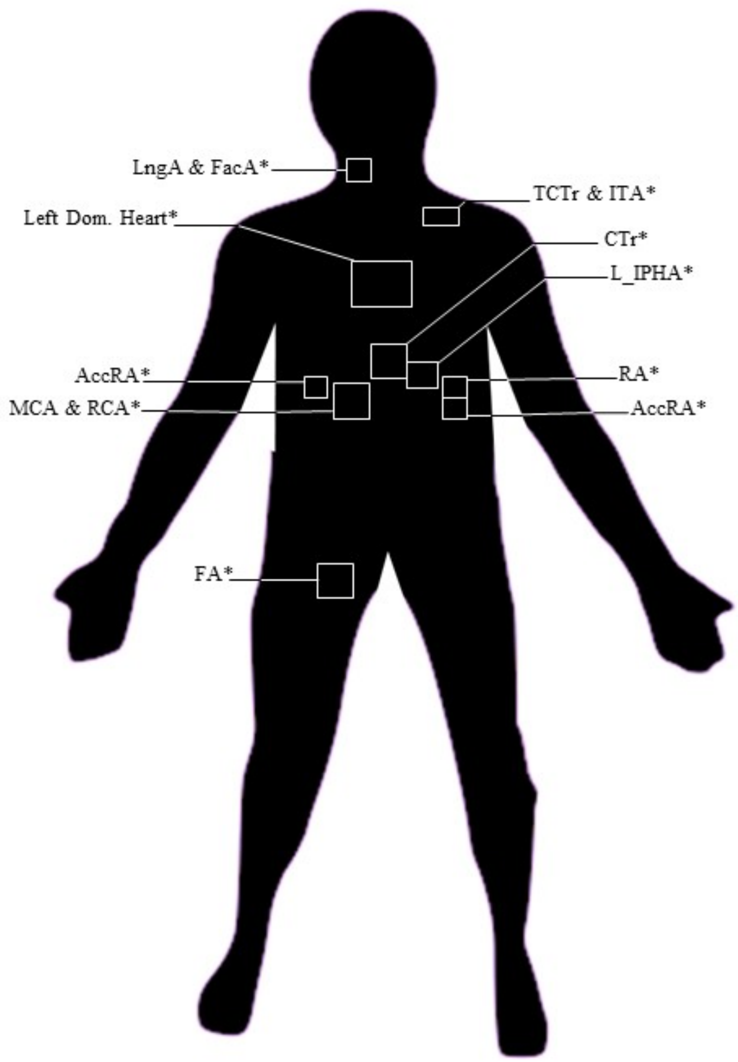

Figure 67: A schematic of the location and number of arterial variants found in body donor, HSFFO.N.

UJOLIBN

Sex: F

Age: 78

COD: Respiratory arrest/progressive squamous cell carcinoma left lung/peripheral neuropathy (chemo related)/COPD/breast cancer stage II/lumpectomy/chemo radiation

Summary of variants present (Figures 68-69)

- There is a **common stem for the middle colic and right colic arteries** off the **SMA**
- The **left colic artery gives off the sigmoid arteries**
- Have **2 left renal arteries** off the abdominal aorta
- In the **right upper extremity**, there is an anomalous origin of the **lateral thoracic artery** off the **subscapular artery**
- In the **right upper extremity**, there are **2 circumflex scapular** arteries
- In the **left upper extremity**, there is a common stem for the anterior and posterior circumflex humeral arteries
- In the **left internal iliac**, there is an anomalous origin of the **inferior gluteal artery** off the **superior gluteal artery**
- In the **left internal iliac**, the orientation of the anterior and posterior divisions is reversed so that the posterior division is more anterior

Detailed Overview:

ARCH OF THE AORTA

The brachiocephalic trunk is normal and bifurcates into the left common carotid and the left subclavian normally. The left subclavian is normal. The left common carotid is normal.

HEART

The left coronary artery is normal. The left anterior descending is normal. The left marginal artery is normal. The left circumflex is normal. The right coronary artery is normal. The right marginal artery is normal. The right coronary artery gives off the posterior interventricular artery normally.

FOREGUT

The celiac trunk is normal and gives off the splenic, left gastric, and common hepatic arteries normally. The splenic artery is normal and gives off the left gastro-omental artery normally. The left gastric artery is normal. The common hepatic artery is normal and gives off the gastroduodenal artery normally. The gastroduodenal artery is normal and gives off the superior pancreaticoduodenal and the right gastro-omental arteries normally. Cannot find the supraduodenal artery. The proper hepatic artery is normal. The proper hepatic artery bifurcates into the right hepatic artery and the left hepatic artery normally. There is no cystic artery because the gallbladder was removed. Cannot find the right gastric artery.

MIDGUT

The SMA is normal. The inferior pancreaticoduodenal artery is normal. The ileal and jejunal branches are normal. The right colic and ileocolic arteries are normal. **There is a common stem for the middle and right colic arteries.**

HINDGUT

The IMA is normal. The left colic is normal and bifurcates into the ascending and descending branches normally. **The sigmoid arteries come off the left colic artery**. The superior rectal artery is cut.

RIGHT RENAL

Have one renal artery coming off the abdominal aorta, bifurcates as it reaches the kidney. The inferior suprarenal artery came off the renal artery normally. The inferior phrenic artery comes off the abdominal aorta normally but is cut before it reaches the diaphragm. Cannot find the middle suprarenal, superior suprarenal, or ovarian arteries.

LEFT RENAL

Have two renal arteries coming off the abdominal aorta, both bifurcate as they reach the kidney. The renal arteries are oriented superior and inferior to one another. The inferior suprarenal artery comes off the superior renal artery and is normal. The inferior phrenic artery comes off the abdominal aorta normally and gives off superior suprarenal arteries normally. Cannot find the middle suprarenal or ovarian arteries.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal. The middle cerebral artery on the left side got torn out when the brain was removed. The anterior and posterior communicating arteries are normal. The basilar artery is normal. The superior cerebellar arteries are normal.

RIGHT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid, lingual, and facial arteries are normal. The external carotid gives off the ascending pharyngeal artery normally, but it gets cut before it reaches its target. Cannot find branches of the facial artery on the face. The ophthalmic artery off the internal carotid is normal.

LEFT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid, lingual, and facial arteries are normal. The external carotid gives off the ascending pharyngeal artery and the occipital artery normally, but they are cut before reaching their targets. The facial artery is normal and gives off the submental and angular branches normally, the other branches were cut. The maxillary artery is normal.

RIGHT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal, but all its branches except for the inferior thyroid artery got cut. The inferior thyroid artery is normal. The costocervical trunk is normal. The dorsal scapular artery is normal and comes off the subclavian.

LEFT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal, but most of the branches got cut. The inferior thyroid artery and the suprascapular artery are normal. Cannot find the costocervical trunk. The dorsal scapular artery is normal and comes off the subclavian.

RIGHT UPPER EXTREMITY

The thoracoacromial trunk and its branches are normal. Cannot find the lateral thoracic artery. the subscapular artery and its branches, the circumflex scapular and thoracodorsal arteries, are normal. The posterior circumflex humeral artery is normal. The anterior circumflex humeral artery is cut but can see the lumen for it on the axillary artery. The axillary artery continues normally as the brachial artery. The deep brachial artery branches off the brachial artery normally. The ulnar and radial arteries are normal and bifurcate in the cubital fossa. The common interosseous artery comes off the ulnar artery normally. The anterior interosseous artery is normal but cannot see the posterior interosseous artery. Can see the part of the superficial palmar arch that comes off the radial artery, but not the part that comes off the ulnar artery. Cannot find the radial recurrent artery or the ulnar collateral arteries.

LEFT UPPER EXTREMITY

The thoracoacromial trunk and its branches are normal. The lateral thoracic artery is normal, but it is cut close to the body. The subscapular artery and its branches, the circumflex scapular and thoracodorsal arteries, are normal. **The anterior and posterior circumflex humeral arteries come from a common trunk.** The axillary artery continues normally as the brachial artery. the deep brachial comes off the brachial artery normally. The ulnar and radial arteries are normal and bifurcate in the cubital fossa. The common interosseous artery comes off the ulnar artery normal. The anterior interosseous artery is normal but cannot see the posterior interosseous artery. Cannot find the superficial palmar arch, ulnar collateral arteries, or the radial recurrent artery.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division is a long branch that everything comes off from. The umbilical artery is normal and gives off superior vesicle arteries normally. Cannot find the obturator artery. The uterine branch is normal. Terminates with a bifurcation into the internal pudendal artery and the inferior gluteal artery, both of which are normal. There is also a branch that goes towards the pubic symphysis.

Posterior division gives off two lateral sacral arteries normally. The superior gluteal artery is normal.

The iliolumbar artery is an independent branch that comes off the common iliac.

The external iliac is normal. The inferior epigastric is normal, bifurcates and the other branch goes down the obturator canal. The deep circumflex iliac artery is normal.

LEFT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally. The orientation of the anterior and posterior divisions is flipped so that the posterior trunk is more anteriorly oriented.

Anterior division is like one long trunk that everything branches from. The umbilical artery is normal and gives off superior vesicle arteries normally. The uterine artery is normal. The uterine artery gives off the vaginal artery. The internal pudendal artery is normal and gives off an inferior vesicle branch. The lateral sacral artery comes off the anterior division.

Posterior division gives off branches that travel towards the anterior pelvic wall. **The inferior gluteal artery comes off the superior gluteal artery.** The superior gluteal artery is otherwise normal.

Cannot find the iliolumbar artery.

The external iliac is normal. The inferior epigastric artery if normal, bifurcates and the other branch goes through the obturator canal. Cannot find the deep circumflex iliac artery.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery postero-laterally. The lateral circumflex femoral artery is normal and comes off the deep femoral. The medial circumflex femoral artery is normal and comes off the deep femoral artery at the same level as the branch point for the lateral circumflex femoral artery. The femoral artery continues normally through the adductor hiatus. The anterior tibial artery is normal and continues as dorsalis pedis normally. The posterior tibial artery is cut at the ankle but is otherwise normal. Cannot see the fibular artery.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery postero-laterally. The lateral circumflex femoral artery is normal and comes off the deep femoral artery. The medial circumflex femoral artery comes off the deep femoral artery superior to the branch point of the lateral circumflex femoral artery. The femoral artery continues normally through the adductor hiatus. The anterior tibial artery is normal and continues normally as the dorsalis pedis artery. The posterior tibial artery is normal. Cannot see the fibular artery.

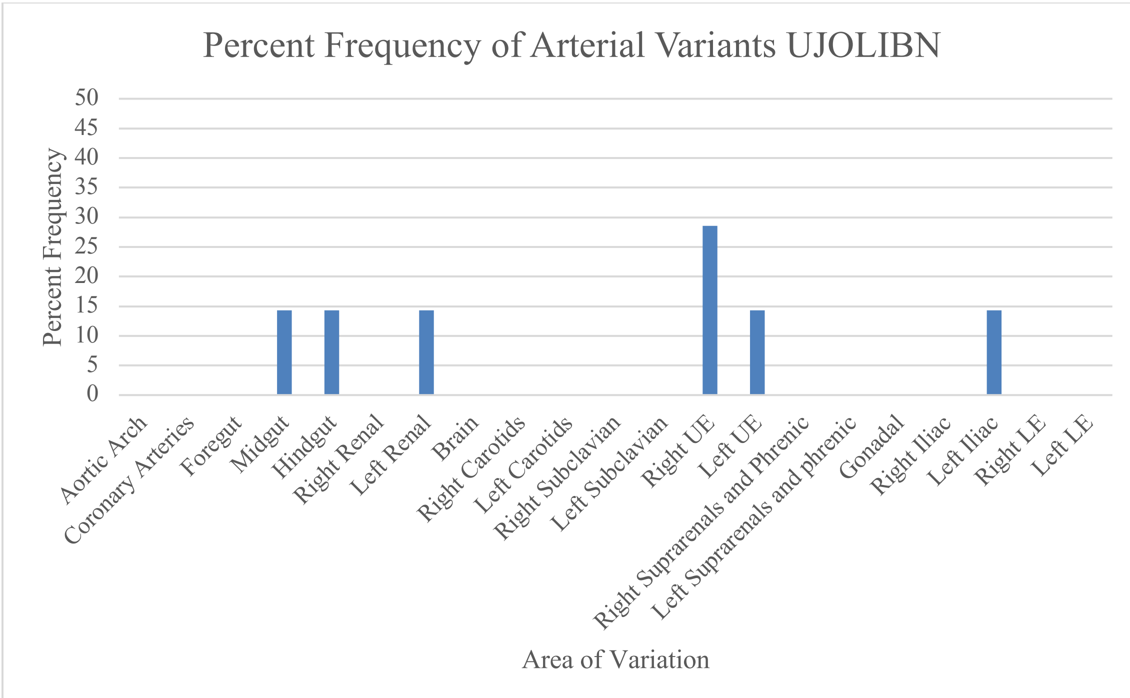

Figure 68: Percent frequency of arterial variants observed in body donor, UJOLIBN.

UJOLIBN

Key
SubA = subscapular artery
CirSA = circumflex scapular artery
ACHA = anterior circumflex humeral artery
PCHA = posterior circumflex humeral artery
RA = renal artery
RCA = right colic artery
MCA = middle colic artery
LCA = left colic artery
SGA = superior gluteal artery

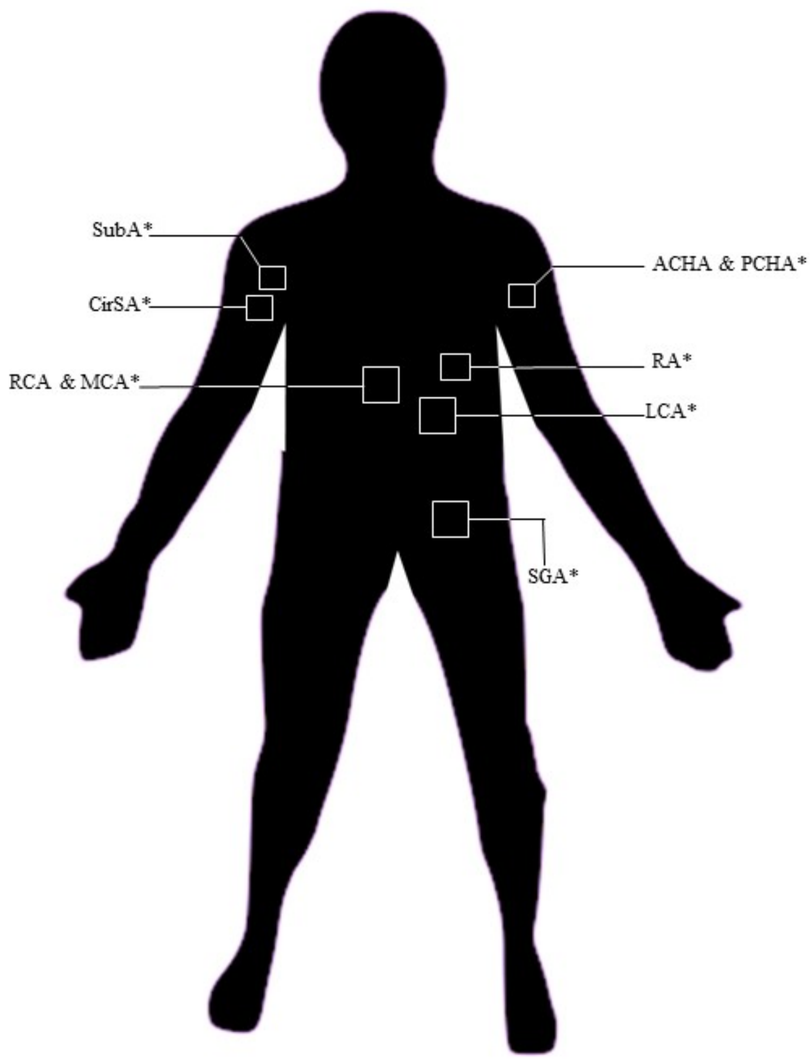

Figure 69: A schematic of the location and number of arterial variants found in body donor, UJOLIBN.

TVMMJMBO

Sex: F

Age: 91

COD: Respiratory failure/heart failure/end stage Alzheimer's

Summary of variants seen (Figures 70-71)

- There are **4 branches off the aorta**. The **left vertebral** branches off the aortic arch between the left common carotid and the left subclavian
- The **celiac trunk only has 2 branches**, the left gastric and the common hepatic (Figure 72)
- **The common hepatic artery gives off the splenic artery** (Figure 72)
- **Left gastric gives off an accessory left hepatic artery**
- The **proper hepatic artery** terminates by branching into an **artery that supplies the pancreas and gives off the cystic artery, the right and left hepatic arteries, and an accessory hepatic artery** (Figure 72)
- There is **a common stem for the middle and right colic arteries** off the **SMA**.
- The middle colic supplies the ascending and transverse colon and has branches that anastomose with the left colic artery of the IMA, **Arc of Riolan**
- On the **left subclavian**, there is a <u>common stem for the thyrocervical trunk and internal thoracic artery</u>

- In the **right upper extremity**, there is an anomalous origin of the **lateral thoracic artery** off the **subscapular artery**
- In the **right upper extremity**, there was an extra branch off the axillary artery across from the circumflex humerals, but it was cut so do not know what it was
- There are **2 right middle suprarenal arteries** coming off the abdominal aorta
- In the **right internal iliac**, the orientation of the anterior and posterior trunks is reversed so that the posterior trunk is more anterior. The superior gluteal artery exits the pelvis more anteriorly and gives off branches to the anterior pelvic wall
- In the **right internal iliac**, there are **3 internal pudendal arteries**. One comes off the anterior division, one comes from the bifurcation of the internal pudendal and inferior gluteal arteries, and the other bifurcates off the second internal pudenda artery
- In the **right lower extremity**, there is a common stem for the lateral circumflex femoral artery and some of its descending branches
- In the **right lower extremity**, there is an anomalous origin of the **medial circumflex femoral artery** off the **femoral artery**

Detailed Overview:

ARCH OF THE AORTA

Have 4 branches off the aortic arch. The brachiocephalic trunk is normal and bifurcates into the left common carotid and the left subclavian normally. The left subclavian is normal. The left common carotid is normal. **The left vertebral artery comes off the aortic arch between the left common carotid and left subclavian arteries**.

HEART

The left coronary artery is normal. The left anterior descending is normal and gives off the diagonal branch normally. The left marginal artery is normal. The left circumflex is normal. The right coronary artery is normal. The right marginal artery is normal. The right coronary artery gives off the posterior interventricular artery normally.

FOREGUT

The celiac trunk only has two branches; the left gastric artery and the common hepatic artery (Figure 72). **The left gastric artery gives off an accessory left hepatic artery. The splenic artery comes off the common hepatic artery** (Figure 72). The splenic artery gives off the left gastro-omental artery and the greater pancreatic artery normally. The common hepatic artery continues and gives off the gastroduodenal artery normally. The gastroduodenal artery is normal and gives off the supraduodenal, superior pancreaticoduodenal, and the right gastro-omental arteries normally. The proper hepatic artery is normal and gives off the right gastric artery normally. **The proper hepatic artery terminates by branching into a pancreatic artery, a common stem for**

the right and left hepatic arteries, and an accessory hepatic artery (Figure 72). The pancreatic artery gives off the cystic artery, a branch to the gallbladder and then continues to the pancreas. The right and left hepatic arteries bifurcate from the common stem normally, making a total of three branches going to the liver near the portal triad.

MIDGUT

The SMA is normal. Cannot find the inferior pancreaticoduodenal artery. The ileal and jejunal branches are normal. The middle colic and ileocolic arteries are normal. **There is a common stem for the right and middle colic arteries. The middle colic artery also has an anastomosis with the left colic artery of the IMA.**

HINDGUT

The IMA is normal. The left colic artery is cut from IMA but can still see it giving off into the ascending and descending branches normally. The left colic artery has an anastomosis with branches of the middle colic artery. The sigmoid arteries are normal. The superior rectal artery is normal.

RIGHT RENAL

Have one renal artery coming off the abdominal aorta normally, bifurcates as it reaches the kidney. The inferior suprarenal artery comes off the renal artery normally. **There are two middle suprarenal arteries off the abdominal aorta.** The inferior phrenic artery comes off the abdominal aorta normally and gives off superior suprarenal arteries normally. Cannot find the ovarian artery.

LEFT RENAL

Have one renal artery coming off the abdominal aorta, bifurcates as it reaches the kidney. The middle suprarenal artery comes off the abdominal aorta normally. Cannot find the inferior phrenic artery, superior suprarenal, inferior suprarenal, or ovarian arteries.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal. The anterior communicating artery is normal, but the posterior communicating arteries got torn as the brain was removed. The brainstem and cerebellum detached from the brain when it was removed. The basilar artery is normal. The superior cerebellar arteries are normal.

RIGHT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid, lingual, and facial arteries are normal. The facial artery is normal and gives off the superior and inferior labial arteries normally, before it gets cut. The maxillary artery is normal.

LEFT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches.

The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The external carotid gives off the ascending pharyngeal artery normally, but it is cut before reaching its targets. The facial artery is normal and gives off the submental and superior and inferior labial branches normally.

RIGHT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal, but most of the branches got cut. The inferior thyroid artery and the suprascapular artery are normal. Cannot find the costocervical trunk or the dorsal scapular artery.

LEFT SUBCLAVIAN

The vertebral artery comes off the aortic arch, but otherwise normal. **The thyrocervical trunk and the internal thoracic artery come from a common stem.** The inferior thyroid artery, ascending cervical artery, and suprascapular artery are normal, the other branches of the thyrocervical trunk are cut. The costocervical trunk is normal. Cannot find the dorsal scapular artery.

RIGHT UPPER EXTREMITY

The thoracoacromial trunk and its branches are normal. **The lateral thoracic is coming off the subscapular artery but is cut before reaching its termination point on the body**. The thoracodorsal and circumflex scapular arteries are normal. The anterior and posterior circumflex humeral arteries are normal. **There is an extra branch coming off the axillary artery close to the circumflex humeral arteries, but it is cut so do not know what it was or where it went**. The axillary artery continues normally as the deep brachial artery. The deep brachial artery comes off the brachial artery normally. The superior ulnar collateral artery is normal. The radial and ulnar arteries are normal and bifurcate in the cubital fossa. The common interosseous artery comes off the ulnar artery normally. The anterior and posterior interosseous arteries are normal. The superficial palmar arch is good. Cannot see the radial recurrent artery.

