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The effect of surgeon hand anthropometry on surgical glove sizing and implications

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THE EFFECT OF SURGEON HAND ANTHROPOMETRY ON SURGICAL GLOVE SIZING AND IMPLICATIONS

by

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ABSTRACT

Though now seen everywhere in the hospital and operating theater, there was a time when surgeons used no hand protection. In the late 19th century, however, as the science of bacteriology became more advanced, surgical glove usage spurred. Today, gloves serve an extremely important role, helping to maintain the sterile field and protect hospital staff from the transfer of bloodborne pathogens. Since they are so valuable, it is equally important that gloves fit properly as to not be detrimental to the surgeon. Gloves that are too tight increase fatigue rate and decrease fine finger dexterity. Gloves that are too loose can reduce tactile sensitivity caused by bunching of material at the fingers. Traditionally, the larger of measurement of hand circumference and hand length are used to determine glove size, but most select a size based on comfort of fit.

To assist manufacturers with creating certain sizes, anthropometry is often used. Anthropometry is the study of the physical measures of the human body. Human-factors engineering is the science of applying anthropometric information to the design of devices intended for human use. In this study, two anthropometric databases, studies by Greiner and Pheasant, were utilized to obtain hand measurements representative of the general population, due to the population studied.

For this study, 59 general surgeons (51 male, 8 female) were invited on separate dates to the Medtronic Minimally Invasive Therapies Group in North Haven, CT for
Voice of Customer laboratories. While there, they completed surveys where they listed their preferred glove size, double gloving sizes, dominant hand, etc. In addition, the following six measurements were taken: hand circumference, maximum grip diameter, Digit 1 (D1) length, Digit 2 (D2) link length, Distance from D2 Metacarpo-phalangeal (MCP) to Distal Interphalangeal (DIP) joint, and D2 distal phalanx length (extrapolated). These measurements were averaged and compared to the numbers reported in the Greiner and Pheasant studies for analysis using a novel Microsoft Excel tool. Commonly used laparoscopic staplers were also measured to assess ergonomic usability amongst the surgeon population.

Male surgeons had statistically significantly larger hands than female surgeons with respect to all measurements taken. Compared to men of the general population, male surgeons had significantly smaller grip diameter, D2 link length, yet a greater D1 Length. Compared to women of the general population, female surgeons had a greater hand circumference, yet smaller D2 link length. All other measurements recorded were statistically equivalent. In general, surgeons seem to select a preferred glove size based on their hand circumference (Pearson’s Correlation 0.799, $R^2$ 63.9%), followed by D2 Link Length (Pearson’s Correlation 0.631, $R^2$ 39.9%). The median glove size for male surgeons was 7.5 (0.50) and 6.0 (0.25) for female surgeons ($p > 0.001$).

To evaluate the ergonomic usability of laparoscopic staplers, the measurement “Distance from D2 MCP to DIP joint” was developed internally to roughly assess effective trigger distance, where larger lengths would force the user to adjust their hand position. The handles of two commonly used laparoscopic staplers were measured to
determine what proportion of the surgeon population could use them effectively. Based on these measurements, for the Medtronic Endo GIA™ Ultra Stapler, nearly all male surgeons and 99.8% of female surgeons could use it ergonomically. For the Ethicon ECHelon Flex™ Endopath® stapler, only 78.2% of male surgeons and 30.9% of female surgeons could use it ergonomically.

This study demonstrated that there exists a large amount of variability between each part of the hand based on the different measurements. Therefore, to best assure proper fitting gloves for the majority of users, a two metric system involving hand circumference and finger length would be useful to accommodate the inherent variability of the hand. With respect to laparoscopic stapling platforms, this study demonstrated that the instruments are simply too large to be used ergonomically by a large portion of the intended audience. Medical device manufacturers should look to create an adjustable handle such that the trigger distance can be manipulated to fit the needs of those surgeons with smaller hands.
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LIST OF ABBREVIATIONS

BMI............................................................................. Body Mass Index
CT ............................................................................. Connecticut
D1............................................................................. Digit 1
D2............................................................................. Digit 2
DIP ............................................................................. Distal Interphalangeal
MAD.......................................................................... Median Absolute Difference
MCP........................................................................... Metacarpo-phalangeal
MeSH.......................................................................... Medical Subject Heading
PIP............................................................................. Proximal Interphalangeal
INTRODUCTION

Sterility in the Operating Field

Regarded as the father of antiseptic surgery, Lord Joseph Lister pioneered the practice of sterility in the operating theater.\textsuperscript{1-3} While a physician at King’s College Hospital in England during the late 1800s, Lister became renowned for his attention to detail and his tireless nature, where he consistently worked to better his practice of medicine.\textsuperscript{3} Now, Lister is most known for his use of carbolic acid as a germicide, where he would saturate his suture, foam pads, and even create a pasty form of the acid to sterilize surgical wounds.\textsuperscript{3} The spread of Listerian Methodology, however, was not rapid. Many elected not to adopt the technology and others used it as they pleased or when they felt it was necessary. In 1882, William Watson Cheyne, one of Lister’s closest students, published “Antiseptic Surgery,” a guide that provided step-by-step instructions on how to follow Listerian Methodology.\textsuperscript{3}