LEFT UPPER EXTREMITY

The thoracoacromial trunk and its branches are normal. The lateral thoracic artery is normal. The anterior and posterior circumflex humeral arteries are normal. The subscapular artery is normal. The thoracodorsal artery is cut but may have a lumen for it on the subscapular artery. the circumflex scapular artery is normal. The axillary artery continues normally as the brachial artery. The deep brachial artery comes off the brachial artery normally. The radial and ulnar arteries are normal and bifurcate in the cubital fossa. The common interosseous artery is normal and comes off the ulnar artery. The anterior interosseous artery is normal but cannot see the posterior interosseous artery. The superficial palmar arch is normal. Cannot see the ulnar collateral arteries or the radial recurrent artery.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally. The orientation of the anterior and posterior divisions is flipped so that the posterior trunk is more anteriorly oriented.

Anterior division is very short, and everything branches off quickly after its origination point off the internal iliac artery. The umbilical artery is normal and gives off superior vesicle arteries normally. Cannot find the obturator artery. Terminates with a bifurcation into the internal pudendal artery and the inferior gluteal artery. The internal pudendal artery bifurcates again and gives off another internal pudendal artery. There is also another independent branch off the anterior division that is the internal pudendal artery, **making a total of three internal pudendal arteries**.

Posterior division is oriented more anteriorly that normal. Gives off branches that go towards the pubic symphysis. The superior gluteal artery is normal but exits more anteriorly than normal.

The iliolumbar artery is an independent branch that comes off the internal iliac before it bifurcates. Gives off the lateral sacral artery.

The external iliac is normal. The inferior epigastric is normal, bifurcates and the other branch goes down the obturator canal. The deep circumflex iliac artery is normal.

LEFT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division is like one long trunk that everything branches from. The umbilical artery is normal and gives off superior vesicle arteries normally. The uterine artery is normal, which is interesting because the uterus was removed, but there is still an ovary. The middle rectal artery is normal. Cannot find the obturator artery. The internal pudendal artery and the inferior gluteal artery bifurcate off a common stem, both are normal. The internal pudendal artery gives off another middle rectal artery.

Posterior division gives off the iliolumbar artery and the lateral sacral artery normally. The superior gluteal artery is normal.

The external iliac is normal. The inferior epigastric artery is normal. The deep circumflex iliac artery is normal.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery postero-laterally. The lateral circumflex femoral artery is normal and comes off the deep femoral. **There is a common trunk for the lateral circumflex femoral artery and a descending branch of it**. **The medial circumflex femoral artery comes off the femoral artery**, superior to the branch point of the lateral circumflex femoral artery. The femoral artery continues normally through the adductor hiatus. The anterior tibial artery is normal and continues normally to the dorsalis pedis. The posterior tibial artery is normal. Cannot see the fibular artery.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery postero-laterally. The lateral circumflex femoral artery is normal and comes off the deep femoral. Cannot find the medial circumflex femoral artery. The femoral artery continues through the adductor hiatus normally. The anterior tibial artery is normal and continues to dorsalis pedis normally. The posterior tibial artery is normal. Cannot find the fibular artery.

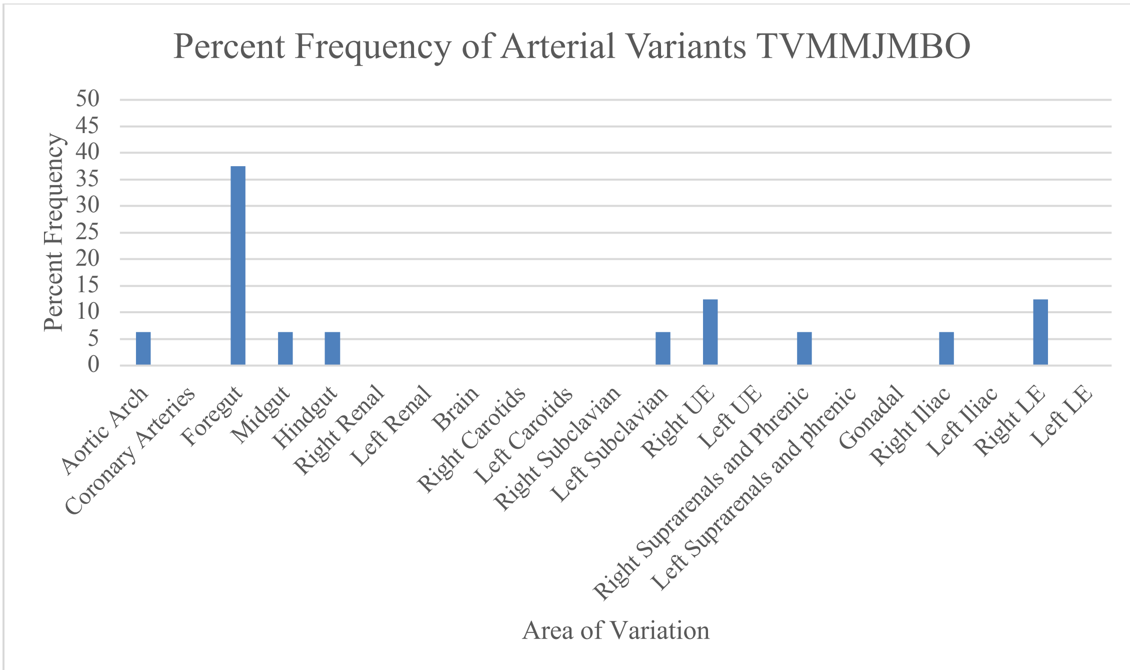

Figure 70: Percent frequency of arterial variants observed in body donor, TVMMJMBO.

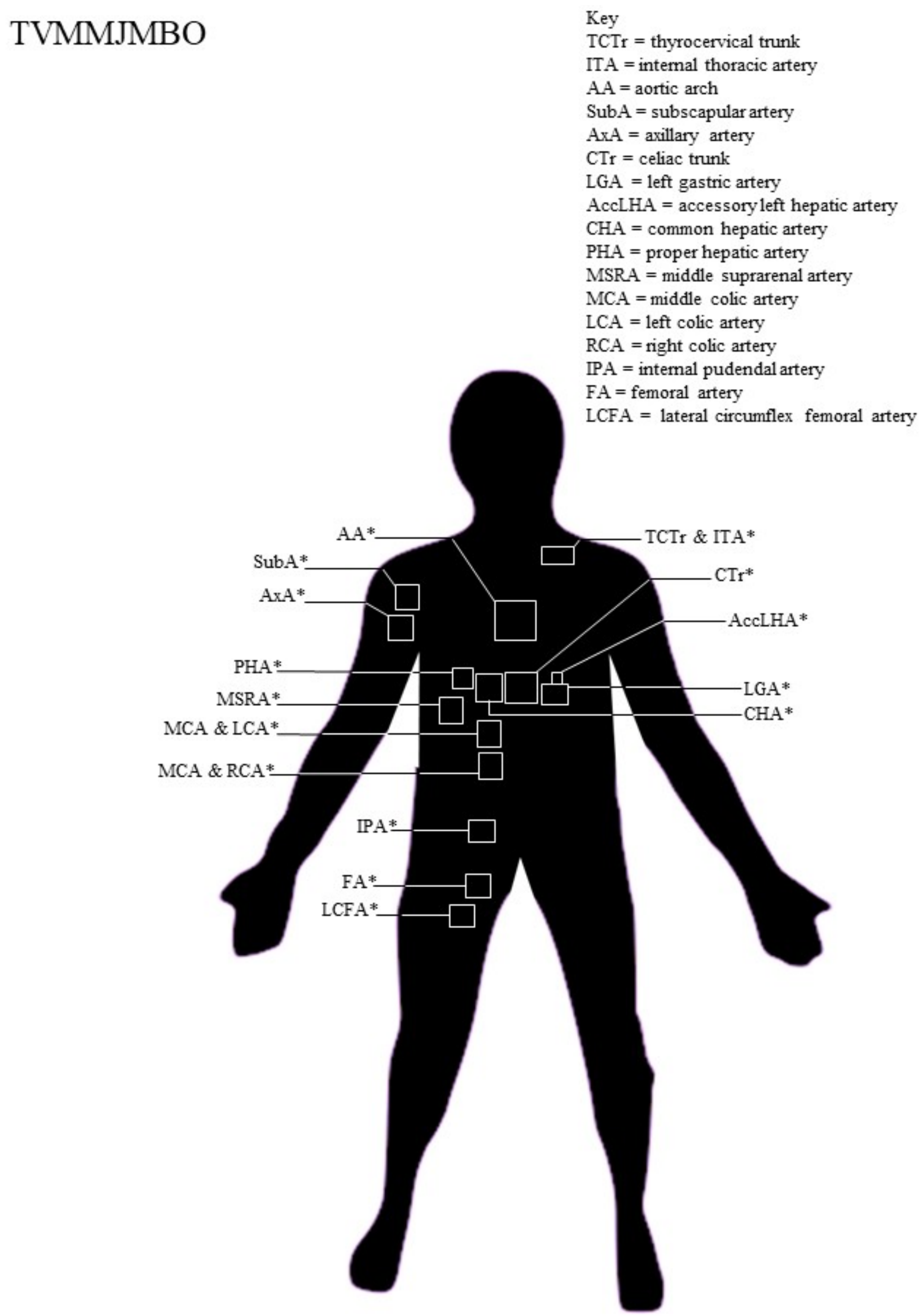

Figure 71: A schematic of the location and number of arterial variants found in body donor, TVMMJMBO.

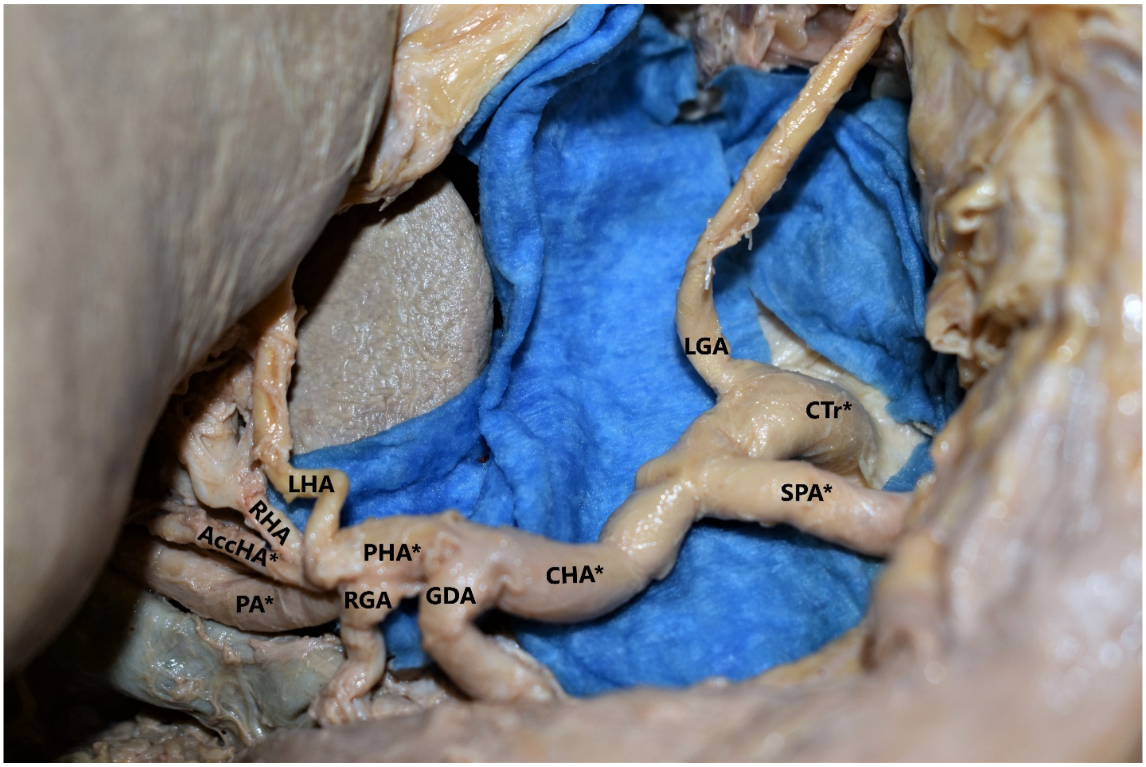

Figure 72: A variant of the celiac trunk in which it only has two branches, the left gastric artery and the common hepatic artery in body donor, TVMMJMBO. The splenic artery has an anomalous origin off the common hepatic artery. Also pictured are the terminal branches of the proper hepatic artery including an anomalous pancreatic arterial branch that gives rise to the cystic artery, the left and right hepatic arteries, and an accessory hepatic artery.

CTr = celiac trunk, LGA = left gastric artery, SPA = splenic artery, CHA = common hepatic artery, GDA = gastroduodenal artery, PHA = proper hepatic artery, RGA = right gastric artery, LHA = left hepatic artery, RHA = right hepatic artery, AccHA = accessory hepatic artery, PA = pancreatic artery, * = variant.

TQFBLNBO

Sex: F

Age: 96

COD: Dementia

Summary of variants seen (Figures 73-74)

- **The common hepatic artery trifurcates into the gastroduodenal, cystic, and proper hepatic arteries**
- The **proper hepatic** curls around the cystic to reach the liver
- There is **a common stem for the middle colic artery and the right colic artery** off the **SMA**
- In the **right carotid artery**, there is a <u>common stem for the lingual and facial</u> arteries
- The right internal carotid makes a big curve after bifurcation from common carotid before ascending the neck normally
- The left internal carotid makes that same curve
- In the **left subclavian**, there is an anomalous origin of the **suprascapular artery** off the **internal thoracic artery**
- In the **right upper extremity**, there are **2 circumflex scapular arteries**
- In the **right upper extremity**, the posterior circumflex humeral artery and the subscapular artery branch at the same level off the axillary artery

- In the **right internal iliac**, there are **2 internal pudendal arteries**. One comes from a bifurcation off the inferior gluteal artery. The other is the terminal branch of the anterior division
- In the left internal iliac, the superior gluteal artery is oriented more anteriorly, and must double back on itself to exit normally
- In the **right lower extremity**, there is a <u>common stem for the medial circumflex femoral artery and the deep femoral artery</u> off the femoral artery
- In the **right lower extremity**, there is a <u>common stem for the lateral circumflex femoral artery and its descending branches</u> off the deep femoral artery
- In the **left lower extremity**, there is a <u>common stem for the medial circumflex femoral artery and muscular branches</u> off the deep femoral artery

Detailed Overview:

ARCH OF THE AORTA

The brachiocephalic trunk is normal and bifurcates into the left common carotid and the left subclavian normally. The left subclavian is normal. The left common carotid is normal.

HEART

The left coronary artery is normal. The left anterior descending is normal and gives off the diagonal branch normally. The left marginal artery is normal. The left circumflex is normal. The right coronary artery is normal. The right marginal artery is normal. The right coronary artery gives off the posterior interventricular artery normally.

FOREGUT

The celiac trunk is normal and gives off the splenic, left gastric, and common hepatic arteries normally. The celiac trunk was adhered to the left tip of the liver. The splenic artery gives off the left gastro-omental artery normally. The left gastric artery is normal. **The common hepatic artery trifurcates into the gastroduodenal artery, the cystic artery, and the proper hepatic artery**. The gastroduodenal artery is normal and gives off the supraduodenal and the right gastro-omental arteries normally. Cannot find the superior pancreaticoduodenal artery but have a lumen for it. The proper hepatic artery curls around the cystic artery to reach the liver, where it bifurcates into the right and left hepatic arteries normally. The proper hepatic artery is normal and gives off the right gastric artery normally. The cystic artery goes to the gallbladder normally.

MIDGUT

The SMA is normal. The inferior pancreaticoduodenal artery is normal. The ileal and jejunal branches are normal. The right colic and ileocolic arteries are normal. **There is a common stem for the middle and right colic arteries off the SMA.**

HINDGUT

The IMA is normal. The left colic artery is normal and gives off the ascending and descending branches normally. The sigmoid arteries are normal. The superior rectal artery is normal.

RIGHT RENAL

Have one renal artery coming off the abdominal aorta normally, bifurcates as it reaches the kidney. The inferior suprarenal artery comes off the renal artery normally. Cannot find the inferior phrenic artery, the middle suprarenal artery, or the ovarian artery.

LEFT RENAL

Have one renal artery coming off the abdominal aorta, bifurcates as it reaches the kidney. The inferior suprarenal artery comes off the renal artery normally. The inferior phrenic artery comes off the abdominal aorta normally and gives off the superior suprarenal arteries normally. The middle suprarenal and ovarian arteries come off the abdominal aorta normally but are cut before they can reach their targets.

BRAIN

The Circle of Willis is normal. The anterior and middle cerebral arteries are normal. The brainstem and cerebellum got torn from the brain when it was removed, damaging the posterior cerebral arteries. The posterior communicating arteries are torn, but normal. The anterior communicating artery is normal. The basilar artery is normal. The superior cerebellar arteries are normal.

RIGHT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery makes a big curve after it comes off the common carotid before ascending more. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal and gives off the superior laryngeal artery normally. **The lingual and facial arteries come off a common**

trunk. The external carotid gives off the occipital artery normally, but it is cut before reaching its target. The facial artery is normal and gives off the superior and inferior labial arteries and the angular artery normally. The ophthalmic artery from the internal carotid artery is normal.

LEFT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery makes the same large curve after it originates from the common carotid artery. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The lingual and facial arteries are normal. The external carotid gives off the occipital artery normally, but it is cut before reaching its target. The facial artery is normal and gives off the submental, superior and inferior labial arteries, and the angular artery normally.

RIGHT SUBCLAVIAN

The right subclavian artery got cut up and the branches are cut off it. Can still see the lumens for the branches. The internal thoracic artery is cut from the subclavian but can still be seen on the rib cage where it is normal. The dorsal scapular artery is normal and comes off the subclavian artery normally.

LEFT SUBCLAVIAN

The vertebral artery is normal. The thyrocervical trunk and the internal thoracic artery branch very close to one another. The branches of the thyrocervical trunk are cut.

The suprascapular artery comes off the internal thoracic artery. Cannot find the costocervical trunk. The dorsal scapular artery is normal and comes off the subclavian normally.

RIGHT UPPER EXTREMITY

The thoracoacromial trunk and its branches are normal. The lateral thoracic artery is cut. The subscapular artery and its branches, the circumflex scapular artery and the thoracodorsal artery, are normal. **There is an extra circumflex scapular artery.** The posterior circumflex humeral artery is normal, but branches at the same level as the subscapular artery. Cannot find the anterior circumflex humeral artery. The axillary artery continues normally as the deep brachial artery. The deep brachial artery comes off the brachial artery normally. The superior ulnar collateral artery is normal. The radial and ulnar arteries are normal and bifurcate in the cubital fossa. The common interosseous artery comes off the ulnar artery normally. The radial recurrent artery is normal. The anterior and posterior interosseous arteries are normal. The superficial palmar arch is good.

LEFT UPPER EXTREMITY

The thoracoacromial trunk and its branches are normal. The lateral thoracic artery is normal. The subscapular artery and its branches, the thoracodorsal and circumflex scapular arteries, are normal. The anterior and posterior circumflex humeral arteries are normal. The axillary artery continues normally as the brachial artery. The deep brachial artery comes off the brachial artery normally. The radial and ulnar arteries are normal and bifurcate in the cubital fossa. The superior ulnar collateral artery is cut. The radial recurrent artery is normal. The common interosseous artery is normal and comes off the ulnar artery. The anterior and posterior interosseous arteries are normal. The superficial palmar arch is normal.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division ends with a bifurcation. The first branch is the umbilical artery which gives off superior vesicle arteries. The second branch is one long trunk that gives off the obturator artery, the vaginal artery, and ends with the internal pudendal artery.

Posterior division is gives off its branches and terminates with the lateral sacral artery. The iliolumbar artery is normal, branches at the same level as a common stem for the inferior gluteal and internal pudendal arteries. The inferior gluteal artery and the internal pudendal artery come off a common stem, which means that **there are two internal pudendal arteries**. The superior gluteal artery is normal.

The external iliac is normal. The inferior epigastric is normal. The deep circumflex iliac artery is normal.

LEFT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division is like one long trunk that everything branches from. The umbilical artery is normal and gives off superior vesicle arteries normally. The uterine artery is normal. The internal pudendal artery is normal. Cannot find the inferior gluteal artery.

Posterior division is oriented more anteriorly than normal. The superior gluteal artery gives off the obturator artery and two branches to the anterior body wall. The superior gluteal artery must double back on itself to exit the pelvis normally.

Cannot find the iliolumbar artery.

The external iliac is normal. The inferior epigastric artery is normal. The deep circumflex iliac artery is normal.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery posteriorly. The lateral circumflex femoral artery is normal and comes off the deep femoral. **There is a common trunk for the lateral circumflex femoral artery and one of its descending branches.** The medial circumflex femoral artery comes off the deep femoral artery at the same level that the deep femoral artery comes off the femoral artery, superior to the branch point of the lateral circumflex femoral artery. The femoral artery continues normally through the adductor hiatus. The anterior tibial artery is normal and continues normally to the dorsalis pedis. The posterior tibial artery is normal. Cannot see the fibular artery.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery postero-laterally. The lateral circumflex femoral artery is normal and comes off the deep femoral. The medial circumflex femoral artery comes off the deep femoral artery normally, just superior to the branch point of the lateral circumflex femoral artery. **The medial circumflex femoral artery comes off a common stem with muscular branches**. The femoral artery continues through the adductor hiatus normally. The anterior tibial artery is normal and continues to dorsalis pedis normally. The posterior tibial artery is normal. Cannot find the fibular artery.

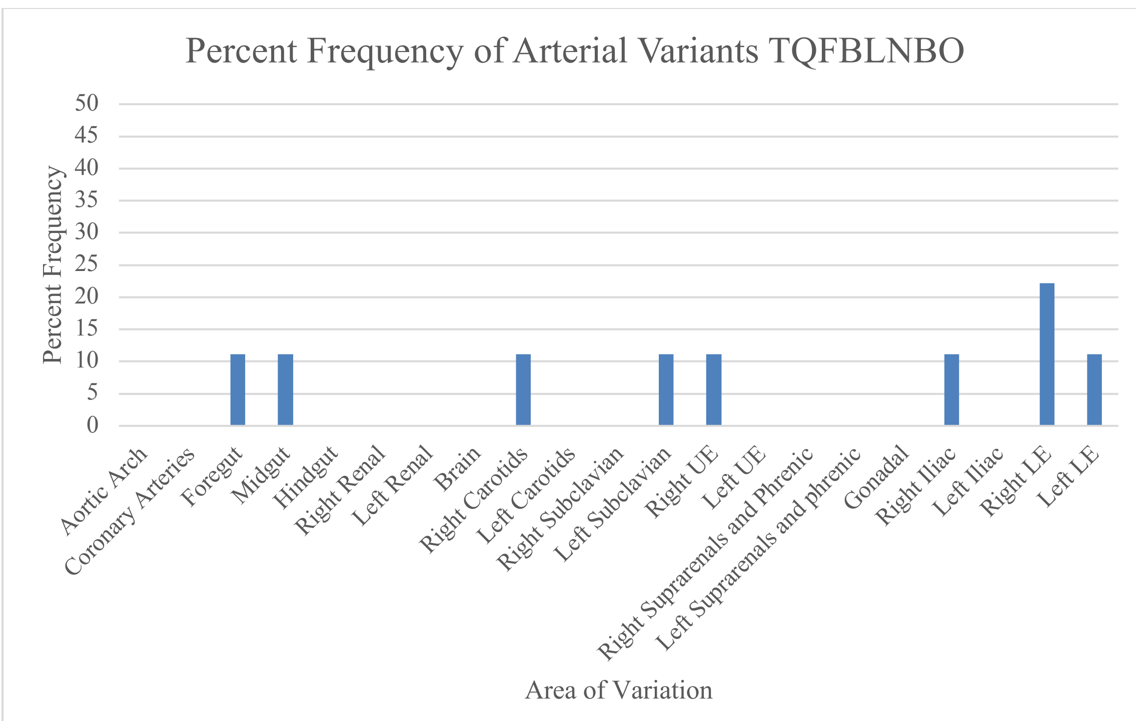

Figure 73: Percent frequency of arterial variants observed in body donor, TQFBLNBO.

TQFBLNBO

Key
LngA = lingual artery
FacA = facial artery
ITA = internal thoracic artery
CirSA = circumflex scapular artery
CHA = common hepatic artery
MCA = middle colic artery
RCA = right colic artery
IPA = internal pudendal artery
DFA = deep femoral artery
LCFA = lateral circumflex femoral artery
MCFA = medial circumflex femoral artery

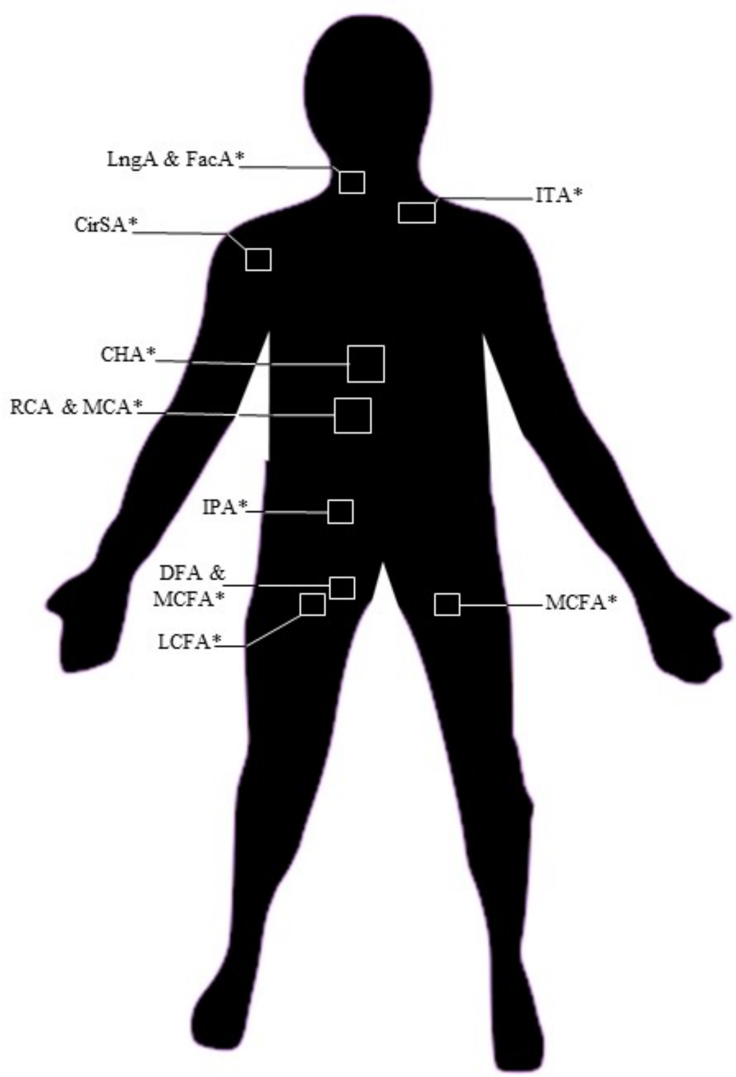

Figure 74: A schematic of the location and number of arterial variants found in body donor, TQFBLNBO.

CFSOJOHFS

Sex: M

Age: 71

COD: End stage pulmonary disease/cor pulmonale

Summary of variant seen (Figures 75-76)

- The **aortic arch has 4 branches**, the **left vertebral** artery is the 4th branch and it comes off in between the left common carotid and the left subclavian (Figure 77)
- The **left coronary artery** has a <u>trifurcation of its 3 main branches</u> instead of the circumflex coming off the marginal (Figure 78)
- **The celiac trunk gives off 5 branches,** 3 are the typical ones plus **(1.) two other branches that got cut**
- The **proper hepatic artery gives off the cystic artery**
- The **SMA gives off an accessory right hepatic artery** that travels to the posterior aspect of the liver, passing by the lateral gallbladder
- There is **no right colic artery** off the **SMA**, the middle colic and ileocolic both supply the ascending colon
- There is an anastomosis between the middle colic artery and the left colic, of the IMA, **Arc of Riolan**
- There is a **right accessory renal artery** off the abdominal aorta going to the inferior pole of the kidney

- On the **left subclavian**, there is a common stem for the thyrocervical trunk and internal thoracic artery
- In the **right upper extremity**, the radial artery travels laterally, kind of looping around the bicipital aponeurosis before continuing to descend the arm
- In the **left upper extremity**, there is a common stem for the anterior and posterior circumflex humeral arteries off the axillary artery
- In the **right lower extremity**, there is a common stem for the lateral circumflex femoral artery and its descending branches off the deep femoral artery
- In the **right lower extremity**, there is a common stem for the medial circumflex femoral artery and the deep femoral off the femoral artery

Detailed Overview:

ARCH OF THE AORTA

Have 4 branches off the aortic arch (Figure 77). The brachiocephalic trunk is normal and bifurcates into the left common carotid and the left subclavian normally. The left subclavian is normal. The left common carotid is normal. **The left vertebral artery comes off the aortic arch between the left common carotid and left subclavian arteries** (Figure 77).

HEART

The left coronary artery trifurcates into its three main branches (Figure 78). The left anterior descending artery is normal and gives off the diagonal branch normally. The left marginal artery is normal. The left circumflex is normal. The right coronary artery is normal. The right marginal artery is normal. The right coronary artery gives off the posterior interventricular artery normally.

FOREGUT

The celiac trunk gives off 5 branches, 3 are the typical ones plus (1.) two other branches that got cut. The splenic artery is normal. All the branches of the splenic artery were cut, so cannot find the left gastro-omental artery. The left gastric artery is normal. The common hepatic artery is normal and gives off the gastroduodenal artery normally. The gastroduodenal artery is normal and gives off the right gastro-omental artery normally. The supraduodenal artery and the superior pancreaticoduodenal artery were cut. The proper hepatic artery is normal and gives off the right and left hepatic arteries normally. **The cystic artery comes off the proper hepatic artery**. The right gastric artery got cut.

MIDGUT

The SMA is normal. **Gives off an accessory right hepatic artery that travels to the posterior aspect of the liver, passing by the lateral gallbladder. The inferior pancreaticoduodenal artery comes off the accessory hepatic artery**. The ileal and jejunal branches are normal. The middle colic and ileocolic arteries are normal. **There is no right colic artery, the middle colic and ileocolic arteries supply the ascending**

colon. The middle colic artery has an anastomosis with the left colic artery of the IMA (Arc of Riolan).

HINDGUT

The IMA is normal. The left colic artery is normal and gives off the ascending and descending branches normally. **The left colic artery has an anastomosis with branches of the middle colic artery (Arc of Riolan)**. The sigmoid arteries are normal. The superior rectal artery is normal.

RIGHT RENAL

Have one renal artery coming off the abdominal aorta normally, bifurcates as it reaches the kidney. **Have an accessory renal artery coming off the abdominal aorta, inferior to the renal artery, and going to the inferior pole of the kidney**. The inferior phrenic artery is normal on the diaphragm but is cut before it reaches its point of origin. The inferior phrenic artery gives off the superior suprarenal arteries normally. The middle suprarenal artery was cut but can see a lumen for it on the abdominal aorta. The testicular artery is normal but cut before it reaches the testes. Cannot find the inferior suprarenal artery.

LEFT RENAL

Have one renal artery coming off the abdominal aorta, bifurcates as it reaches the kidney. The inferior phrenic artery is normal on the diaphragm but cut before it reaches its point of origin. The inferior phrenic gives off the superior suprarenal arteries normally. The testicular artery is normal. Cannot find the inferior suprarenal artery or the middle suprarenal artery.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal. The anterior and posterior communicating arteries are normal. The basilar artery is normal. The superior cerebellar arteries are normal.

RIGHT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The lingual and facial arteries are normal. The external carotid artery gives off the ascending pharyngeal artery normally, but it is cut before reaching its target. The facial artery is normal and gives off the submental branch and the superior and inferior labial arteries normally, before it gets cut. The maxillary artery is normal. The sphenopalatine artery is normal. The ophthalmic branch of the internal carotid artery is normal.

LEFT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The lingual and facial arteries are normal. The external carotid gives off the ascending pharyngeal artery and the occipital artery normally, but they are cut before reaching their targets. The facial artery is normal and gives off the submental branch, superior and inferior labial branches, and the angular branch normally.

RIGHT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal. The inferior thyroid artery and the suprascapular artery are normal, but the transverse cervical artery got cut. Cannot find the costocervical trunk or the dorsal scapular artery.

LEFT SUBCLAVIAN

The vertebral artery comes off the aortic arch, but otherwise normal. **The thyrocervical trunk and the internal thoracic artery come from a common stem.** The inferior thyroid artery, ascending cervical artery, and the suprascapular artery are normal, the transverse cervical artery is cut. Cannot find the costocervical trunk. The dorsal scapular artery is normal and comes off the subclavian normally.

RIGHT UPPER EXTREMITY

The thoracoacromial trunk and its branches are normal. The lateral thoracic artery is normal. The subscapular artery and its branches, the thoracodorsal and circumflex scapular arteries, are normal. The anterior and posterior circumflex humeral arteries are normal. The axillary artery continues normally as the deep brachial artery. The deep brachial artery comes off the brachial artery normally. The radial and ulnar arteries are normal and bifurcate in the cubital fossa. The radial artery travels laterally, kind of looping around the bicipital aponeurosis before continuing to descend the arm. The ulnar artery continues normally to the wrist. The common interosseous artery comes off the ulnar artery normally. The anterior and posterior interosseous arteries are normal. Cannot see the ulnar collateral arteries, the radial recurrent artery, or the superficial palmar arch.

LEFT UPPER EXTREMITY

The thoracoacromial trunk and its branches are normal. The lateral thoracic artery is cut. **The anterior and posterior circumflex humeral arteries come from a common trunk**. The subscapular artery and its branches, the circumflex scapular artery and the thoracodorsal artery, are normal. The axillary artery continues normally as the brachial artery. The deep brachial artery comes off the brachial artery normally. The radial and ulnar arteries are normal and bifurcate in the cubital fossa. The common interosseous artery is normal and comes off the ulnar artery. The anterior interosseous artery is normal but cannot see the posterior interosseous artery. The superficial palmar arch is normal. Cannot see the ulnar collateral arteries or the radial recurrent artery.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally. Anterior and posterior divisions are not very clear and look more like one long artery.

Anterior division (approximately): the umbilical artery is normal and gives off superior vesicle arteries normally. The internal pudendal artery branches next and gives off the inferior vesicle artery and the middle rectal artery normally. The internal pudendal artery is cut before exiting the pelvis. The inferior gluteal artery is normal and gives off the obturator artery normally.

Posterior division gives off the lateral sacral artery normally. The superior gluteal artery is normal.

Cannot find the iliolumbar artery.

The external iliac is normal. The inferior epigastric is normal. The deep circumflex iliac artery is normal.

LEFT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal but does not really bifurcate into clear anterior and posterior division. Instead, it looks more like one long artery giving off branches.

Anterior division (approximately): the obturator artery is normal and gives off a branch to the pubic symphysis. The umbilical artery is normal and gives off superior vesicle arteries normally. The inferior vesicle artery is normal. The middle rectal artery is normal. Have a branch going through the greater sciatic foramen, but not sure if it is the internal pudendal artery or the inferior gluteal artery.

Posterior division gives off the lateral sacral artery normally. The superior gluteal artery is normal.

The iliolumbar artery is an independent branch that comes off the internal iliac before it bifurcates.

The external iliac is normal. The inferior epigastric artery is normal. Cannot fine the deep circumflex iliac artery.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery postero-laterally. The lateral circumflex femoral artery is normal and comes off the deep femoral. **There is a common trunk for the lateral circumflex femoral artery and its descending branches off the deep femoral artery**. **The medial circumflex femoral artery comes off a common trunk with the deep femoral artery**, superior to the branch point of the lateral circumflex femoral artery. The femoral artery continues normally through the adductor hiatus. The anterior tibial artery is normal and continues normally to the dorsalis pedis. The posterior tibial artery is normal. Cannot see the fibular artery.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery postero-laterally. The lateral circumflex femoral artery is normal and comes off the deep femoral. The medial circumflex femoral artery comes off the deep femoral artery normally, superior to the branch point of the lateral circumflex femoral artery. The femoral artery continues through the adductor hiatus normally. The anterior tibial artery is normal and continues to dorsalis pedis normally. The posterior tibial artery is normal. Cannot find the fibular artery.

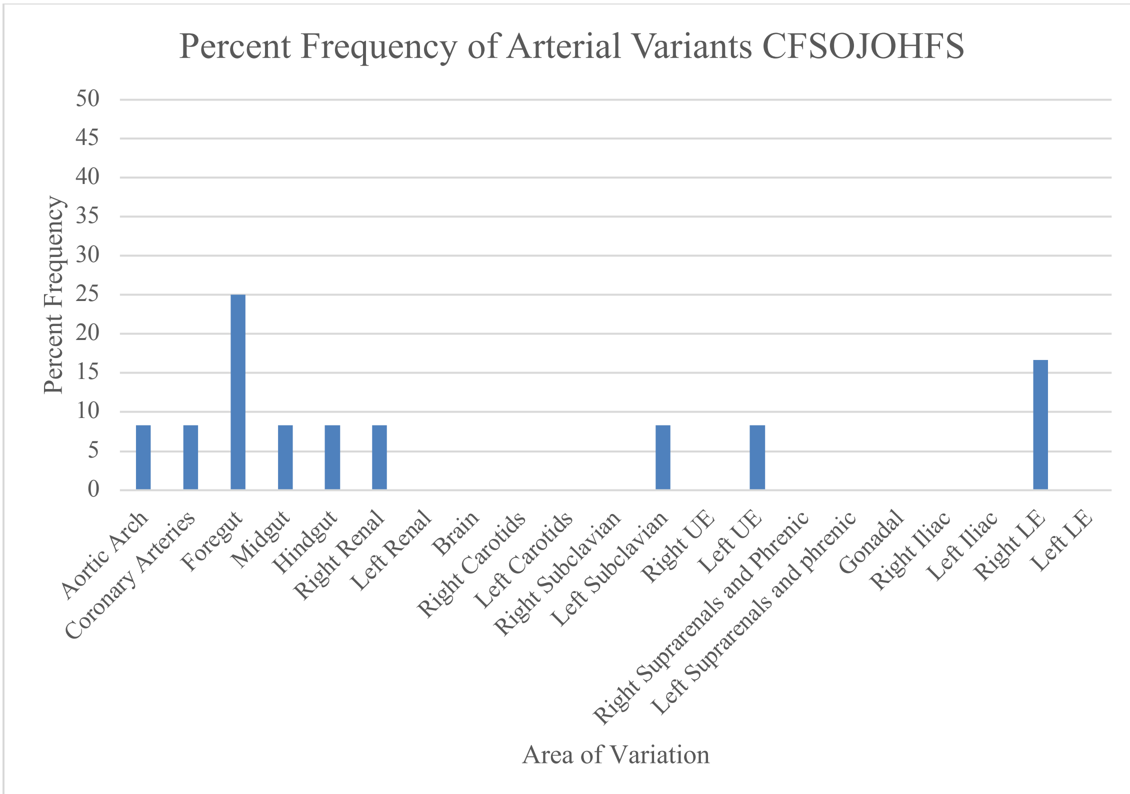

Figure 75: Percent frequency of arterial variants observed in body donor, CFSOJOHFS.

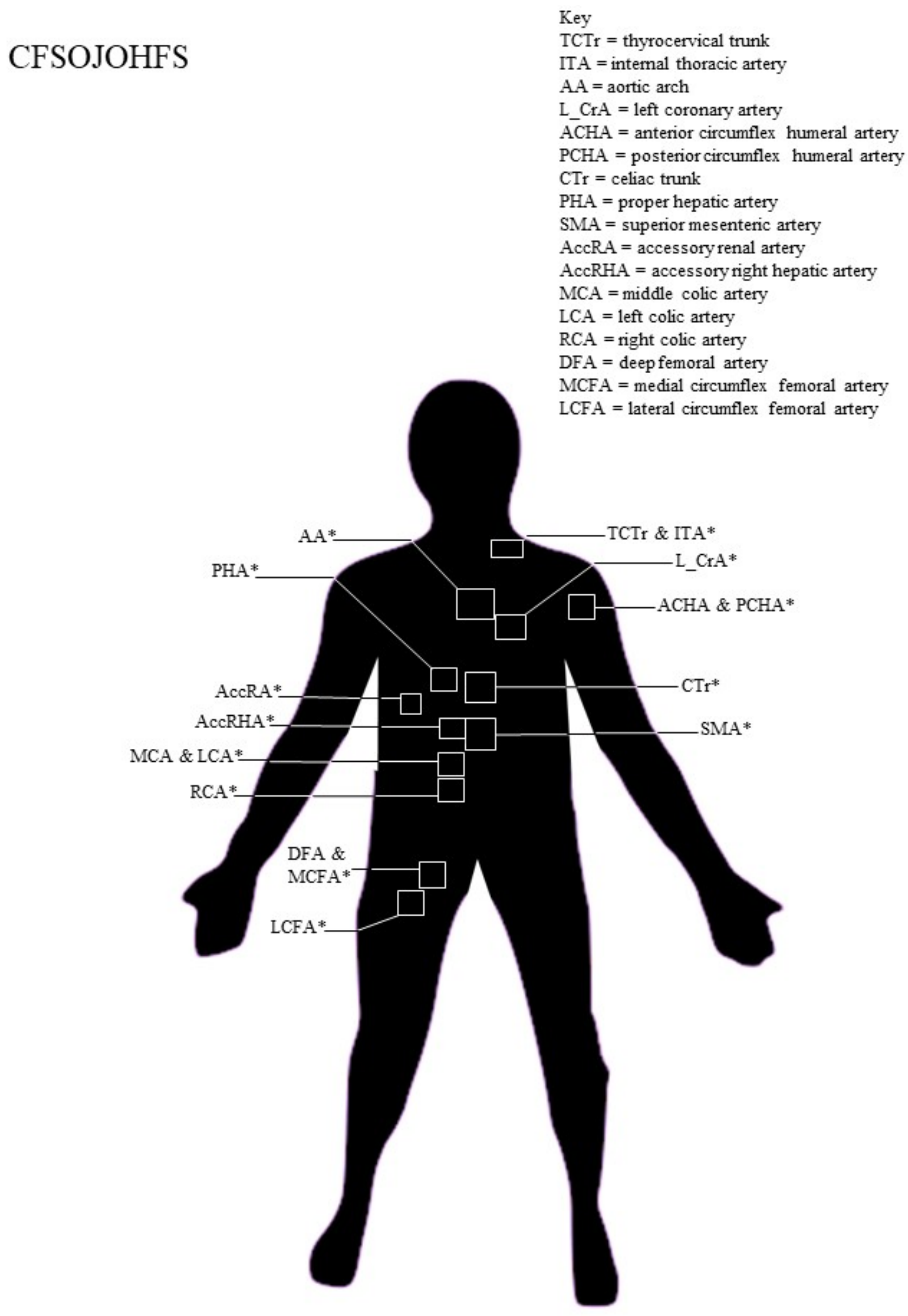

Figure 76: A schematic of the location and number of arterial variants found in body donor, CFSOJOHFS.

Figure 77: A variant of the aortic arch in which there are four branches with the fourth branch being the left vertebral artery in body donor, CFSOJOHFS.

AA = aortic arch, BRCt = brachiocephalic trunk, R-SCA = right subclavian artery, R-CCA = right common carotid artery, L-CCA = left common carotid artery, L-VA = left vertebral artery, L-SCA = left subclavian artery, * = variant.

Figure 78: A variant of the left coronary artery in which it trifurcates into its three main branches in body donor, CFSOJOHFS.

L-CrA = left coronary artery, LCxA = left circumflex artery, LMA = left marginal artery, LAD = left anterior descending artery, DiagB = diagonal branch, * = variant.

TVMMJWBO.S.J

Sex: F

Age: 95

COD: Congestive heart failure/aspiration pneumonia

Summary of variants seen (Figures 79-80)

- **The left gastric gives off the left hepatic artery** (Figure 81)
- **The left gastric artery gives off a second branch** that goes to the right side of the lesser curvature of the stomach, which is the course of the right gastric artery (Figure 81)
- The **SMA gives off the right hepatic artery** (Figure 81)
- There is **a common stem for the middle and right colic arteries** off the **SMA**
- In the **right upper extremity**, the **brachial artery** gives off the circumflex scapular artery, just superior to the branch point of the deep brachial artery
- In the **right upper extremity**, there is a high branch point of the radial and ulnar arteries, about halfway down the arm. The radial artery crosses over the ulnar artery and continues to the wrist normally (Figure 82)
- In the **left upper extremity**, there is an anomalous origin of the **circumflex scapular artery** off the **brachial artery**, just superior to the branch point of the deep brachial artery

Detailed Overview:

ARCH OF THE AORTA

The brachiocephalic trunk is normal and bifurcates into the left common carotid and the left subclavian normally. The left subclavian is normal. The left common carotid is normal.