Meanwhile, in German-speaking countries, the practice of asepsis, the prevention of any germs from entering the wound, became the standard as opposed to antisepsis.\textsuperscript{4} This was perhaps due to the great national interest in bacteriology, where many labs were actively developing methods to control microorganisms in surgery, Robert Koch’s laboratory in particular.\textsuperscript{4} Another laboratory that emerged as a worldwide leader in the 1890s for pioneering the aseptic method was located at a surgical university hospital in the Ziegelstrasse in Berlin. Head surgeon Ernst von Bergmann hired Kurt Schimmelbusch, whom created the standardized sterilization system, “Guide to Aseptic Wound Treatment” in 1892.\textsuperscript{4} Schimmelbusch’s aseptic method, however, was not enough
to prevent infection. Following this, others sought to fill the voids in the aseptic method. To accomplish this, others began developing additional pieces of equipment for the surgeon to protect the patient. For example, Johannes von Mikulicz, head of surgery at the University of Breslau in 1890, working alongside colleague Carl Flügge, invented face masks to protect the patient from what they coined “droplet infection” from the surgeon’s mouth.  

The Advent of Surgical Gloves

The first reported use of gloves came from Johann Julius Walbaum, where in 1758, used the cecum of a sheep to partially cover his hand for use in his obstetric practice. In this instance, gloves were not used for protection of the patient, but rather to prevent any injury to the surgeon’s hand when it was inserted into the vagina during obstetrical and gynecological procedures.  

In 1844, Charles Goodyear discovered the process of vulcanization, which is used to stabilize rubber to increase durability, greatly increasing its usability. As mentioned previously, in 1867, Joseph Lister introduced his antiseptic methods where he utilized the caustic solution of carbolic acid to kill germs in the operative field. This solution, however, was too harsh for the skin of many surgeons so they were motivated to wear gloves to protect their hands from the acid. Gloves were regarded as a natural progression from the pioneering efforts of Lister. As Lister pioneered the necessity for operative sterility, gloves evolved to help maintain that sterility and prevent the spread of infection, even if this initially occurred by chance to prevent the surgeon and hospital staff from sustaining hand injury.
One of the most well-known stories regarding the first use of gloves occurred in 1889 at the Johns Hopkins University. Dr. William Stewart Halsted had a pair of rubber gloves made by Goodyear for his favorite scrub nurse, Caroline Hampton, whom eventually became Halsted’s wife.\textsuperscript{1,2,5} Following this event, Halsted’s apprentice, Dr. Joseph Bloodgood, began wearing gloves for all of his operations in his hernia practice, and noticed a drastic decrease in his infection rate, down to nearly zero.\textsuperscript{1,5} It was this finding that spurred widespread adoption of surgical glove use.

In Europe during this same time period in the 1890s, more specifically in German-speaking nations, the first reports regarding the necessity of glove use was heavily criticized by an Austrian surgeon Alexander Fraenkel.\textsuperscript{4} He believed that the goal of a completely aseptic operating field was flawed. Others, however, held a completely opposite viewpoint. They were surprised that it took such brilliant individuals so many years to understand the importance of surgical gloves.\textsuperscript{4} Werner Zoege von Manteuffel is recognized as the individual that introduced gloves to the German-speaking world in 1897.\textsuperscript{4} Though he was well aware of the importance of gloves from the standpoint of operative sterility, he had many issues with the primitive rubber gloves at the time. Manteuffel noted that if he wore gloves that were too small, the blood flow to his hands was reduced, which causes him to fatigue too early; conversely if they were too large, then there would be excess material in his fingers, which made using instruments difficult.\textsuperscript{4} Another common criticism of gloves was their negative affect on tactile sensation, all of which were common reasons to justify not using gloves in surgical practice.\textsuperscript{4} The marked decline in infection rates, however, was enough for glove use to
gain support. Paul Leopold Friedrich became a large advocate for the use of surgical
gloves, so much so that he warned his colleagues not to touch a wound with “non-
boilable objects,”¹⁴ the manner in which rubber gloves were sterilized in Germany.² At
this time, there was also a debate between what type of sterility was necessary in the
operating field, did there have to be a complete absence of bacteria, coined
bacteriological sterility, or could there be limited amounts of bacteria, termed surgical
sterility?¹⁴ This debate prompted Fraenkel to redefine the term asepsis as a wound that
heals without pus formation, which is significant because some of his colleagues, such as
Theodor Kocher, who used a permeable cotton glove. Kocher was able to find bacteria in
his wounds, but did not notice any adverse healing consequences, and thus cautioned
against bacteriological sterility.⁴