HEART

The left coronary artery is normal. The left anterior descending is normal and gives off the diagonal branch normally. The left marginal artery is normal. The left circumflex is normal. The right coronary artery is normal. The right marginal artery is normal. The right coronary artery gives off the posterior interventricular artery normally.

FOREGUT

The celiac trunk is normal and gives off the splenic artery, left gastric artery, and common hepatic artery normally. The splenic artery gives off the left gastro-omental artery and the posterior gastric artery normally. **The left gastric artery gives off the left hepatic artery** (Figure 81). **The left gastric artery also gives off a second branch that goes to the right side of the lesser curvature of the stomach, which is the location for the right gastric artery** (Figure 81**)**. The common hepatic artery is normal and gives off the gastroduodenal artery normally. The gastroduodenal artery is normal and gives off the supraduodenal and the right gastro-omental arteries normally. Cannot find the superior pancreaticoduodenal artery. The proper hepatic artery looks more like a branch off the gastroduodenal artery, but it continues to the liver normally. Cannot find the right gastric or cystic arteries.

MIDGUT

The SMA is normal. **The SMA gives off the right hepatic artery** (Figure 81). The inferior pancreaticoduodenal artery is normal. The ileal and jejunal branches are normal. The ileocolic artery is normal. **There is a common stem for the middle and right colic arteries**.

HINDGUT

The IMA is normal. The left colic artery is normal and gives off the ascending and descending branches normally. Cannot find the sigmoid arteries or the superior rectal artery.

RIGHT RENAL

Have one renal artery coming off the abdominal aorta normally, bifurcates as it reaches the kidney. The inferior suprarenal artery comes off the renal artery normally. Cannot find the inferior phrenic artery, superior suprarenal artery, middle suprarenal artery, or the ovarian artery.

LEFT RENAL

Have one renal artery coming off the abdominal aorta, bifurcates as it reaches the kidney. The inferior suprarenal artery comes off the renal artery normally. Cannot find the inferior phrenic artery, superior suprarenal, middle suprarenal, or ovarian arteries.

BRAIN

The Circle of Willis is normal. The anterior, middle, and posterior cerebral arteries are normal, but the middle cerebral artery got torn on the left side. Cannot see the left posterior communicating artery on the left side. The right posterior communicating artery is normal and the anterior communicating artery is normal. The basilar artery is normal. The superior cerebellar arteries are normal.

RIGHT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The lingual and facial arteries are normal. The facial artery is normal and gives off the superior and inferior labial arteries normally, before it gets cut. The maxillary artery is normal.

LEFT CAROTID

The common carotid is normal and bifurcates into the internal and external carotid arteries normally. The internal carotid artery is normal but cut shortly after its origination point. The external carotid is normal but cut before it divides into its terminal branches. The superior thyroid artery is normal and gives off the superior laryngeal artery normally. The lingual and facial arteries are normal. The facial artery is normal and gives off the superior and inferior labial branches normally, before getting cut.

RIGHT SUBCLAVIAN

The artery got cut up very badly during dissection. Can see the lumens for branches, but none of the branches themselves.

LEFT SUBCLAVIAN

The vertebral artery is normal. The internal thoracic artery is normal. The thyrocervical trunk is normal, but its branches are cut. Cannot find the costocervical trunk. The dorsal scapular artery is normal and comes off the subclavian normally.

RIGHT UPPER EXTREMITY

The thoracoacromial trunk and its branches are normal. The lateral thoracic is normal. The anterior and posterior circumflex humeral arteries are normal. The subscapular artery is normal and gives off the thoracodorsal artery normally. **The brachial artery gives off the circumflex scapular artery, just superior to the branch point of the deep brachial artery**. The axillary artery is otherwise normal and continues as the brachial artery normally. The deep brachial artery comes off the brachial artery normally. **There is a high branch point of the radial and ulnar arteries**, about halfway down the arm (Figure 82). The radial artery crosses over the ulnar artery and continues to the wrist normally. The ulnar artery continues normally and gives off the anterior ulnar recurrent artery normally. The common interosseous artery comes off the ulnar artery normally. The anterior and posterior interosseous arteries are normal. The superficial palmar arch is normal. Cannot see the radial recurrent artery or the other ulnar collateral arteries.

LEFT UPPER EXTREMITY

The thoracoacromial trunk and its branches are normal. The lateral thoracic artery is cut. The anterior circumflex humeral artery is normal, but the posterior circumflex humeral artery is cut. The subscapular artery is normal and gives off the thoracodorsal artery normally. **The brachial artery gives off the circumflex scapular artery just superior to the branch point of the deep brachial artery**. The axillary artery is otherwise normal and continues as the brachial artery normally. The deep brachial artery comes off the brachial artery normally. The radial and ulnar arteries are normal and bifurcate in the cubital fossa. The common interosseous artery is normal and comes off the ulnar artery. The anterior and posterior interosseous arteries are normal. Cannot find the superficial palmar arch, ulnar collateral arteries, or the radial recurrent artery.

RIGHT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal and bifurcates into the anterior and posterior divisions normally.

Anterior division looks like one long artery that terminates in a bifurcation and gives off branches along the way. The terminal bifurcation is the inferior gluteal artery and internal pudendal artery, both of which are normal. Have a common trunk for the umbilical and vaginal arteries, both are normal. The obturator artery is normal and gives off a branch to the pubic symphysis. There is another branch that goes to the pubic symphysis.

Posterior division gives off two lateral sacral arteries normally. The superior gluteal artery is normal.

The iliolumbar artery is an independent branch that comes off the internal iliac before it bifurcates.

The external iliac is normal. The inferior epigastric is normal, bifurcates and the other branch goes to the pubic symphysis. The deep circumflex iliac artery is normal.

LEFT ILIAC

The common iliac bifurcates normally into the internal and external iliac arteries. The internal iliac is normal but does not have anterior and posterior divisions so much as one long trunk with branches.

Anterior division (approximately) has two major divisions. The more anterior of the divisions gives off the umbilical artery and the superior vesicle arteries normally. It also gives off a common trunk for the obturator artery and the vaginal artery, both of which are normal. The more posterior division gives off a common trunk for the internal pudendal artery and the inferior gluteal artery. Both are normal and give off middle rectal artery branches. The common trunk also gives off a lateral sacral artery.

Posterior division (approximately) gives off the lateral sacral artery normally. The superior gluteal artery is normal.

The iliolumbar artery is an independent branch that comes off the internal iliac before it bifurcates.

The external iliac is normal. The inferior epigastric artery is normal but gets cut. Cannot find the deep circumflex iliac artery.

RIGHT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery postero-laterally. The lateral circumflex femoral artery is normal and comes off the deep femoral. Cannot find the medial circumflex femoral artery. The femoral artery continues normally through the adductor hiatus. The anterior tibial artery is normal and continues normally to the dorsalis pedis. The posterior tibial artery is normal. Cannot see the fibular artery.

LEFT LOWER EXTREMITY

The femoral artery is normal. The deep femoral artery is normal and comes off the femoral artery posteriorly. The lateral circumflex femoral artery is normal and comes off the deep femoral. Cannot find the medial circumflex femoral artery. The femoral artery continues through the adductor hiatus normally. The anterior tibial artery is normal and continues to dorsalis pedis normally. The posterior tibial artery is normal. Cannot find the fibular artery.

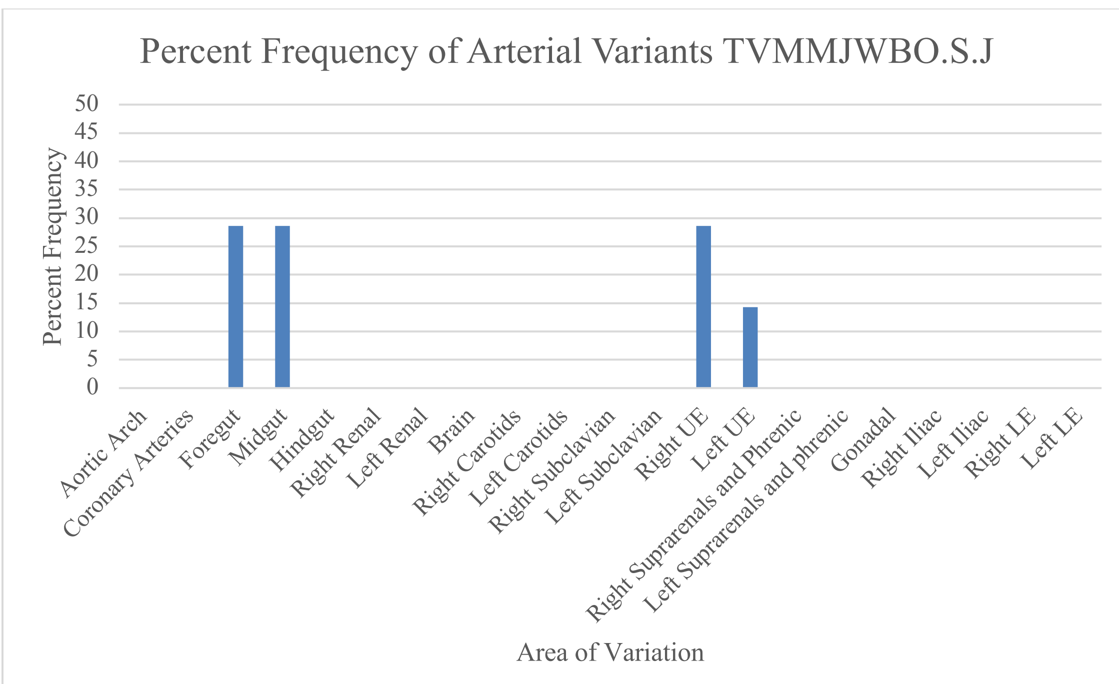

Figure 79: Percent frequency of arterial variants observed in body donor, TVMMJWBO.S.J.

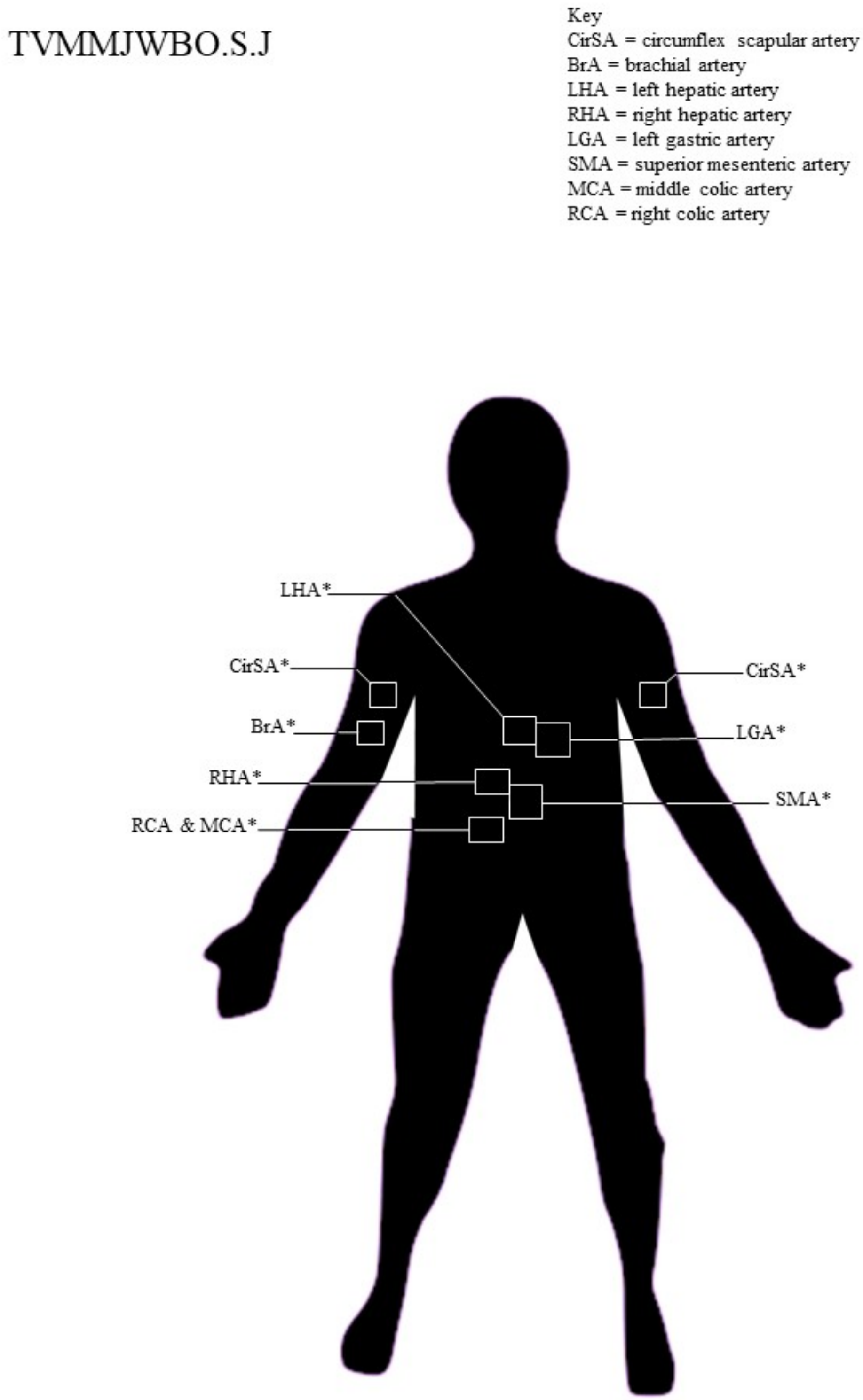

Figure 80: A schematic of the location and number of arterial variants found in body donor, TVMMJWBO.S.J.

Figure 81: A variant of the left gastric artery in which it gives off the left hepatic artery in body donor, TVMMJWBO.S.J. The right hepatic artery can also be seen approaching the liver after originating from the SMA. Also note the left gastric artery giving off two arteries to the lesser curvature of the stomach, one of which supplies the right side of the lesser curvature and one supplies the left side.

CTr = celiac trunk, SPA = splenic artery, CHA = common hepatic artery, GDA = gastroduodenal artery, PHA = proper hepatic artery, RHA = right hepatic artery, LGA = left gastric artery, LHA = left hepatic artery, * = variant.

Figure 82: A high branch point of the radial and ulnar arteries from the brachial artery in the right upper extremity of body donor, TVMMJWBO.S.J.
BrA = brachial artery, DBrA = deep brachial artery, SUCA = superior ulnar collateral artery, UlnA = ulnar artery, RadA = radial artery, * = variant.

DISCUSSION

Aortic Arch Variants

In the current study, normal anatomy of the aortic arch occurred with an incidence of 80% (20 of 25 cases). This falls within the range of 74.29% to 90.3% reported in the literature (Nayak et al., 2006, Rojas et al., 2017).

The next most frequent arch morphology identified in the current study (4 of 25 cases; 16%), was the Type III arch, in which the left vertebral artery emerged directly from the aortic arch. This arch morphology is reportedly the second most common arch variant, after the bovine aortic arch, with a reported frequency of 0.79% to 8.57% (Natsis et al., 2009, Rojas et al., 2017). The frequency of the Type III anatomy in the current study is considerably higher (16%) relative to the previously reported range. Additionally, this variant was the most common aortic arch variant identified in the current study. This finding may be due to the relatively small sample size in this study. Nonetheless, this variant has been reported across multiple studies, indicating that it is not an uncommon variant of the aortic arch.

In general, anomalies of the aortic arch anatomy are formed by persistence of vessels that normally regress and/or regression of vessels that normally persist (Hanneman et al., 2016). Typically, the left vertebral artery is formed by the longitudinal anastomosis between the seven cervical intersegmental arteries, which arise from the dorsal aorta (Yuan, 2016). All but the seventh intersegmental artery are obliterated, and the seventh intersegmental artery develops into the lateral aspect of the subclavian artery with the vertebral artery originating from it (Yuan, 2016). The origin of the left vertebral artery from the aortic arch can be explained by a failure of the anastomosis to form between the sixth and seventh intersegmental arteries on the left side. This allows the sixth intersegmental artery to persist, connecting the left vertebral artery to the aortic arch (Yuan, 2016).

People with an aberrant left vertebral artery are usually asymptomatic (Yuan, 2016). However, the different course of anomalous arteries can lead to altered hemodynamics and predispose patients to arterial dissection and formation of intracranial aneurysms (Dudich et al., 2005, Satti et al., 2007). Vertebral artery dissection involves a tear in the wall of the vessel; this allows blood to flow between the layers of the vessel wall (Park et al., 2008). Blood can clot in between the layers of the arterial wall, leading to occlusion of the vessel or to the formation of an aneurysmal dilation in the vessel (Park et al., 2008). Vertebral artery dissections can occur spontaneously and may lead to ischemic stroke (Park et al., 2008). There are two classifications of spontaneous vertebral artery dissection, (1) the ischemic type, which is caused by ischemic symptoms and/or disruption of the blood supply to the brain due to occlusion of the vessel and, (2) the hemorrhagic type, which causes a subarachnoid hemorrhage due to the rupture of the arterial wall (Park et al., 2008). There is some evidence that an anomalous origin of the vertebral artery from the aortic arch may predispose patients to spontaneous formation of vertebral artery dissections (Dudich et al., 2005, Komiyama et al., 2001).

In a study by Komiyama et al. (2001), the link between vertebral artery dissection and origin of the vessel was investigated by looking at the angiograms of 860 patients over a five-year period. They found 21 cases (2.4%) of the left vertebral artery originating from the aortic arch. Of these cases, 4 of 21 (19%) patients had vertebral artery dissection, whereas only 9 of the 837 (1.1%) normal cases had it (Komiyama et al., 2001). Thus, the patients with an anomalous origin of the vertebral artery from the aortic arch had a significantly higher incidence of vertebral artery dissection compared to patients with a normal origin of the artery ($p < 0.001$), meaning that an aberrant vertebral artery could be a risk factor for vertebral artery dissection (Komiyama et al., 2001). There are at least two possible explanations for this, congenital defects of the arterial wall or altered hemodynamics (Komiyama et al., 2001).

Patients with spontaneous dissections of the vertebral artery are usually thought to have an underlying structural defect of the arterial wall (Schievink, 2001). The exact type of defect is typically unknown, but heritable tissue-connective disorders are associated with an increased risk of spontaneous vertebral artery dissection (Schievink, 2001). The structure of the vertebral arteries in Komiyama et al. (2001) could not be observed because of the retrospective design of the study and the use of patient images without a full medical record, thus structural defects cannot be ruled out as the cause of the vertebral artery dissections.

The anomalous origin of the vertebral artery may cause changes in cerebral hemodynamics by altering the blood pressure through the left vertebral artery (Komiyama et al., 2001). All arteries are constantly subject to hemodynamic forces including pressure acting perpendicular to the arterial wall, cyclic strain, and shear stress (Resnick et al., 2003). Shear stress is the force of the blood acting parallel to the arterial wall, creating a frictional shear force on the surface of the endothelium lined wall

(Resnick et al., 2003). The shear stress changes with the pulsatile nature of the cardiovascular system producing a range of shear stress levels that each vessel experiences (Resnick et al., 2003). Normally, when the left vertebral artery originates from the left subclavian artery, it would receive dampened blood flow due to the pulsatile flow first traveling through the proximal subclavian artery (Komiyama et al., 2001). However, when the vertebral artery originates from the aortic arch it may experience a greater shear stress because it is receiving direct arterial pulsatile flow (Komiyama et al., 2001). An inability to resist shear stress has been linked to a predisposition of patients to develop arterial dissections, which is possibly occurring in the anomalous left vertebral artery (Davies et al., 1996). The anomalous origin of the left vertebral artery from the aortic arch also changes its anatomical course, which could contribute to altered hemodynamics as well (Komiyama et al., 2001). Normally, the left vertebral artery enters the transverse foramen at the C6-7 intervertebral level, but when it originates from the aortic arch it enters at the higher C5-6 intervertebral level (Komiyama et al., 2001). The increased extra-cranial portion may cause increased shear stress in the distal portion of the artery because the artery is more mobile in the neck than when it travels in the transverse foramen (Komiyama et al., 2001).

The next most common aortic arch variant encountered was Type II, the bovine aortic arch, with an incidence of 4% (1 of 25 cases). This frequency of the bovine aortic arch reported in the literature is 4.8%-18.28% (Huapaya et al., 2015, Nayak et al., 2006). In this study, the incidence of the Type II anatomy is lower than that reported in the literature and was the third most common variant found as opposed to the second most common seen in the other studies. A low frequency of the bovine aortic arch has been found in a prior cadaveric study performed in 193 American-Japanese male subjects, with only 1 of 193 cases (1.03%) displaying the Type II morphology (Nelson and Sparks, 2001). The relatively lower frequency of the bovine arch in this study and Nelson and Sparks (2001) could represent different frequency distributions of this variant in different ethnic groups.

The bovine arch occurs during embryonic development when there is slow growth of the ventral aortic roots between aortic arches three and four, allowing fusion of the brachiocephalic and left common carotid arteries (Malone et al., 2012, Nelson and Sparks, 2001). Traditionally, the bovine aortic arch has been considered clinically insignificant, though the variant is considered in the planning of interventional and surgical procedures (Malone et al., 2012, Wanamaker et al., 2013). However, an association between bovine arch and aortic dilation was found in older patients (Malone et al., 2012). Malone et al. (2012) compared the CT images of 391 control cases to 191 cases with a dilated aorta. The control group had 80 cases (20.5%) of bovine arch and the dilated aorta group had 50 cases (26.2%) of bovine arch. While the frequency of the bovine arch in the dilated aorta group was not significantly greater than the control, there was a trend towards increased prevalence ($p = 0.12$), (Malone et al., 2012). When the patients were separated into different age groups (>70, 40-70, <40), the over 70 group had 29 of 91 (31.9%) cases of bovine arch; this was significantly greater than the over 70 control group who had 13 of 81 (16%) cases ($p = 0.016$), (Malone et al., 2012). The location of the aortic dilation was also separated into subgroups, including ascending aorta, arch involvement, descending aorta, and diffuse. Only the arch subgroup displayed a significantly higher incidence of bovine arch compared to controls with 10 of 21 (47.6%) patients displaying the morphology ($p = 0.003$), (Malone et al., 2012). Thus, an association between aortic dilation and the bovine arch morphology is seen in patients above 70 and when the dilation involves the arch of the aorta.

The mechanism linking the bovine arch and aortic dilation is still yet to be determined, but the significance of it in the older age group and at the specific arch location, suggest that it may be a chronic, focal process (Malone et al., 2012). The association between aortic dilation and bovine arch was only significant in the above 70 age group, suggesting that it is a progressive process that takes many years to manifest into clinical significance. Similarly, the significance of the association is only seen at the aortic arch, meaning that changes are occurring at one focal spot and not systemically. This suggests that aortic dilation could occur as specific arteries weaken over time due to their aberrant morphology (Malone et al., 2012).

The weakening of the vessels may be a result of altered hemodynamic flow in the bovine aortic arch (Malone et al., 2012). Normally, the flow of blood through the brachiocephalic trunk would follow the principles of fluid mechanics, in which a stream of fluid from a nozzle – in this case blood coming through the aortic valve – becomes progressively wider as it moves into the surrounding fluid (French and Guntheroth, 1970). Simultaneously, the velocity of the stream decreases proportionally to the wider path of the stream and the kinetic energy is dissipated down the length of the stream. An area of low pressure is created at the proximal margins of the stream and a counterflow is created to equalize pressure (French and Guntheroth, 1970). A three-dimensional model was created to simulate the flow of blood through the aortic arch and its branches and found that blood flows very similarly to what would be expected as predicted by fluid mechanics (Shahcheraghi et al., 2002). However, because of the contractile nature of blood flow, there is an asymmetry of the blood flow through the aorta and its branches as seen through higher shear forces on certain parts of the arterial walls (Shahcheraghi et al., 2002). The normal brachiocephalic trunk has the least pronounced asymmetry of flow compared to the other branches of the aorta (Shahcheraghi et al., 2002). But when the left common carotid artery and the brachiocephalic trunk share a common origin, this increases the size of the trunk and may alter hemodynamics by producing an effect similar to the Coanda effect (Malone et al., 2012). The Coanda effect is the tendency for a jet stream to adhere to a boundary wall (French and Guntheroth, 1970). It can occur when there is any disturbance to the shape of the boundary that the jet stream flows into, which is exactly what happens in the bovine arch as the brachiocephalic trunk increases in size (French and Guntheroth, 1970). A change in the boundary shape causes the stream to deviate against a boundary wall. The altered flow path is maintained by creating an area of low pressure between the stream and the boundary wall it is adhered to and establishing a countercurrent flow on the opposite side of the stream (French and Guntheroth, 1970). This could lead to an increased shear stress on the wall the stream is adhered to, and increased shear stress has been linked to vessel wall dilation and injury (Malone et al., 2012, Malek et al., 1999). Thus, the change in blood flow could explain a link between bovine arch and the development of an aortic dilation. Even without a clear mechanism linking bovine arch and aortic dilation, bovine arch should be considered a risk factor for aortic dilation and not just a benign anatomical variant.

Coronary Artery Variants

Of the 5 cases of variant coronary artery morphology, none of them fell into the categories of anomalous origin or coronary artery fistulas as proposed by Yamanaka and Hobbs (1990). One possible explanation could be that variant coronary arteries were surgically repaired during life. Multiple body donors had evidence of cardiac surgery, however, medical records were not provided to determine the details of those surgeries. Although, data was recorded for grossly visible surgical procedures, it is possible a congenital anomaly, corrected by surgery, was overlooked. In general, cadaveric studies focusing on the coronary arteries have reported a lower frequency of variants with 0.3% being the incidence rate found as opposed to 1.3% seen in the angiographic studies (Yamanaka and Hobbs, 1990, Yildiz et al., 2008). In angiographic studies, dye is injected into the vessels and X-ray technology is used to illuminate their paths. While the dye may not be able to reach into the microvasculature, it can still illuminate many of the smaller vessels that may be overlooked or damaged during dissection. Thus, a more complete map of the coronary arterial system can be better visualized with angiography.

While anomalies of origin of the coronary arteries and fistulas were not found in this study, left-dominant hearts were, with 2 out of 25 (8%) body donors displaying this morphology. The incidence of left-dominant hearts in this study is slightly lower than the incidence (9.1%) found in Knaapen et al. (2013), but the frequencies are comparable. There were no cases of co-dominant hearts, which is much lower than the frequency of

9.7% found in Knaapen et al. (2013). This could be because of the limited sample size of this study or because there is a decrease in the prevalence of co-dominant hearts with an increase of age (Knaapen et al., 2013). Knaapen et al. (2013), looked at the prevalence of coronary artery dominance using postmortem cardiac angiograms in 1,453 cases; they were divided into three age cohorts of less than 64, 64-74, and older than 75. There was a significant increase ($p = 0.001$) in the frequency of right-dominant systems across the three age groups, with the incidence of the right-dominant system increasing from 76.6% in the 64 and younger age group, to 80.6% in the 64-75 age group, and finally, to 85.6% in the 75 and older age group (Knaapen et al., 2013). This was accompanied by a simultaneous decrease in the frequency of left-dominant and co-dominant systems across the three age groups, though only the decrease in frequency of the co-dominant system was significant ($p < 0.01$), (Knaapen et al., 2013). The mean age of the cadavers in this study was 85 years and taken with the results of Knaapen et al. (2013), the lack of co-dominant cases could reflect the decreased prevalence of that morphology in this age cohort.

The decreasing prevalence of left and co-dominant coronary systems may indicate a worse prognosis for patients with those variants (Knaapen et al., 2013). Indeed, more research is being performed to explore the link between coronary vessel dominance in relation to the prognosis of patients with significant coronary artery disease. In one such study, 1,425 patients who underwent CT coronary angiography were followed for a median period of 24 months in order to determine the impact of vessel dominance on the progression of significant coronary artery disease as measured by the occurrence of non-fatal myocardial infarction and all-cause mortality (Veltman et al., 2012). Researchers found that there was no significant difference in the frequency of significant coronary artery disease between patients with right-dominant, left-dominant, and co-dominant coronary artery systems (Veltman et al., 2012). However, they did find that after a three-year follow-up, patients with significant coronary artery disease and a left-dominant system had a significantly worse outcome with a cumulative incidence of non-fatal myocardial infarction and all-cause mortality of 35% compared to a cumulative incidence of 9.5% in patients with a right-dominant system and significant coronary artery disease ($p < 0.001$), (Veltman et al., 2012). This provides evidence that there is an association between a left-dominant coronary system and a worse prognosis for patients with significant coronary artery disease (Veltman et al., 2012) Additionally, the presence of a left-dominant system alone, does not seem to put individuals at a greater risk for the development of coronary artery disease, but it is associated with a greater risk of non-fatal myocardial infarction and all-cause mortality compared to those with a right-dominant system (Veltman et al., 2012).

The worse prognosis for patients with a left-dominant coronary artery system may be caused by a larger myocardial area at risk with myocardial infarction (Knaapen et al., 2013). Infarct size has been associated with prognosis, with larger infarcts having higher mortality rates and a greater prevalence of congestive heart failure (Herlitz et al., 1988). In the right-dominant coronary system, the left ventricle is supplied by both the right – via the posterior interventricular artery - and left coronary arteries – via the LAD and left marginal arteries. However, in the left-dominant coronary system, the entire blood supply to the left ventricle is derived from the left coronary artery because it gives rise to the posterior interventricular artery (Abu-Assi et al., 2016). Therefore, if there is an occlusion of the left coronary artery in the left-dominant system, a larger area of myocardium is at risk relative to patients with a right-dominant system (Abu-Assi et al., 2016). Additionally, the LAD was found to be longer in patients with left-dominant coronary systems, wrapping around the apex of the heart in 87% of cases versus 47% in patients with right-dominant coronary systems (Ilia et al., 2001). This means that there could be a larger area of the myocardium at risk during infarction around the apex of the heart in cases of LAD occlusions in a left-dominant coronary system, leading to a worse prognosis for those patients.

As for the other variants seen in the coronary arteries, there were two cases (8%) of trifurcation of the left coronary artery. This is a known variant of the left coronary artery in which the left coronary artery branches into the LAD and the left circumflex artery with an artery between them called the ramus intermedius (Kini et al., 2007). The ramus intermedius can act as a diagonal branch or a marginal branch, supplying the lateral and inferior walls of the myocardium (Kini et al., 2007). In one study that examined the branching pattern of the left coronary artery in 75 cadaveric hearts, they found a trifurcation in 11 of 75 cases (14.7%), (Hosalinaver and Hosalinaver, 2018). The incidence of trifurcation of the left coronary artery is higher in their study than the incidence observed here, but that could be because of the difference in sample size. The trifurcation of the left coronary artery is clinically significant in terms of coronary artery disease because it increases the difficulty of treating the disease (Shammas, 2007).

Trifurcating coronary artery disease can involve any combination of the three branches with or without the inclusion of the main stem (Shammas, 2007). This creates a much larger range of presentations of coronary artery disease when compared to the disease seen in bifurcations, as well as a corresponding increase in the range of treatments needed to control it. Thus, while a trifurcating left coronary artery is not common, an awareness of it is needed for clinicians because of the potential complications it creates in relation to coronary artery disease.

The final variation seen in the coronary arteries, a triplication of the posterior interventricular artery was seen in 1 of 25 cases (1 male, 4%). In this case, the right coronary artery continued to the posterior aspect of the heart and trifurcated into the posterior interventricular arteries. One of those branches then bifurcated so that there was a total of four posterior interventricular arteries. The triplication of the posterior interventricular artery is not a completely novel variant. In one study of 108 preserved hearts from an Indian population, there were 12 cases (11%) of a triplicated posterior interventricular artery arising from the right coronary artery (Sabnis, 2013). However, this prevalence seems to be an outlier as there are few other mentions of this variation in the literature. A study of 50 cadavers in a Brazilian population found one case (2%) of a duplication of the posterior interventricular artery, but in that case each of the coronary arteries supplied a posterior interventricular artery, which is a different pattern than the one seen here (Nordon and Rodrigues Júnior, 2012). It is possible that there is a difference in the distribution pattern of this variant among ethnic groups with a greater prevalence in the Indian population. Alternatively, it is possible that this variant is present in many ethnic groups but has simply not been reported.

This variant may arise from an interruption of signaling molecules that are responsible for growing and remodeling the primitive vascular plexus that forms the coronary arteries (Bernanke and Velkey, 2002). The development of the coronary arteries involves a mosaic of signaling molecules derived from multiple locations including the endocardium, myocardium, and epicardium (Pérez-Pomares et al., 2016). If there is an environmental or genetic factor that influences any of these signaling molecules, then the patterning of the coronary arteries could be altered leading to a variation such as the triplication of the posterior interventricular artery (Pérez-Pomares et al., 2016).

Celiac Trunk Variants

The normal anatomy of the foregut, defined as Type I in Michels (1966) classification scheme was observed in two cases (8%). Type II, IV, V, VI, VII, and IX were all observed in one case each. There were no observations of Type III, VIII, or X anatomy. The most common anatomy observed were cases that did not fit into Michels (1966) classification scheme, with 14 cases (56%) being considered miscellaneous. Three cases (12%) were unable to be classified because pathology had altered the abdominal blood flow.

The normal celiac anatomy, as defined by the trifurcation into the common hepatic, left gastric, and splenic arteries, arises when the paired ventral segmental arteries from the dorsal aortae fuse in the midline (Lin and Chaikof, 2000). Regression and fusion of the 10^{th}, 11^{th}, and 12^{th} ventral segmental arteries form the celiac trunk and its branches (Alakkam et al., 2016). During the embryonic stage, the developing liver is supplied by three arteries; the embryonic left hepatic artery – derived from the left gastric artery – supplies the left portion of the liver, the common hepatic artery supplies the median segment, and the embryonic right hepatic artery – derived from the SMA – supplies the right segment (Alakkam et al., 2016). As the liver continues to grow, the three arteries are incorporated into the hilum of the liver and some of them regress to form the normal anatomy by the end of the eighth week (Alakkam et al., 2016). However, if the embryonic left and right hepatic arteries do not regress, they become an accessory or replaced right and left hepatic artery (Jin et al., 2008). Most variants of the celiac trunk can be explained by abnormal regression or persistence of ventral segmental arteries (Yildirim et al., 1998). For example, an origin of the celiac trunk branches from the aorta may be caused by the roots of the celiac branches developing separately as opposed to uniting to form the trunk. If the roots develop separately, any combination of them may maintain their attachment to the aorta, while the others unite to form a trunk (e.g. hepato-gastric trunk with splenic arising from aorta, spleno-gastric trunk with common hepatic artery arising from aorta), (Yildirim et al., 1998). An origin of vessels from the SMA occurs in a similar fashion. Typically, the ventral segmental arteries that form the branches of the celiac trunk are separated from the segmental artery that forms the SMA. If this separation occurs too high, then the branch or branches below the separation will translocate to the SMA (Yildirim et al., 1998).

The prevalence of Type I anatomy found in this study is much lower than the frequencies reported in the literature (Table 2). The typical range for Type I anatomy is reported to be between 61.3% and 81% whereas, in this study, it is only 8% (Covey et al., 2002, Noussios et al., 2017). The low incidence of normal anatomy in this study could be explained by the Michels (1966) classification scheme not fitting the data. Many of the variants found did not fit into the classification scheme because there were extra branches from the celiac trunk or because there were anomalous branching patterns of the distal branches. Michels classification scheme does not include these types of variants and thus could not account for the variations that were observed in this study. This is a problem encountered across multiple studies looking at the hepatic arterial system. For examples, the prevalence of unclassified variants identified by Noussios et al. (2017) was 4.1% (784 of 19,013 cases), the highest frequency of any of the variant categories. Even with the prevalence of non-classified variants in Noussios et al. (2017), there may be an underestimation of the variants actually seen. Because Michels' classification scheme is the most widely used system, many studies may be limited in what they report, using only those categories so that their results are easily compared to the results reported in other studies (Covey et al., 2002). Thus, the frequency of variants may be higher than the values seen in the literature.

The frequency of Type II anatomy in this study, 4%, falls into the range reported in the literature, 3.8% to 9.7% (Table 2) (Covey et al., 2002, Lopez-Andujar et al., 2007). However, with a sample size of 25 in the current study, there was only one case displaying Type II morphology and even then, that case had additional variants off the celiac trunk that could preclude it from truly being considered Type II anatomy. The low frequency once again highlights that Michels' classification system may too constraining to actually capture the scope of variations seen in the celiac axis.

There were no cases of Type III anatomy observed in this study which is reportedly the most common variant morphology (Table 2) (Noussios et al., 2017). This may be due to population differences, with the population of this study not having this morphology. In general, the hepatic arterial system seen in this population involved a combination of variations, so not many cases fell into the categories only involving one variant present, such as in Type III anatomy.

Type IV anatomy, which involves a combination of variants, was seen in one case (4%) in the present study, which is similar to the frequency of 0.5% to 3.1% seen in the literature (Table 2) (Covey et al., 2002, Lopez-Andujar et al. 2007). The incidence in the present study is slightly higher, but that is because of the smaller sample size used. Similarly, there was one case (4%) each of Type V, VI, VIII, and IX anatomy, giving a frequency that is similar to that reported in the literature (Table 2). However, these cases also had more variants in addition to the ones described by Michels. There were no cases of Type VIII and X, which is similar to the prevalence in the literature since those are some of the more uncommon variants reported. Although the data in the current study did not directly correspond with Michels' classification scheme, the data does highlight the large number of variants in this region as well as reinforcing the importance of understanding these variants, especially in the clinical setting.

A replaced or accessory right hepatic artery is the most commonly encountered vascular variant during the pancreaticoduodenectomy (PD) and is one of the most common hepatic arterial system variants in general (Noussios et al., 2017, Rammohan et al., 2014). The presence of an aberrant (includes replaced and accessory) right hepatic artery during PD can necessitate an alteration in surgical approach and may have adverse effects on the outcome of the procedure (Rammohan et al., 2014). In order to assess the impact of an aberrant right hepatic artery on the PD procedure and outcome, Rammohan et al. (2014) divided 225 patients undergoing PD into two groups; those with an aberrant right hepatic artery and those without. Within the groups they documented the arterial anatomy encountered, the variations and complexities of the procedure, such as surgical time, and the outcome through operative mortality and histopathology. Of the 225 patients undergoing PD, 43 cases (19.1%) had arterial variants, with a replaced or accessory right hepatic artery from the SMA being the most common types found. Operating time significantly increased ($p < 0.05$) in the group with arterial variants by approximately an hour, but there were no other significant differences in intraoperative variables or outcome (Rammohan et al., 2014). The increase in surgical time came from dissection and preservation of the aberrant right hepatic arteries. Preoperative imaging only revealed the anomalous arteries in 58% of the cases, meaning that the operative complexity increased in the cases when the anomaly was encountered for the first time during the procedure (Rammohan et al., 2014). The aberrant right hepatic arteries need to be preserved because of their role in blood supply to the liver and to the extrahepatic biliary tree. Injury to the right hepatic artery can lead to ischemia of the liver and the biliary anastomosis, causing a bile leak in the abdominal cavity (Rammohan et al., 2014). The best way to prevent injury to an aberrant artery is recognition and awareness of the normal and variant anatomies possible. Based on the results of this study, an aberrant right hepatic artery may be found in up to one fifth of patients undergoing PD and that is something surgeons need to be aware of so that the aberrant vessels can be properly managed during the procedure to minimize adverse outcomes.

Like the aberrant right hepatic artery, an aberrant left hepatic artery can have implications during abdominal surgeries. In a radical gastrectomy for treatment of gastric cancer, removal of the hepatogastric ligament may be required as part of the procedure (Huang et al., 2013). However, arterial variants, including accessory left hepatic arteries, travel through the hepatogastric ligament, which could create complications during a radical gastrectomy (Huang et al., 2013). In order to assess the impact of an accessory left hepatic artery in patients undergoing a radical gastrectomy, Huang et al. (2013) retrospectively analyzed data of 1,173 gastric cancer patients who underwent the procedure laparoscopically to determine the prevalence of an accessory left hepatic artery in the patients and their short-term clinical outcomes. Patients were divided into two groups based on the presence or absence of an accessory left hepatic artery and then further stratified within the groups based on the presence or absence of chronic liver disease. The presence of an accessory left hepatic artery was found intraoperatively during dissection of the hepatogastric ligament in 11.5% (135) patients and severed as part of the surgical procedure. There were no significant differences in intraoperative characteristics, postoperative recovery, and short-term morbidity between the groups. However, when comparing patients with chronic liver disease, those with an accessory left hepatic artery that got severed as part of the procedure, had significantly higher liver function indices than those without an accessory left hepatic artery (Huang et al., 2013). Thus, the presence and then subsequent loss of the accessory left hepatic artery can create an adverse outcome in gastric surgical procedures in patients with liver disease. Clinicians need to be aware of this so that they can adjust surgical procedures accordingly and try to spare the accessory left hepatic artery in patients that have a compromised liver. Without the knowledge of this arterial variant and its path, intraoperative bleeding or ischemia of the liver could occur upon removal of the hepatogastric ligament, putting the patient at risk (Huang et al., 2013).

Adverse outcomes of surgical procedures are an important reason to be aware of the scope of variants found off the celiac trunk, especially the variant morphologies that are not described in Michels classification system. One such morphology is the double common hepatic artery, which was found in two cases (8%) in this study. The double common hepatic artery is a known variant. Covey et al. (2002) found this morphology in 22 of 600 cases (3.7%). Similar frequencies were reported in Sureka et al. (2013) based on a study of 600 CTA images, where 14 cases (2.33%) had a double common hepatic artery and in Thangarajah and Parthasarathy (2016) in which 7 of 200 cases (3.5%) had this morphology as found in CTA images. Relative to these reports, the frequency of the double common hepatic artery in the current study is higher (8%). However, if the definition of the double common hepatic artery described by Covey et al. (2002) is used and elaborated on by Sureka et al. (2013) – in which it is defined by one or more of the common hepatic arteries branching directly off the celiac trunk or aorta or it is an early branching of the right and left hepatic arteries of the celiac trunk – then one of the cases does not fit into that definition. In one of the cases observed in the current study, both common hepatic arteries originate from the celiac trunk and then come back together to form the proper hepatic artery after the gastroduodenal artery is given off (Figure 39). That morphology is not covered by the definitions set forth in the literature and could be considered a new variant that has not been previously classified. If that case is excluded from the double common hepatic artery category, then the prevalence of said category seen in our study becomes 4%, which is comparable with the frequency previously reported in the literature.

Another variant that was observed in multiple cases, but not part of Michels classification scheme is the dorsal pancreatic artery originating from the celiac trunk. This morphology was seen in three cases (12%). The dorsal pancreatic artery is most commonly a branch of the splenic artery (Bertelli et al., 1998). It travels dorsal to the splenic vein, dividing into terminal branches that run in opposite directions to supply the head and the tail of the pancreas. Often the terminal branches form anastomoses with pancreatic branches given off from the SMA and gastroduodenal arteries (Witte et al., 2001). While it most commonly arises from the splenic artery (70%), the dorsal pancreatic artery has been found to originate from the celiac trunk (10%), the SMA (10%) and the gastroduodenal artery (10%), (Bertelli et al., 1998). The prevalence of this morphology seen in this study is comparable to that reported in the literature, indicating that this morphology is stable across multiple populations.

The dorsal pancreatic artery is the most important artery for supplying blood to the tail of the pancreas and thus, plays an important role in pancreas transplants (Baranski et al., 2016). For a pancreas to be successfully transferred it must be removed from the donor with an intact blood supply. During a pancreas transplant, branches of the common hepatic artery and the celiac trunk that pass to the pancreas should be identified. Failure of clinicians to realize that the dorsal pancreatic artery can arise ectopically from the celiac trunk may lead to it being damaged or cut, compromising the blood supply to the tail of the pancreas and decreasing the viability of the donor organ (Baranski et al., 2016). If the dorsal pancreatic artery is cut, angiography may have to be used to determine the viability of the blood supply to the pancreas and efforts should be made to re-vascularize it to the splenic artery, increasing the complexity of the procedure (Baranski et al., 2016).

SMA Variants

The normal anatomy of the SMA and its branches was seen in only 5 of 25 cases (20%). The most common variations seen involved an ectopic origin of the right colic artery – 14 of 25 cases (56%) – an arc of Riolan – 5 of 25 cases (20%) – and variations involving the hepatic arteries as discussed previously – 4 of 25 cases (16%).

The right colic artery originated from the SMA in 20% of the cases (5 of 25), which is lower than the frequency reported in the literature (Table 5), (Gamo et al., 2016, Haywood et al., 2016, Michels et al., 1965, Negoi et al., 2018). Although the prevalence of the right colic artery originating from the SMA appears lower than that in the literature, the sample size of this study (n = 25) is the same as that of Haywood et al. (2016). There are only 3 more cases of the normal SMA anatomy in Haywood et al. (2016) than reported here. However, because of the limited sample size in both studies, the percent frequencies can appear more different than they really are. Thus, while the frequency of the normal anatomy appears lower than the range reported in the literature, it is actually similar to the values reported in Haywood et al. (2016) and Michels et al.

(1965) (Table 5).

The most common variant of the SMA branches was a common stem of the middle and right colic arteries; this was observed in 48% of the cases (12 of 25). This is the same as the frequency reported in Haywood et al. (2016) and is similar to the frequency of 52% reported in Michels et al. (1965). Although these studies are in consensus about the frequency of a common stem of the middle and right colic arteries, the frequency of this morphology is reported to be much lower in studies that include imaging and cadaveric based cases in which the prevalence was reported to be 15.4% and 4.28%-20% in Negoi et al. (2018) and Gamo et al. (2016), respectively. The difference in these values could be due to difficulty in imaging the blood supply to the small intestine. The small intestine has traditionally been a difficult site to image correctly due to its folded structure (Masselli, 2013). Additionally, nonspecific clinical presentations of many abdominal disorders make it difficult to know where to image (Masselli, 2013). Thus, the retrospective design of many imaging studies may be analyzing images that do not accurately portray the anatomy of the mesenteric blood supply because of these limitations. These studies are further constrained by a retrospective design because there is no ability to follow-up with patients and get additional scans. Therefore, it is possible that the prevalence of right colic artery variations may be under-reported in imaging studies. Even with these complications, imaging and cadaveric based studies agree that the origin of the right colic artery most often arises from the SMA or from a common stem with the middle colic artery and that is in line with the morphologies observed in this study.

The next most common variants seen were a common stem for the ileocolic and right colic arteries with a frequency of 8% (2 of 25 cases) and an absent right colic artery with a frequency of 8% (2 of 25 cases). The frequency of a common stem for the ileocolic and right colic arteries falls into the range reported in the literature of 8-15% (Table 5), (Gamo et al., 2016, Haywood et al., 2016, Michels et al., 1965, Negoi et al., 2018). The frequency of the absent right colic artery observed here falls into the upper limit of the frequency reported in the literature, 2.32-8%, but that may be because of the sample size of this study (Table 5), (Gamo et al., 2016, Haywood et al., 2016, Michels et al., 1965, Negoi et al., 2018).

There were zero cases of a common stem for all 3 colic arteries and supernumerary right colic arteries. The lack of a common stem for all 3 colic arteries is consistent with the frequency reported in the literature, with most studies reporting zero cases of this morphology (Table 5), (Gamo et al., 2016, Haywood et al., 2016, Michels et al., 1965, Negoi et al., 2018). The frequency of supernumerary right colic arteries reported here agrees with the frequency reported in Gamo et al. (2016) and Negoi et al. (2018) with zero cases reported. However, a higher frequency was found in Haywood et al. (2016) and Michels et al. (1965) with an incidence of 8-16% of cases. The difference in frequencies could be due to populational variations. Overall though, the frequencies of right colic artery variants identified in the current study were consistent with those reported in the literature demonstrating that variants in the right colic artery are stable across multiple populations and are something clinicians need to be aware of as they are likely to come across such variations.

Another variant that was commonly found was the arc of Riolan with a prevalence of 20% (5 of 25 cases). This frequency is similar to that reported in Gourley and Gering (2005) of 17.8%. The relatively few reports related to the arc of Riolan, however, makes it difficult to determine if this frequency range is consistent across multiple populations, but the similarity in prevalence seen in this study and Gourley and Gering (2005) suggests it may.

Variants of the SMA occur during embryogenesis (Gourley and Gering, 2005). The SMA, along with the celiac trunk and IMA, are formed by the fusion of paired ventral segmental arteries and interconnected via longitudinal anastomoses (Lin and Chaikof, 2000). Persistence of these primitive longitudinal anastomoses can result in variant morphologies of the SMA such as an ectopic origin of the right colic artery (Mishra et al., 2018). The reason for persistent anastomoses is still unknown, but an interplay between genetic determination and vessel plasticity based on environmental cues is the most likely explanation (Jones et al., 2006). It is accepted that blood flow through an embryonic vessel can change the identity, course, and patterning of that vessel, in a process known as flow-driven plasticity (Jones et al., 2006). As the embryonic gut continues to develop, it is highly mobile and receives blood from a dense vascular network (Mishra et al., 2018). Thus, as the gut continues to rotate, the final origin and course of the abdominal arteries may be influenced by the positioning of the organs, possibly leading to variant patterns of blood flow as the most efficient flow paths are established for each organ (Jones et al., 2006, Mishra et al., 2018).

A thorough understanding of the vascular patterns of the SMA and the possible variant morphologies is essential in oncological surgeries involving the right colon. One such procedure, the complete mesocolic excision, is a procedure used for those with colon cancer, in which the affected right colon and the lymphovascular supply draining the tumor are removed, including the colic arteries (Dimitriou and Griniatsos, 2015, Haywood et al., 2016). Clinicians must be aware of the variant morphologies of the right colic artery so that they can ensure that the correct vessel is ligated. Typically, part of the middle colic artery is left behind to maintain collateral blood flow pathways to the transverse and descending colons (Dimitriou and Griniatsos, 2015). If the right colic artery originates from the middle colic artery and the clinician is unaware of this, then it is possible that tumor cells may be missed which could lead to a worse surgical outcome (Dimitriou and Griniatsos, 2015, Haywood et al., 2016). Similarly, clinicians need to be aware of the possibility of supernumerary right colic arteries because if they are not identified then there is a potential that lymphatics with tumor deposits are left behind (Haywood et al., 2017). Thus, prior knowledge of variant morphologies of the SMA and right colic artery, in particular, are necessary for clinicians as they perform abdominal procedures to ensure the best outcomes for their patients.

Knowledge of the arc of Riolan is similarly important during abdominal procedures, specifically during anterior resections, in which part of or the entire descending colon and/or rectum are removed and an anastomosis to the remaining colon is created. As part of the procedure, the IMA is ligated from the abdominal aorta, meaning that the blood supply to the proximal anastomotic segment is derived from the SMA through the middle colic artery (Toh et al., 2018). If a patient has an arc of Riolan, that represents a collateral circulatory pathway and should be preserved to ensure proper blood flow to the proximal anastomotic segment. If the arc of Riolan is inadvertently injured during the procedure it can lead to acute colonic ischemia, which would then necessitate another procedure to fix the damage (Toh et al., 2018). Toh et al. (2018) compared the rates of acute colonic ischemia after anterior resection in cases with and without arc of Riolan sparing techniques. The rate of acute colonic ischemia before the arc of Riolan was routinely looked for, identified and spared, was 0.8% (6 of 723 cases). The rate after identifying and preserving the arc of Riolan was 0% (0 of 576 case), highlighting the importance of recognizing and sparing anatomical variants to provide the best surgical outcomes.

IMA Variants

The most commonly observed morphology of the IMA and its branches in this study was the typically described, normal anatomy with a frequency of 68% (17 of 25 cases). This is higher than the frequency reported in the literature, in which the highest reported frequency was 46.4% and the lowest reported frequency was 12% (Table 6), (Wang et al., 2018, Sinkeet et al., 2013). The frequency observed in the current study fell well outside this range, which could reflect population variability in IMA morphologies. Similarly, the incidence of a common stem for the left colic artery and the sigmoid artery observed here (4%) was outside the range of 23.6%-39.6% reported in the literature (Table 6), (Singh, 2016, Sinkeet et al., 2013, Wang et al., 2018). There were also no observed cases of a common stem for all three branches of the IMA, which was the second most common morphology found in Wang et al. (2018) with a frequency of

30.3%. The disparity of the results obtained from this study versus those reported in the literature may reflect population variability or an inconsistency in the frequency of IMA variants. Another explanation could also be derived from the methodology of this study. As part of the abdominal dissection procedure the abdominal viscera were removed from the abdominal cavity, meaning that the sigmoid colon gets separated from the rectum. Depending on where the cut was made, some of the branches of the IMA may have been severed from their target, making it difficult to determine the identity of those branches. Thus, there could be an underreporting of variant morphologies due to an inability to identify the terminal branches of the IMA.

The presence of IMA morphologies that do not fit into the traditional classification system are important to note because they demonstrate that the IMA can take on even more forms than previously thought. There were 2 cases (8%) in which the IMA branched differently than the variant anatomies described in the literature. The presence of other variant morphologies is not novel concept as there was also a case of a miscellaneous morphology in Singh (2016). The greater number of variant morphologies of the IMA is important to note for clinicians performing left colon resections because they need to be aware of which arteries are supplying the left colon. During a left colon resection either the entire colon or a section of the colon can be removed, and an artificial anastomosis is created between the remaining length of colon (Trebuchet et al., 2002). Part of this procedure involves ligating the IMA with a high-tie – which occurs where the IMA branches from the abdominal aorta – or with a low-tie in which the IMA is ligated below the branch point of the left colic artery, thus preserving it (Wang et al., 2018). If there is variant anatomy of the IMA, especially a common trunk of all three of the branches, a high-tie may not be an option because it could damage blood supply to the remaining colon (Wang et al., 2018). Knowledge of the IMA branches are crucial to colorectal surgeons so that they can ensure proper post-operative blood supply to the colon anastomosis and prevent intraoperative colon ischemia resulting from interrupted blood supply.

Renal Artery Variants

Normal renal artery morphology was observed in 58.3% of cases. Supernumerary renal arteries were found in 41.7% of cases with multiple renal arteries observed in 20.8% of cases, accessory renal arteries observed in 12.5% of cases, and a combination of multiple and accessory renal arteries observed in 8.3% of cases. The frequency of supernumerary renal arteries observed here is similar to that found in Talović et al. (2007) cadaveric based study in which a frequency of 46.15% was observed. However, the frequency observed in the current study is higher than that observed in imaging-based studies where a range of 24%-26.2% was observed for supernumerary renal arteries (Kuczera et al., 2009, Özkan et al., 2006). This could be explained by the difficulty in observing accessory renal arteries on imaging scans due to their small caliber (Kuczera et al., 2009, Özkan et al., 2006).

Interestingly, the frequency of multiple renal arteries observed in this study was greater than the frequency of accessory renal arteries. Even with the discrepancy in frequency ranges of renal artery variants, the literature most often finds accessory renal arteries at a higher frequency than multiple renal arteries (Table 9), (Kuczera et al., 2009, Özkan et al., 2006, Talović et al., 2007). The greater frequency of multiple renal arteries observed here may be due to population differences or sample size. The sample size of this study is smaller than the aforementioned studies meaning that the frequency appears higher even though a similar number of cases with multiple renal arteries was actually found when it is compared to Talović et al. (2007). Either way, the frequency of the multiple renal arteries (20.8%) observed in this study is still similar, though slightly higher, to that reported in the literature of 11.2%-17.95% (Table 9), (Kuczera et al., 2009, Özkan et al., 2006, Talović et al., 2007).

The frequency of accessory renal arteries observed here – 12.5% – falls into the range reported in the literature of 12.4%-28.2% (Table 9), (Kuczera et al., 2009, Özkan et al., 2006, Talović et al., 2007). While the observed frequency does fall into the reported range, it is still slightly lower than may be expected based on the results of the other cadaveric-based dissection study. This could reflect local populational differences. There is also a possibility that some accessory renal arteries may have been lost during the dissections creating a lower than expected frequency.

The addition of a variant group including a combination of the multiple and accessory renal arteries in this study may also be responsible for changing the frequencies of the other variants because those variants are reported in this category as opposed to the others. In the literature, it is difficult to determine how many cases have co-occurring variants, as that frequency is not often expressed explicitly. However, the inclusion of this category provides a clearer picture of the morphologies seen and demonstrates that the presence of one variant does not preclude another variant from also existing. It is important to realize that multiple variations can be present at the same time or can occur together.

Variations of the renal artery can be explained embryologically by the development of the mesonephric arteries (Özkan et al., 2006). The developing kidney is supplied by many pairs of mesonephric arteries arising from the lateral segmental arteries of the dorsal aorta (Budhiraja et al., 2010). The fifth through ninth mesonephric arteries form the rete arteriosum urogenitale, an extensive arterial network that supply the mesonephros, metanephros, and reproductive gland (Özkan et al., 2006). According to the ladder theory, as the developing kidney ascends into the abdominal cavity it is supplied by multiple mesonephric arteries. The dominant artery becomes enlarged and is the precursor to the definitive renal artery and the other mesonephric arteries degenerate. However, if any of the mesonephric arteries persist, that can lead to supernumerary renal arteries (Budhiraja et al., 2013). This embryological explanation may not fully explain supernumerary renal arteries as it only works if the ladder theory is true, which as discussed previously, may not accurately depict the development of renal vascularization. It is likely that renal artery variants develop through a combination of factors, including the incorrect regression of mesonephric arteries as well as vasculogenesis of new renal arteries from the abdominal aorta as the primordial kidney ascends (Isogai et al., 2010).

Regardless of the mechanism in which supernumerary renal arteries develop, their presence in postnatal life is important as they can have a clinical significance. Clinicians need to be aware of the possible variants in the renal vasculature especially multiple and/or accessory renal arteries because a link between multiple renal arteries and the emergence of arterial hypertension has been observed (Glodney et al., 2000). Stimulation of the renin-angiotensin-aldosterone system (RAAS) is believed to underlie the association between multiple renal arteries and hypertension (Glodney et al., 2001). The RAAS is an enzymatic signaling cascade responsible for regulating blood pressure (DeMello and Re, 2009). The kidneys release renin in response to low blood pressure, initiating a signal transduction pathway in which renin cleaves the hepatically derived protein, angiotensinogen, into angiotensin I. Angiotensin I is then converted to angiotensin II via angiotensin-converting enzyme (ACE). Angiotensin II simultaneously stimulates vasoconstriction, the release of vasopressin from the pituitary gland, and the release of adrenaline, noradrenaline, and aldosterone from the adrenal gland. Adrenaline and noradrenaline further stimulate vasoconstriction while aldosterone acts on the kidneys causing them to retain more sodium and water while excreting more potassium. Vasopressin similarly acts on the kidneys, suppressing the excretion of water from the body. The cumulative effect of this signaling pathway is an increase in blood pressure which occurs as a greater volume of blood flows through constricted arteries, increasing the pressure on the arterial wall (DeMello and Re, 2009).

Glodney et al. (2000) investigated this link between hypertension and multiple renal arteries by quantifying plasma renin levels in patients with single renal arteries versus patients with multiple renal arteries. Blood pressure and blood samples were collected from each group at rest and at 30 and 60 minutes after an injection of frusemide, a medication meant to lower blood pressure. Blood pressure and plasma renin concentrations were significantly higher in the group with multiple renal arteries across all three time points, supporting the idea that the presence of multiple renal arteries stimulates the renin-angiotensin-aldosterone axis which may lead to hypertension (Glodney et al. 2000). The proposed mechanism linking multiple renal arteries and hypertension lies in the pressure gradient created by the renal arteries. The diameter of the duplicate and accessory renal arteries is usually smaller than that of a single renal artery, leading to a smaller volume of blood passing through the arteries and likely a lower blood pressure (Glodney et al. 2000). The low pressure is a signal for the kidneys to release renin, which begins the RAAS signaling cascade, leading to an increase in blood pressure. Thus, patients with multiple renal arteries may be more susceptible to developing hypertension because of a sustained increase in plasma renin levels. While the mechanism between multiple renal arteries and hypertension is not fully illuminated, it shows that vascular variants may have more of a role in the development of disorders than previously thought. The presence of the variant does not mean causation of the pathology, but it is still important to consider that arterial variants can be considered risk factors for certain diseases.

Central Vs. Peripheral

Examining the relationship between the central and peripheral arterial variants, the most common variants to occur in tandem were variants of the foregut and midgut with variants of the left subclavian artery, the upper and lower extremities, and the right iliac artery (Table 18). This could indicate that there is an association between the variants of the abdominal vasculature and peripheral vascular variants. However, when looking at the frequency of normal central arterial anatomy occurring with normal peripheral arterial anatomy, there is a greater number of cases with this relationship compared to groupings of variant central and variant peripheral arterial anatomy. The only groups where this pattern does not hold true are the foregut and midgut.

The foregut and midgut are unique compared to the other central categories because there is a greater frequency of cases involving the variant foregut/midgut + variant central anatomy and the variant foregut/midgut + variant peripheral arterial anatomy. In contrast, the other central arterial categories are more often observed in groupings involving normal central arterial anatomy + variant central arterial anatomy and normal central arterial anatomy + variant peripheral arterial anatomy (Tables 24-27). It is possible that this indicates an association between variant abdominal vasculature and vascular variants elsewhere. However, this association may also be explained by the high prevalence rate of variant foregut and midgut arterial anatomy. Normal foregut arterial morphology was only observed in 8% of the cases in the present study, whereas the incidence rates for normal foregut arterial anatomy are reported between 61.3% and 81% in the literature (Covey et al., 2002, Noussios et al., 2017). Similarly, the incidence rate of normal midgut arterial anatomy observed in the present study, 20%, is lower than that reported in the literature of 32%-73.69% (Gamo et al., 2016, Haywood et al., 2016, Michels et al., 1965, Negoi et al., 2018). The greater frequency of variant foregut and midgut cases in the present study makes it appear as if there is a relationship between central and peripheral variants. The sheer number of foregut and midgut cases means it is far more likely that the peripheral variants will be observed co-occurring with them simply because there are almost no cases with the alternative option.

When variants with a lower frequency rate in the present study are considered, (e.g. the aortic arch and renal arteries), there is less of an association between variant central arterial anatomy + variant central arterial anatomy, and variant central arterial anatomy + variant peripheral arterial anatomy. This can be seen with the aortic arch, in which there was a higher frequency of cases involving the normal aortic arch + variant central arterial anatomy, as opposed to the variant aortic arch + variant central anatomy (Table 20). This pattern also holds true when considering peripheral vascular variants, the normal aortic arch + variant peripheral arterial anatomy was more often observed than variant aortic arch + variant peripheral arterial anatomy (Table 21). The difference in groupings between the foregut and midgut and the aortic arch indicate that there is not a consistent pattern in which arterial variants occur throughout the body. However, as previously noted, this inconsistency may simply reflect the high incidence rates of these foregut and midgut arterial variants. The incidence of normal aortic arch anatomy observed in the present study (80%), falls into the range reported in the literature, 74.29% to 90.3% (Nayak et al., 2006, Rojas et al., 2017). This agreement of frequency ranges generates support that the pattern of arterial variants observed for the aortic arch may be more indicative of the actual relationship between arterial variants than the patterns observed with the foregut and midgut.

The pattern of arterial variants seen for the aortic arch also holds true for another category of the central vasculature, the renal arteries. The trend of a higher frequency of cases involving the normal renal artery anatomy + variant central arterial anatomy and normal renal artery anatomy + variant peripheral arterial anatomy, was also observed for the right and left renal arteries (Tables 30-33). And like the aortic arch, the prevalence rate for the renal arteries observed in the current study (41.7%) is similar to Talović et al's. (2007) cadaveric based study in which a frequency of 46.15% was observed. The repetition of this pattern across multiple central variants with observed prevalence rates that are consistent with prior reports, supports the idea that this is most reflective of the relationship between central and peripheral vascular anatomy as opposed to the pattern seen with the variant foregut and midgut.

Other areas of central vasculature agree with this pattern even though their observed frequencies are less supported by prior reports. The observed frequency of coronary artery variants in this study was lower than that reported in the literature, though the incidence rates were comparable. Either way, the coronary arteries display the same pattern as the aortic arch and the renal arteries in which the normal anatomy is more often observed in tandem with variant central and variant peripheral anatomy. This indicates that this relationship is preserved across multiple areas of central vasculature (Tables 22-23).

This pattern is also preserved when looking at the relationship of the hindgut to the other areas of central and peripheral vasculature. Like the coronary arteries, the observed frequency of IMA variants, 32%, was lower than that reported in the literature where a range of 53.6% to 88% has been observed (Table 28-29) (Wang et al., 2018, Sinkeet et al., 2013). However, the similarity of vascular variant groupings including the normal hindgut to the aforementioned central variants, indicates that lower frequency of variants observed in the current study may not impact the observed relationship between central and peripheral variants. Indeed, it is possible that the pattern of the hindgut with other central and peripheral vascular variants is actually a more accurate depiction of the relationship between abdominal vascular variants and other vascular variants throughout the body. The greater frequency of variant foregut and midgut cases in the present study makes it appear as if there is a relationship between central and peripheral variants. However, if the frequency rates of variant foregut and midgut cases was more similar to the frequency rate of hindgut variants than it is possible that they would also have displayed the same pattern as the other central vascular areas. Nonetheless, without the support of the literature regarding the frequency of hindgut variation observed in this study, it is uncertain if that would be the case.

Taken together, the relationship between central and peripheral arterial variants does not seem to follow the pattern observed with the foregut and midgut, but rather is more similar to that observed with the other central vascular areas. The frequency of cases involving normal central anatomy and variant peripheral anatomy means that vascular variants in the periphery are likely unrelated to variants in the central body cavities. However, it does seem like there are “hot spots” for arterial variants to occur. There was a consistently higher frequency of cases involving peripheral variations of the left subclavian artery, right and left upper extremities, the right iliac artery, and the right and left lower extremities.

Similarly, central vascular variants seem unrelated to one another. The only exceptions were variants in the foregut and midgut; these seem to have a relationship to one another. When looking at the frequency of multiple central variants compared simultaneously, the highest frequencies occurred when the foregut and midgut were paired together. This could indicate that variants of foregut arteries may be associated with variants of midgut arteries, and vice versa. An association between variants of the foregut and midgut is very plausible based on their embryonic development. The celiac trunk, SMA, and IMA are formed by the fusion of paired ventral segmental arteries and interconnected via longitudinal anastomoses (Lin and Chaikof, 2000). Typically, the ventral segmental arteries that form the branches of the celiac trunk are separated from the segmental artery that forms the SMA, but if the separation occurs at the wrong location or if there is an inappropriate regression or persistence of the segmental arteries then variations of the celiac trunk and SMA can occur (Gourley and Gering, 2005, Yildirim et al., 1998). The IMA may not necessarily be affected because the celiac trunk and SMA develop in very close proximity to one another while the IMA is further down the abdominal aorta (Lin and Chaikof, 2000).

The development of blood vessels helps explain the lack of relationship between the central and peripheral variants. It is well known that blood vessels form through a combination of vasculogenesis – the formation of new blood vessels from an aggregation of endothelial cells – and angiogenesis – the creation of new vessels from existing vessels (Udan et al., 2013). As capillary networks are established throughout the body, the primordial arteries undergo vascular remodeling, maturation, and patterning all of which contribute to the final organization of arteries seen later in life (Udan et al., 2013). These processes are regulated by a multitude of factors including hemodynamic forces, viscous forces imparted by blood flow, and oxygenation levels (Rodríguez-Niedenführ et al., 2001, Udan et al., 2013). It is still unknown how these forces are interpreted at the cellular level, but it is understood that there is a mechanism that is likely guided by an interplay of an underlying genetic blueprint and local environmental cues (Rodríguez-Niedenführ et al., 2001, Udan et al., 2013). The local environmental cues - such as the hemodynamic forces or the secretion of growth factors - on the primordial vessels can impact blood vessel patterning at the local level, possibly leading to the arterial variations seen in the adult form (Udan et al., 2013). Because of the local nature of these factors, variations can develop in specific areas in the body without impacting other areas of the body.

This may lead to the vascular variant patterns seen in this study, in which most specimens contained multiple vascular variations that appear to be unrelated to one another. It is important to note, that the relationships between vascular variants observed in the present study were based on qualitative observation rather than statistical analysis. This means that although there was no discernable pattern found between vascular variants in the present study, that does not preclude the possibility that there is a significant relationship between certain vascular variants. Future research is needed to elucidate if there are any significant relationships between different vascular variants.

Either way, the high prevalence of cases with multiple arterial variations suggests that they may be more likely to occur than previously thought. Clinicians need to be aware of this because it increases the possibility of finding multiple variants during a procedure. And depending on the diameter of the aberrant vessels, they may not be detectable on pre-operative imaging scans. Thus, a thorough understanding of the possible arterial variations they may encounter is necessary to avoid intraoperative complications.

APPENDIX I

Lab 3: Axilla and Arm

Pod:__________ Table:___________

Reference Plates: Netter (6^{th} edition) 414, 415, 420, 460

AXILLA AND ARM (please check if variant is present)

Artery	Right (variant present)	Left (variant present)	Comment (Optional)
Axillary artery			
Thoracoacromial artery			
Lateral thoracic artery			
Subscapular artery			
Circumflex scapular artery			
Thoracodorsal artery			
Posterior circumflex humeral artery			
Anterior circumflex humeral artery			
Brachial artery			
Ulnar artery			
Radial artery			
Deep brachial artery			
Superior ulnar collateral artery			
Inferior ulnar collateral artery			

Lab 4: Forearm and Hand

Pod:_________ Table:__________

Reference Plates, Netter 6th edition: 434, 435, 449, 453, 460

FOREARM AND HAND (Please check if variant is present)

Artery	Right (Variant Present)	Left (Variant Present)	Comment (Optional)
Radial artery			
Ulnar artery			
Radial recurrent artery			
Common interosseous artery			
Anterior interosseous artery			
Posterior interosseous artery			
Superficial palmar arch			
Deep palmar arch			

Lab 5: Lower Extremity 1

Pod:_________ Table:__________

Reference Plates, Netter 6th edition: 487, 488, 489, 499

LOWER EXTREMITY 1 (Please check if variant is present)

Artery	Right (Variant Present)	Left (Variant Present)	Comment (Optional)
Inferior gluteal artery			
Superior gluteal artery			
Femoral artery			
Deep femoral artery (deep artery of the thigh			
Lateral circumflex femoral artery			
Medial circumflex femoral artery			

Lab 6: Lower Extremity 2

Pod:_________ Table:__________

Reference Plates, Netter 6th edition: 499, 505, 508, 509, 523

LOWER EXTREMITY 2 (Please check if variant is present)

Artery	Right (Variant Present)	Left (Variant Present)	Comment (Optional)
Popliteal artery			
Superior lateral genicular artery			
Superior medial genicular artery			
Inferior lateral genicular artery			
Inferior medial genicular artery			
Posterior tibial artery			
Anterior tibial artery			
Fibular artery			
Dorsalis pedis artery			
Deep plantar artery			
Plantar arch			
Arcuate artery			
Medial plantar artery			
Lateral plantar artery			

Lab 1: Thoracic and Abdominal Walls; Thoracic Cavity

Pod:__________ Table:___________

Reference Plates: Netter (6^{th} edition) 186, 187, 190, 195 245, 246, 247, 251

Artery	Right (variant present)	Comment (Optional)
Internal thoracic artery		
Intercostal arteries		
Superior epigastric artery		
Inferior epigastric artery		
Pulmonary artery		
Pericardiophrenic arteries		
Ascending aorta		
Arch of the aorta		

Lab 2: Heart and Mediastinum

Pod:__________ Table:___________

Reference Plates: Netter (6th edition) 203, 209, 215, 216, 233

Artery	Variant present	Comment (Optional)
Arch of the aorta		
Brachiocephalic trunk		
Left common carotid artery		
Left subclavian artery		
Left coronary artery		
Left anterior descending artery (LAD)		
Circumflex branch		
Right coronary artery		
Anterior right atrial branch		
Sinuatrial nodal branch		
Right marginal artery		
Posterior interventricular artery		
Esophageal arteries		
Bronchial arteries		
Posterior intercostal arteries		

Lab 3: Abdominal Viscera and Vasculature

Pod:__________ Table:___________

Reference Plates: Netter (6th edition) 283, 284, 286, 287, 288,

Artery	Variant Present	Comment (Optional)
Celiac trunk		
Left gastric artery		
Common hepatic artery		
Gastroduodenal artery		
Right gastro-omental (gastroepiploic) artery		
Hepatic artery proper		
Right gastric artery		
Left hepatic artery		
Right hepatic artery		
Cystic artery		
Anterior superior pancreaticoduodenal artery		
Posterior superior pancreaticoduodenal artery		
Splenic artery		
Short gastric arteries		
Left gastro-omental (gastroepiploic) artery		
Dorsal pancreatic artery		
Superior mesenteric artery		
Inferior pancreaticoduodenal artery		
Ileocolic artery		
Appendicular artery		

Right colic artery		
Middle colic artery		
Inferior mesenteric artery		
Left colic artery		
Sigmoid arteries		
Superior rectal artery		

Lab 4: Removal of Viscera; Posterior Abdominal Walls

Pod:__________ Table:___________

Reference Plates: Netter (6th edition) 259, 308, 310,

Artery	Variant Present	Comment (Optional)
Celiac trunk		
Superior mesenteric artery		
Inferior mesenteric artery		
Testicular artery		
Ovarian artery		
Left renal artery		
Right renal artery		
Inferior suprarenal artery		
Ureteric branch		
Superior suprarenal arteries		
Middle suprarenal artery		
Inferior suprarenal artery		
Lumbar arteries		
Inferior phrenic artery		
Common iliac artery		

Lab 5: Perineum

Pod:__________ Table:___________

Reference Plates: Netter (6th edition) 355, 357, 358, 376, 382, 383,

Artery	Variant Present	Comment (Optional)
Inferior rectal artery		
Internal pudendal artery		
Testicular artery		
Dorsal artery of the penis		
Deep artery of the penis		
Posterior labial artery		
Dorsal artery of the clitoris		

Lab 6: Pelvic Contents and Vasculature

Pod:__________ Table:___________

Reference Plates: Netter (6th edition) 376, 378, 379, 380, 381, 382, 383

Artery	Variant Present	Comment (Optional)
Superior rectal artery		
Common iliac artery		
External iliac artery		
Internal iliac artery		
Umbilical artery		
Superior vesicle arteries		
Obturator artery		
Uterine artery		
Vaginal artery		
Inferior vesical artery		
Middle rectal artery		
Internal pudendal artery		
Inferior gluteal artery		
Iliolumbar artery		
Lateral sacral artery		
Superior gluteal artery		

Lab 1: Triangles of the Neck

Pod:__________ Table:___________

Reference Plates: Netter (6th edition) 32, 33, 34, 72, 77

Artery	**Right (variant present)**	**Left (variant present)**	**Comment (Optional)**
Common carotid artery			
Internal carotid artery			
External carotid artery			
Superior thyroid artery			
Superior laryngeal artery			
Lingual artery			
Facial artery			
Occipital artery			
Posterior auricular artery			
Ascending pharyngeal artery			
Subclavian artery			
Vertebral artery			
Internal thoracic artery			
Thyrocervical trunk			
Costocervical trunk			
Dorsal scapular artery			

Lab 2: Face

Pod:__________ Table:___________

Reference Plates: Netter (6^{th} edition) 3, 35, 72, 87

Artery	**Right (variant present)**	**Left (variant present)**	**Comment (Optional)**
Facial artery			
Superior labial artery			
Inferior labial artery			
Angular artery			
Mental artery			
Maxillary artery			
Superficial temporal artery			
Infraorbital artery			
Supraorbital artery			

Lab 3: Intracranial Fossa; Cranial Contents

Pod:__________ Table:___________

Reference Plates: Netter (6th edition) 51, 72, 140, 141, 142, 143

Artery	Right (variant present)	Left (variant present)	Comment (Optional)
Maxillary artery			
Middle meningeal artery			
Deep temporal arteries			
Inferior alveolar artery			
Buccal artery			
Posterior superior alveolar artery			
Posterior inferior cerebellar artery			
Basilar artery			
Anterior inferior cerebellar artery			
Superior cerebellar artery			
Posterior cerebral artery			
Posterior communicating artery			
Middle cerebral artery			
Anterior cerebral artery			
Anterior communicating artery			

Lab 5: Orbit, Nasal, and PPF

Pod:__________ Table:___________

Reference Plates: Netter (6th edition) 40, 51, 57, 87

Artery	Right (variant present)	Left (variant present)	Comment (Optional)
Ophthalmic artery			
Supraorbital artery			
Supratrochlear artery			
Sphenopalatine artery			
Descending palatine artery			
Greater palatine artery			
Lesser Palatine artery			
Infraorbital artery			

Lab 6: Oral Cavity and Larynx

Pod:__________ Table:___________

Reference Plates: Netter (6th edition) 56, 59

Artery	Right (variant present)	Left (variant present)	Comment (Optional)
Lingual artery			
Sublingual artery			
Deep lingual artery			

REFERENCES

Abu-Assi, E., Castiñeira-Busto, M., González-Salvado, V., Raposeiras-Roubin, S., Abumuaileq, R., R-Y., Peña-Gil, C., Rigueiro-Veloso, P., Ocaranza, R., García-Acuña, J. M., and González-Juanatey, J. R. (2016). Coronary Artery Dominance and Long-term Prognosis in Patients With ST-segment Elevation Myocardial Infarction Treated with Primary Angioplasty, *Revista Española de Cardiología*, 69:19-27.

Aird, W. C. (2011). Discovery of the cardiovascular system: from Galen to William Harvey, *Journal of Thrombosis and Haemostasis*, 9:118-129.

Agarwal, S., Lalwani, R., and Ramesh Babu, C. S. (2016). Embryological Basis and Clinical Importance of the Variant Branching Pattern of the Axillary Artery, *Journal of Dental and Medical Sciences*, 15:101-104.

Alakkam, A., Hill, R.V., and Saggio, G. (2016). Superior mesenteric origin of the common hepatic artery: embryological and clinical implications, *Surgical and Radiologic Anatomy*, 38:747-750.

Alsabilah, J., Kim, W. R., and Kim, N. K. (2017). Vascular Structures of the Right Colon: Incidence and Variations with their Clinical Significance, *Scandinavian Journal of Surgery*, 106:107-115.

Al Talalwah, W. B. and Getachew, D. R. (2015). The Clinical Significance of Ulnar Artery Morphology in Artificial Arterial-Venous Fistula for Hemodialysis, *Malaysian Journal of Medical Sciences*, 22:41-47.

Al Talalwah, W., Getachew, D., and Soames, R. (2015). Morphological feature of brachial artery and its clinical significance, *Journal of Morphological Science*, 32:129-134.

Arévalo Pérez, J., Gragera Torres, F., Marín Toribio, A., Koren Fernández, L., Hayoun, C., and Daimiel Naranjo, I. (2013). Angio CT assessment of anatomical variants in renal vasculature: its importance in the living donor, *Insights into Imaging*, 4:199–211.

Baranski, A. G., Lam, H-D., Braat, A. E., and Schaapherder, A. F. (2016). The dorsal pancreatic artery in pancreas procurement and transplantation: anatomical considerations and potential implications, *Clinical Transplantation*, 30:1360-1364.

Bergman, R. A., Afifi, A. K. and Miyauchi, R. (2018). Suprarenal Arteries. In R. A. Bergman (Ed.), *Anatomy Atlases*. Retrieved from www.anatomyatlases.org.

Bernanke, B.H., and Velkey, M. (2002). Development of the Coronary Blood Supply: Changing Concepts and Current Ideas, *The Anatomical Record*, 269:198-208.

Bertelli, E., Di Gregorio, F., Mosca, S., and Bastianini, A. (1998). The arterial blood supply to the pancreas: a review. V. The dorsal pancreatic artery. An anatomic review and a radiologic study, *Surgical and Radiologic Anatomy*, 20:445-452.

Bilhim, T., Pereira, J. A., Fernandes, L., Tinto, H. R., and Pisco, J. M. (2014). Angiographic Anatomy of the Male Pelvic Arteries, *American Journal of Roentgenology,* 203:373-382.

Bogers, A. J. J. C., Gittenberger-de Groot, A. C., Poelmann, R. E., Péault, B. M., and Huysmans, H. A. (1989). Development of the origin of the coronary arteries, a matter of ingrowth or outgrowth? *Anatomy and Embryology,* 180:437-441.

Bradley, R. L. (1973). Surgical Anatomy of the Gastroduodenal Artery, *International Surgery*, 58:1-3.

Brantley, S. K., Rigdon, E. E., and Raju, S. (1993). Persistent sciatic artery: Embryology, pathology, and treatment, *Journal of Vascular Surgery*, 18:242-248.

Budhiraja, V., Rastogi, R., Anjankar, V., Ramesh Babu, C. S., and Goel, P. (2013). Supernumerary Renal Arteries and Their Embryological and Clinical Correlation: A Cadaveric Study from North India, *International Scholarly Research Notices Anatomy*, 2013:1-4.

Budhiraja, V., Rastogi, R., and Asthana, A. K. (2010). Renal artery variations: embryological basis and surgical correlation, *Romanian Journal of Morphology and Embryology*, 51:533-536.

Cahill, D. R., Leonard, R. J., Weiglein, A. H., and von Lüdinghausen, M. (2002). Viewpoint: unrecognized values of dissection considered, *Surgical and Radiologic Anatomy*, 24:137-139.

Ciná, C. S., Arena, G. O., Bruin, G., and Clase, C. M. (2000). Kommerell's diverticulum and aneurysmal right-sided aortic arch: A case report and review of the literature, *Journal of Vascular Surgery*, 32:1208-1214.

Covey, A. M., Brody, L. A., Maluccio, M. A., Getrajdman, G. I., and Brown, K. T. (2002) Variant hepatic arterial anatomy revisited: digital subtraction angiography performed in 600 patients, *Radiology*, 224:542-547.

Darmanis, S., Lewis, A., Mansoor, A., and Bircher, M. (2007). Corona mortis: An anatomical study with clinical implications in approaches to the pelvis and acetabulum, *Clinical Anatomy*, 20:433-439.

Davies, M. J., Treasure, T., and Richardson, P. D. (1996). The pathogenesis of spontaneous arterial dissection, *Heart,* 75:434-435.

De Cecco, C. N., Ferrari, R., Rengo, M., Paolantonio, P., Vecchietti, F., and Laghi, A. (2009). Anatomic variations of the hepatic arteries in 250 patients studied with 64-row CT angiography, *European Radiology* 19:2765-2770.

DeMello, W. C., and Re, R. N. (2009). Systemic Versus Local Renin Angiotensin System. An Overview. In E. D. Frohlich and W. C. DeMello (Eds.), *Renin Angiotensin System and Cardiovascular Disease* (pp. 1-5). New York, NY: Humana Press.

De Martino, R. R. (2015). Normal and Variant Mesenteric Anatomy. In G. S. Oderich (Ed.), *Mesenteric Vascular Disease* (pp. 9-23). New York, NY: Springer Science+Business Media.

Dimitriou, N. and Griniatsos, J. (2015). Complete mesocolic excision: Techniques and outcomes, *World Journal of Gastrointestinal Oncology*, 7:383–388.

Dixit, D., Kubavat, D. M., Rathod, S. P., Pateld, M. M., and Singel, T. S. (2011). A Study Of Variations In The Origin Of The Profunda Femoris Artery And Its Circumflex Branches, *International Journal of Biological and Medical Research,* 2:1084-1089.

Dudich, K., Bhadelia, R., and Srinivasan, J. (2005). Anomalous vertebral artery origin may be an independent risk factor for arterial dissection, *European Journal of Neurology*, 12(7): 571-572.

Dungan, D. H. and Heiserman, J. E. (1996). The Carotid Artery Embryology, Normal Anatomy, and Physiology, *Neuroimaging Clinics of North America*, 6:789-799.

Dutta, S. (2010). Suprarenal gland-arterial supply: an embryological basis and applied importance, *Romanian Journal of Morphology and Embryology,* 51:137-140.

Ellis, H. (2001). Teaching in the Dissecting Room, *Clinical Anatomy*, 14:149-151.

Farmery, A. D., Shlugman, D., and Anslow, P. (2003). How high do the subclavian arteries ascend into the neck? A population study using magnetic resonance imaging, *British Journal of Anesthesia*, 90:452-456.

Favelier, S., Germain, T., Genson, P-Y., Cercueil, J-P., Denys, A., Krausé, D. and Guiu, B. (2015). Anatomy of liver arteries for interventional radiology, *Diagnostic and Interventional Imaging*, 96:537-546.

Fisher, D.F. Jr, and Fry, W.J. (1987). Collateral mesenteric circulation, *Surgery, Gynecology, and Obstetrics*, 164:487–492.

French, J. W., and Guntheroth, W. G. (1970). An Explanation of Asymmetric Upper Extremity Blood Pressures in Supravalvular Aortic Stenosis: The Coanda Effect, *Circulation*, 42:31-36.

Gamo, E., Jiménez, C., Pallares, E., Simón, Valderrama, F., Sañudo, J. R., and Arrazola, J. (2016). The superior mesenteric artery and the variations of the colic patterns. A new anatomical and radiological classification of the colic arteries, *Surgical and Radiologic Anatomy*, 38:519-527.

Glodny, B., Cromme, S., Reimer, P., Lennarz, M., Winde, G., and Vetter, H. (2000). Hypertension associated with multiple renal arteries may be renin-dependent, *Journal of Hypertension*, 18:1437-1444.

Glodny, B., Cromme, S., Wörtler, K., and Winde, G. (2001). A possible explanation for the frequent concomitance of arterial hypertension and multiple renal arteries, *Medical Hypotheses*, 56:129-133.

Gourley, E.J. and Gering, S. A. (2005). The Meandering Mesenteric Artery: A Historical Review and Surgical Implications, *Diseases of the Colon and Rectum*, 48:996-1000.

van Gulik T. M., and Schoots I. (2005). Anastomosis of Riolan Revisited The Meandering Mesenteric Artery, *Archives of Surgery*, 140:1225–1229.

Ha, H. I., Kim, M-J., Kim, J., Park, S-Y., Lee, K., and Jeon, J. Y. (2016). Replaced common hepatic artery from the superior mesenteric artery: multidetector computed tomography (MDCT) classification focused on pancreatic penetration and the course of travel, *Surgical and Radiologic Anatomy*, 38:655-662.

Hannemen, K., Newman, B., and Chan, F. (2016). Congenital Variants and Anomalies of the Aortic Arch, *RadioGraphics,* 37:32-51.

Hapugoda, S., Hsu, C. C.-T., Kwan, G. N. C., Watkins, T. W., and Rophael, J. A. (2016). Duplication of the superficial femoral artery: comprehensive review of imaging literature and insight into embryology, *Acta Radiologica Open*, *5*:1-4.

Harcourt, Glenn. (1987). Andreas Vesalius and the Anatomy of Antique Sculpture, *Representations*, 17: 28–61

Haywood, M., Molyneux, C., Mahadevan, V., Lloyd, J., and, Srinivasaiah, N. (2016). The right colic artery: An anatomical demonstration and its relevance in the laparoscopic era, *Annals of The Royal College of Surgeons of England*, 98: 560–563.

Haywood, M., Molyneux, C., Mahadevan, V., and Srinivasaiah, N. (2017). Right colic artery anatomy: a systematic review of cadaveric studies, *Techniques in Coloproctology*, 21:937-943.

Hazirolan, T., Öz, M., Türkbey, B., Karaosmanoğlu, Oğuz, B. S., and Canyiğit, M. (2011). CT angiography of the renal arteries and veins: normal anatomy and variants, *Diagnostic and Interventional Radiology*, 17:67-73.

Herlitz, J., Hjalmarson, A., Lomsky, M., and Wiklund, I. (1988). The relationship between infarct size and mortality and morbidity during short-term and long-term follow-up after acute myocardial infarction, *American Heart Journal*, 116(5 pt 1): 1378-1382.

Hinata, N., Suzuki, R., Ishizawa, A., Miyake, H., Rodriguez-Vasquez, J. F., Murakami, G., and Fujisawa, M. (2015). Fetal development of the mesonephric artery in humans with reference to replacement of the adrenal and renal arteries, *Annals of Anatomy*, 202:8-17.

Horton, K. M. and Fishman, E. K. (2002). Volume-rendered 3D CT of Mesenteric Vasculature: Normal Anatomy, Anatomic Variants, and Pathologic Conditions, *RadioGraphics,* 22:161-172.

Hosalinaver, J. and Hosalinaver, A. (2018). A study of incidence of trifurcation of left coronary artery in adult human hearts, *Italian Journal of Anatomy and Embryology*, 123:51-54.

Huang, C-M., Chen, Q-Y., Lin, J-X., Zheng, C-H., Li, P., Xie, J-W., Wang, J-B., and Lu, J. (2013). Short-Term Clinical Implications of the Accessory Left Hepatic Artery in Patients Undergoing Radical Gastrectomy for Gastric Cancer, *PLoS ONE*, 8:e64300.

Huapaya, J. A., Chávez-Trujillo, K., Trelles, M., Carbajal, R. D., and Espadin, R. F. (2015). Anatomic variations of the branches of the aortic arch in a Peruvian population, *Medwave*, 15:6194.

Ilia, R., Rosenshtein, G., Weinstein, J., Cafri, C., Abu-Ful, A., and Gueron, M. (2001). Left anterior descending artery length in left and right coronary artery dominance, *Coronary Artery Disease*, 12:77-78.

Iqbal, S. (2013). A Comprehensive Study of the Anatomical Variations of the Circle of Willis in Adult Human Brains, *Journal of Clinical and Diagnostic Research*, 7:2423-2427.

Isogai, S., Horiguchi, M., and Hitomi, J. (2010). The para-aortic ridge plays a key role in the formation of the renal, adrenal and gonadal vascular systems, *Journal of Anatomy*, *216*:656–670.

Jin, G. Y., Yu, H. C., Lim, H-S., Moon, J. I., Lee, J. H., Chung, J. W., and Cho, B. H. (2008). Anatomical variations of the origin of the segment 4 hepatic artery and their clinical implications, *Liver Transplantation*, 14:1180-1184.

Jones, E. A., le Noble, F., and Eichmann, A. (2006). What determines blood vessel structure? Genetic pre-specification vs. hemodynamics, *Physiology*, 21:388-395.

Kau, T., Sinzig, M., Gasser, J., Lesnik, G., Rabitsch, E., Celedin, S., and Hausegger, K. A. (2007). Aortic Development and Anomalies, *Seminars in Interventional Radiology* 24: 141–152.

Kim, D., Orron, D. E., and Skillman, J. J. (1989). Surgical Significance of Popliteal Artery Variants A Unified Angiographic Classification, *Annals of Surgery*, 210:776-781.

Kini, S., Bis, K. G., and Weaver, L. (2007). Normal and Variant Coronary Arterial and Venous Anatomy on High-Resolution CT Angiography, *American Journal of Roentgenology,* 188:1665-1674.

Kloesel, B., DiNardo, J. A., and Body, S. C. (2016). Cardiac Embryology and Molecular Mechanisms of Congenital Heart Disease: A Primer for Anesthesiologists, *Anesthesia and Analgesia*, 123:551-569.

Knaapen, M., Koch, A. H., Koch, C., Koch, K. T., Li, X., van Rooji, P. C., Tijssen, J. G. P., Peters, R. J., van der Wal, A. C., Damman, P., and de Winter, R. J. (2013). Prevalence of left and balanced coronary arterial dominance decreases with increasing age of patients at autopsy. A postmortem coronary angiograms study, *Cardiovascular Pathology*, 22:49-53.

Komiyama, M., Morikawa, T., Nakajima, H., Nishikawa, M., and Yasui, T. (2001). High Incidence of Arterial Dissection Associated With Left Vertebral Artery of Aortic Origin, *Neurologica Medico-Chirurgica (Tokyo),* 41:8-12.

Kuczera, P., Włoszczyńska, E., Adamczak, M., Pencak, P., Chudek, J., and Więcek, A. (2009). Frequency of renal artery stenosis and variants of renal artery vascularization in hypertensive patients: analysis of 1550 angiographies in one centre, *Journal of Human Hypertension*, 23:396-401.

Kumar, G. P. (2011). Bilateral Superior Accessory Renal Arteries – Its embryological Basis and Surgical Importance – A Case Report, *Journal of Clinical Case Reports*, 2:e105.

Kumar, V., Kumar, V. V., Murlimanju, B. V., and Naveen, N. S. (2011). High origin of the deep femoral artery: a case report and literature review, *Journal of Vascular Surgery,* 10:243-245.

Lale, P., Toprak, U., Yagiz, G., Kaya, T., and Uyanik, S. A. (2014). Variations in the Branching Pattern of the Aortic Arch Detected with Computerized Tomography Angiography, *Advances in Radiology,* 2014:1-7.

Lezzi, R., Cotroneo, A. R., Giancristofaro, D., Santoro, M., and Storto, M. L. (2008). Multidetector-row CT angiographic imaging of the celiac trunk: anatomy and normal variants, *Surgical and Radiologic Anatomy*, 30:303-310.

Lin, P.H. and Chaikof, E. L. (2000). Embryology, anatomy, and surgical exposure of the great abdominal vessels, *Surgical Clinics of North America*, 80:417-433.

Lluri, G. and Aboulhosn, J. (2014). Coronary Arterial Development: A Review of Normal and Congenitally Anomalous Patterns, *Clinical Cardiology*, 37:126-130.

Lopez-Andujar, R., Moya, A., Montalva, E., Berenguer, M., De Juan, M., San Juan, F., Pareja, E., Vila, J. J., Orbis, F., Prieto, M., and Mir, J. (2007). Lessons learned from anatomic variants of the hepatic artery in 1,081 transplanted livers. *Liver Transplantation*, 13:1401-1404.

Loukas, M., Groat, C., Khangura, R., Owens, D. G., and Anderson, R. H. (2009). The Normal and Abnormal Anatomy of the Coronary Arteries, *Clinical Anatomy*, 22:114-128.

Loukas, M., Hanna, M., Alsaiegh, N., Shoja, M. M., and Tubbs, R. S. (2011). Clinical anatomy as practiced by ancient Egyptians, *Clinical Anatomy*, 24:409-415.

Malek, A. M., Alper, S. L., and Izumo, S. (1999). Hemodynamic shear stress and its role in atherosclerosis, *The Journal of the American Medical Association*, 282:2035-2042.

Malone, C. D., Urbania, T. H., Crook, S. E. S., and Hope, M. D. (2012). Bovine aortic arch: A novel association with thoracic aortic dilation, *Clinical Radiology,* 67:28-31.

Mamatha, H., Hemalatha, B., Vinodini, P., Souza, A. S. D., and Suhani, S. (2015). Anatomical Study on the Variations in the Branching Pattern of Internal Iliac Artery, *The Indian Journal of Surgery*, 77:248–252.

Masselli, G. (2013). Small Bowel Imaging: Clinical Applications of the Different Imaging Modalities—A Comprehensive Review, *ISRN Pathology*, 2013:1-13.

Mehrdad, J. and Sadeghi, Y. (2007). A Case Report of Variation in Subclavian Artery Branches, *Journal of Medical Sciences*, 7:457-459.

Menshawi, K., Mohr, J. P., and Gutierrez, J. (2015). A Functional Perspective on the Embryology and Anatomy of the Cerebral Blood Supply, *Journal of Stroke*, 17:144-158.

Michalinos, A., Chatzimarkos, M., Arkadopoulus, N., Safioleas, M., and Troupis, T. (2016). Anatomical Considerations on Surgical Anatomy of the Carotid Bifurcation, *Anatomical Research International,* 2016:1-8.

Michels, N. A. (1966). Newer anatomy of the liver and its blood supply and collateral circulation, *The American Journal of Surgery,* 112:337-347.

Michels, N. A., Siddharth, P., Kornblith, P. L., and Parke, W. L. (1965). The variant blood supply to the descending colon, rectosigmoid and rectum based on 400 dissections. Its importance in regional resections, *Diseases of the Colon and Rectum*, 8:251-258.

Mishra, V., Barua, M., Singh, B., and Sharm, V. (2018). Variant origin and course of the left colic artery: An embryological perspective, *International Journal or Anatomical Variations*, 11:24-25.

Moore, K. L., Dalley, A. F., and Agur, A. M. R. (2014). Neurovascular Structures of Pelvis. In K. L. Moore, A. F. Dalley and A. M. R. Agur (Eds.), *Clinically Oriented Anatomy* (pp. 349-362). Philadelphia, PA: Wolters Kluwer.

Moore, K. L., Persaud, T. V. N., and Torchia, M. G. (2016). Cardiovascular System. In *Before we are Born: Essentials of Embryology and Birth Defects* (pp. 189-222). Philadelphia, PA: Saunders.

Moorman, A., Webb, S., Brown, N. A., Lamers, W., and Anderson, R. H. (2003). Development of the Heart: (1) Formation of the Cardiac Chambers and Arterial Trunks, *Heart,* 89:806–814.

Mubarak, M. Y., Kamarul, A. T., and Noordini, M. D. (2011). Right-sided Aortic Arch with Aberrant Left Subclavian Artery from Kommerell's Diverticulum, *Iranian Journal of Radiology*, *8*: 103–106.

Mugunthan, N., Kannan, R., Jebakani, C. F., and Anbalagan, J. (2016). Variations in the Origin and Course of Right Hepatic Artery and its Surgical Significance, *Journal of Clinical and Diagnostic Research: JCDR*, 10:AC01–AC04.

Nasr, A. Y., Badawoud, M. H., Al-Hayani, A. A., and Hussein, A. M. (2014). Origin of profunda femoris artery and its circumflex femoral branches: anatomical variations and clinical significance, *Folia Morphologica*, 73:58-67.

Nasr, N. Y. (2012). The radial artery and its variations: anatomical study and clinical implications, *Folia Morphologica*, 71:252-262.

Natsis, K. I., Tsitouridis, I. A., Didagelo, M. V., Fillipidis, A. A., Vlasis, K. G., and Tsikaras, P. D. (2009). Anatomical variations in the branches of the human aortic arch in 633 angiographies: clinical significance and literature review, *Surgical and Radiologic Anatomy*, 31:319-323.

Nayak, B. S. (2008). Abnormal Branch of External Iliac Artery in the Iliac Fossa, *International Journal of Morphology,* 26:445-446.

Nayak, R. S., Pai, M. M., Prabhu, L. V., D'Costa, S., and Shetty, P. (2006). Anatomical organization of aortic arch variations in the India: embryological basis and review, *The Journal of Vascular Surgery*, 5:95–100.

Negoi, I., Beuran, M., Hostiuc, S., Negoi, R. I., and Inoue, Y. (2018). Surgical Anatomy of the Superior Mesenteric Vessels Related to Colon and Pancreatic Surgery: A Systemic Review and Meta-Analysis, *Scientific Reports*, 8:4184.

Nelson, M. L., and Sparks, C. D. (2001). Unusual Aortic Arch Variation: Distal Origin of Common Carotid Arteries, *Clinical Anatomy*, 14:62-65.

Nizankowski, C., Rajchel, Z., and Ziolkowksi, M. (1975). Abnormal origin of arteries from the aortic arch in man, *Folia Morphologica*, 34:109–116.

Nobuyuki, H., Suzuki, R., Ishizawa, A., Hideaki, M., Rodriguez -Vasquez, J. F., Murakami, G., and Fujisawa, M. (2015). Fetal development of the mesonephric artery in humans with reference to replacement by the adrenal and renal arteries, *Annals of Anatomy,* 202:8-17.

Nordon, D. G. and Rodrigues Júnior, O. F. (2012). Variations in the anatomy of the coronary arteries, *Journal of Morphological Science*, 29:178-181.

Noussios, G., Dimitriou, I., Chatzis, I., and Katsourakis, A. (2017). The Main Anatomic Variations of the Hepatic Artery and Their Importance in Surgical Practice: Review of the Literature, *Journal of Clinical Medicine Research,* 9:248-252.

Older, J. (2004). Anatomy: A must for teaching the next generation, *Journal of the Royal Colleges of Surgeons of Edinburgh and Ireland*, 2:79-90.

Özbülbül, N. I. (2011). CT angiography of the celiac trunk: anatomy, variants and pathologic findings, *Diagnostic and Interventional Radiology*, 17:150-157.

Özkan, U., Tercan, F., Kizilkiliç, O., Koç, Z., and Koca, N. (2006). Renal artery origins and variations: angiographic evaluation of 855 consecutive patients, *Diagnostic and Interventional Radiology*, 12:183-186.

Pai, M. M., Krishnamurthy, A., Prabhu, L. V., Pai, M. V., Kumar, S. A., and Hadimani, G. A. (2009). Variability in the Origin of the Obturator Artery, *Clinics (Sao Paulo, Brazil)*, *64*(9):897–901.

Panagouli, E., Venieratos, D., Lolis, E., and Skandalakis, P. (2013). Variations in the anatomy of the celiac trunk: A systematic review and clinical implications, *Annals of Anatomy*, 195:501-511.

Pandey, S. K., Bhattacharya, S., Mishra, R. N., and Shukla, V. K. (2004). Anatomical Variations of the Splenic Artery and Its Clinical Importance, *Clinical Anatomy*, 17:497-502.

Parizek, P., Haman, L., Harrer, J., Tauchman, M., Rozsival, V., Varvarovsky, I., Pleskot, M., Mestan, M., and Stasek, J. (2010). Bland–White–Garland syndrome in adults: sudden cardiac death as a first symptom and long-term follow-up after successful resuscitation and surgery, *EP Europace*, 12:1338–1340.

Park, K.-W., Park, J.-S., Hwang, S.-C., Im, S.-B., Shin, W.-H., and Kim, B.-T. (2008). Vertebral Artery Diss5ection: Natural History, Clinical Features and Therapeutic Considerations, *Journal of Korean Neurosurgical Society*, 44:109–115.

Pérez-Pomares, J. M., de la Pompa, J. L., Franco, D., Henderson, D., Ho, S. Y., Houyel, L., Kelly, R. G., Sedmera, D., Sheppard, M., Sperling, S., Thiene, G., van den Hoff, M., and Basso; C. (2016). Congenital coronary artery anomalies: a bridge from embryology to anatomy and pathophysiology—a position statement of the development, anatomy, and pathology ESC Working Group, *Cardiovascular Research*, 109:204–216.

Poonam, Jyoti, N., Singla, R. K., and Sharma, T. (2013). Anatomical Considerations and Clinical Implications of Subclavian Artery, *Journal of Evolution of Medical and Dental Sciences*; 2:5484-5491.

Raikos, A. and Dade Smith, J. (2015). Anatomical Variations: How Do Surgical and Radiology Training Programs Teach and Assess Them in Their Training Curricula? *Clinical Anatomy*, 28:717-724.

Rammohan, A., Palaniappan, R., Pitchaimuthu, A., Rajendran, K., Perumal, S. K., Balaraman, K., Ramasamy, R., Sathyanesan, J., and Govindan, M. (2014). Implications of the presence of an aberrant right hepatic artery in patients undergoing pancreaticoduodenectomy, *World Journal of Gastrointestinal Surgery*, 6: 9–13.

Rani, N., Singh, S., Dhar, P., and Kumar, R. (2014). Surgical Importance of Arterial Segments of Human Kidneys: An Angiography and Corrosion Cast Study, *Journal of Clinical and Diagnostic Research for Doctors*, 8:1-3.

Resnick, N., Yahav, H., Shay-Salit, A., Shushy, M., Schubert, S., Zilberman, L. C. M., and Wofovitz, E. (2003). Fluid shear stress and the vascular endothelium: for better and for worse, *Progress in Biophysics & Molecular Biology*, 81:177-199.

Rodríguez-Niedenführ, M., Burton, G. J., and Sañudo, J. R. (2001). Development of the arterial pattern in the upper limb of staged human embryos: normal development and anatomic variations, *Journal of Anatomy*, 199:407-417.

Rodríguez-Niedenführ, M., Vázquez, T., Parkin, I. G., and Sañudo, J. R. (2003). Arterial patterns of the human upper limb: update of human anatomical variations and embryological development, *European Journal of Anatomy*, 1:21-28.

Rojas, M., Muete, W., and Quijano, Y. (2017). Anatomical variations of the aortic arch in a sample Colombian population, *The Journal of the Faculty of Medicine*, 65:49-54.

Saba, L. and Mallarini, G. (2011). Anatomic variations of arterial liver vascularization: an analysis by using MDCTA, *Surgical and Radiologic Anatomy*, 33:559-568.

Sabnis, A. S. (2013). Morphology of Posterior Interventricular Artery, *World Research Journal of Anatomy*, 1:7-10.

Sakthivelavan, S., Aristotle, S., Sivanandan, A., Sendiladibban, S. and Jebakani, C. F. (2014). Variability in the Branching Pattern of the Internal Iliac Artery in Indian Population and Its Clinical Importance, *Anatomy Research International*, 2014:1-6.

Sakthivelavan, S., Sendiladibban, and S. D., Felicia, C. (2010). Branching Pattern of Fetal Internal Iliac Artery, *Revista Argentina de Anatomía Clínica*, 2:100-105.

Satti, S. R., Cerniglia, C. A., and Koenigsberg, R.A. (2007). Cervical Vertebral Artery Variations: An Anatomic Study, *American Journal of Neuroradiology,* 28:976-80.

Satyanarayana, N., Sunitha, P., Shaik, M. M., and Satya Vathi Devi, P. (2010). Brachial artery with high up division with its embryological basis and clinical significance development, *International Journal of Anatomical Variations,* 3:56-58.

Schievink, W. I. (2001). Spontaneous Dissection of the Carotid and Vertebral Arteries, *New England Journal of Medicine*, 344:898-906.

Silva Junior, G. O.; Miranda, S. W. S., and Mandarim-de-Lacerda, C. A. (2009). Origin and development of the coronary arteries, *International Journal of Morphology*, 27:891-898.

Singer, E. (1933) Embryological pattern persisting in the arteries of the arm, *Anatomical Record*, 55:403–409.

Singh, G., Kharat, A., Sehrawat, P., and Kulkarni, V. (2015). Imaging findings in the right aortic arch with mirror image branching of arch vessels: An unusual cause of dysphagia, *Medical Journal of Dr. D. Y. Patil Vidyapeeth*, 8:250-253.

Singh, R. (2016). Variations in the branching pattern in inferior mesenteric artery: a series of five cases, *Journal of Morphological Sciences*, 23:193-196.

Sinkeet, S., Mwachaka, P., Muthoka, J., and Saidi, H. (2013). Branching Pattern of Inferior Mesenteric Artery in a Black African Population: A Dissection Study, *ISRN Anatomy*, 2013:1-4.

Shahcheraghi, N., Dwyer, H. A., Cheer, A. Y., Barakat, A. I., and Rutaganira, T. (2002). Unsteady and Three-Dimensional Simulation of Blood Flow in the Human Aortic Arch, *Journal of Biomechanical Engineering*, 124:378-387.

Shammas, N. W. (2007). Trifurcating Coronary Artery Disease, A proposed Classification and Treatment Methodology, *Journal of Invasive Cardiology*, 19:32-35.

Shortell, C. K., Illig, K. A., Ouriel, K., and Green, R. M. (1998). Fetal internal iliac artery: Case report and embryologic review, *Journal of Vascular Surgery*, 28:1112-1114.

Shotwell, R. A. (2016). Animals, Pictures, and Skeletons: Andreas Vesalius's Reinvention of the Public Anatomy Lesson, *Journal of the History of Medicine and Allied Sciences*, 71:1-18.

Skinner, D. and Van Fossen, K. (2018). Anatomy, Abdomen, Arteries, Inferior Mesenteric. In *StatPearls*. Treasure Island, FA: StatPearls Publishing.

Spasojevic, M., Stimec, B. V., Fasel, J. F., Terraz, S., and Ignjatovic, D. (2011). 3D relations between right colon arteries and the superior mesenteric vein: A preliminary study with multidetector computed tomography, *Surgical Endoscopy*, 25:1883-1886.

Takafuji, T. and Sato, Y. (1991). Study on the Subclavian Artery and its Branches in Japanese Adults, *Okajimas Folia Anatomica Japonica,* 68:171-186.

Talović, E., Kulenović, A., Voljevica, A., and Kapur, E. (2007). Review of supernumerary renal arteries by dissection method, *Acta Medica Academica*, 36:59-69.

Tapia, G. P., Zhu, X., Xu, J., Liang, P., Su, G., Liu, H., Liu, Y., Shu, L., Liu, S., and Huang, C. (2015). Incidence of Branching Patterns Variations of the Arch in Aortic Dissection in Chinese Patients, *Medicine*, 94: e795.

Thomson, A. (1893). Third annual report of the Committee of Collective Investigation of the Anatomical Society of Great Britain and Ireland for the year 1891–1892, *Journal of Anatomy*, 27:183–194.

Toh, J. W. T., Matthews, R., and Kim, S-H. (2018). Arc of Riolan-Preserving Splenic Flexure Takedown During Anterior Resection: Potentially Critical to Prevent Acute Anastomotic Ischemia, *Diseases of the Colon and Rectum*, 61:411-414.

Trebuchet, G., Lechaux, D., and Lecalve, J. L. (2002). Laparoscopic left colon resection for diverticular disease, *Surgical Endoscopy*, 16:18-21.

Udan, R. S., Culver, J. C., and Dickinson, M. E. (2013). Understanding vascular development: WIRE Developmental Biology, *Wiley Interdisciplinary Reviews: Developmental Biology*, 2:327-346.

Urban, B. A., Ratner, L. E., and Fishman, E. K. (2001). Three-dimensional Volume-rendered CT Angiography of the Renal Arteries and Veins: Normal Anatomy, Variants, and Clinical Applications, *RadioGraphics*, 21:373-386.

Wanamaker, K. M., Amadi, C. C., Mueller, J. S., and Moraca, R. J. (2013). Incidence of Aortic Arch Anomalies in Patients with Thoracic Aortic Dissections, *Journal of Cardiac Surgery*, 28:151-154.

Wang, K-X., Cheng, Z-Q., Liu, Z., Wang, X-Y., and Bi, D-S. (2018). Vascular anatomy of inferior mesenteric artery in laparoscopic radical resection with the preservation of left colic artery for rectal cancer, *World Journal of Gastroenterology*, 24:3671-3676.

Witte, B., Fröber, R., and Lin, B. (2001). Unusual blood supply to the pancreas by a dorsal pancreatic artery, *Surgical and Radiologic Anatomy*, 23:197-200.

White, R. D., Weir-McCall, J. R., Sullivan, C. M., Mustafa, S. A. R., Yeap, P. M., Budak, M. J., Sudarshan, T. A., and Zeally, I. A. (2015). The Celiac Axis Revisited: Anatomic Variants, Pathologic Features, and Implications for Modern Endovascular Management, *RadioGraphics*, 35:879-898.

Yamaki, K-I., Saga, T., Doi, Y., Aida, K., and Yoshizuka, M. (1998). A Statistical Study of the Branching of the Human Internal Iliac Artery, *Kurume Medical Journal,* 45:333-340.

Yamanaka, O. and Hobbs, R. E. (1990). Coronary Artery Anomalies in 126,595 Patients Undergoing Coronary Arteriography, *Catheterization and Cardiovascular Diagnosis*, 21(1):28-40.

Yildirim, M., Ozan, H., and Kutoglu, T. (1998). Left gastric artery originating directly from the aorta, *Surgical and Radiologic Anatomy,* 20:303-305.

Yildiz, A., Okcun, B., Peker, T., Arslan, C., Olcay, A., and Vatan, M. B. (2008). Prevalence of Coronary Artery Anomalies in 12,457 Adult Patients Who Underwent Coronary Angiography, *Clinical Cardiology*, 33:E60-E64.

Yuan, S.-M. (2016). Aberrant Origin of Vertebral Artery and its Clinical Implications, *Brazilian Journal of Cardiovascular Surgery*, 31:52–59.

CURRICULUM VITAE

[redacted]

[redacted]

[redacted]

464