As an item that was initially used to protect the hand of the surgeon from
corrosive germ-killing solutions, they evolved to being worn to protect the patient from
infection to now, where they are also worn to protect hospital employees from the
potential transmission of blood-borne pathogens.⁵ Traditional wisdom from Anton
Wölfer, a Prague surgeon, tends to govern how gloves are designed today in that surgical
gloves should be: impermeable, flexible, tear-resistant, fit well, breathable, and
sterilizable.⁴

**Relevant Hand, Wrist, Forearm, Upper Extremity Anatomy**

The hand is enormously complex. In the hand and wrist, there are a total of 27
bones, not including the five sesamoid bones located throughout the digits.⁶ The wrist
bones are broadly referred to as the carpal bones, of which there are eight: trapezoid,
trapezium, scaphoid, lunate, triquetrum, pisiform, capitate, and hamate bones. In the remaining hand, there are five metacarpals, five proximal phalanges, four middle phalanges, and five distal phalanges. There are five digits, with the thumb starting as digit 1, which only has proximal and distal phalanges. The forearm is composed of two bones, the radius and ulna, and the upper arm is comprised solely of the humerus. Completing the bones of the upper extremity are the scapula and clavicle which make up the shoulder girdle, along with the proximal end of the humerus. The nerves that innervate the hand are the median, ulnar and radial nerves, which divide into many smaller branches. There are a total of 34 muscles that control the fingers and thumb. 17 of these are located in the palm, 18 are located in the forearm. Those associated with finger/wrist flexion are located on the anterior surface of the palm and forearm. Those associated with finger/wrist extension are located on the posterior surface of the palm and forearm. There are no muscles in the fingers; instead, finger movement comes from those muscles located in the forearm. They are connected to the tips of the fingers by tendons which are guided and supported by fascia and fibrous sheaths located along the digits.

**Grip Physiology**

Various components of the hand come together and work in synchrony to perform a wide range of functions. The functions of the hand are conveniently broken up into four categories: tactile sensing, active haptic sensing, prehension (grasping), non-prehensile skilled movements. Tactile sensing involves stimulating the passive hand, thus providing the individual with information regarding the surrounding environment. Active haptic sensing occurs when the hand is in motion and information is gathered from various
sensors. Grasping is a motor function of the hand but also is reliant on sensory pathways to allow for enhanced coordination. Non-grasping skill movements refer to all other possible motions/tasks the hand is capable of. The hand is comprised of many different receptors that allow for detection of information from the surrounding environment, including, but not limited to: mechanoreceptors, thermoreceptors, nociceptors, etc. In the context of grip physiology, mechanoreceptors are most important, as they allow for the proper distribution of forces to ensure a coordinated and even grip. In terms of grip types, there are two. The first is a precision grip, in which the tips of the fingers have a greater influence on feedback. The second is a power grip, where there is increased importance placed on stabilizing with the entire anterior surface of the digits that come into contact with the object.

Overall, grip strength is defined as the total amount of strength that can be generated by the flexor muscles located on the anterior aspect of the forearm against the palmar, thenar, and hypothenar region of the hand. Not surprisingly, the strongest grip that can be produced occurs when all five digits are used, followed all fingers minus the thumb. Distribution of grip strength amongst the digits is interesting. The digits situated around the medial aspect of the hand appear to have a greater contributing role towards maximal grip strength, with the middle finger contributing 31%, the ring and little finger contributing 29% together, the index finger contributing 22% and the thumb contributing 17%.

Overall, the average grip strength for men is greater than for women and the grip strength of the dominant hand is greater than the non-dominant hand. In men, forearm
circumference was predictive of grip strength, but this trend did not hold for women.\textsuperscript{10,11} There is concern, however, over the strength of correlation between forearm circumference and grip strength, as forearm circumference can be influenced by the amount of body fat.\textsuperscript{9} Since grip strength proved to be independent of height, weight, and BMI,\textsuperscript{10} this could serve as an issue. Hand circumference is much less likely to be influenced by the total amount of body fat and proved to have the strongest correlation with maximum grip strength for both hands.\textsuperscript{9} In addition to hand circumference, hand width and the third digit length had a strong correlation with overall hand grip strength.\textsuperscript{11}

**Hand Anthropometry**

Anthropometry is the study of the physical measures of the human body including size and functional capability.\textsuperscript{12} Human-factors engineering, also known as ergonomics, is the science of applying anthropometric information to the design of devices intended for human use.\textsuperscript{13} The goal of human-factors engineering is to improve the safety and usability of devices to increase efficiency and reduce the incidence of injury or errors.\textsuperscript{13}

With respect to the hand and wrist, there exists a large amount of anthropometric measurements to characterize shape and geometry. In total, there are approximately 86 different measurements that can be taken to gather a complete picture of the hand and neighboring anatomy.\textsuperscript{14} This information can then be applied to ensure the device or item that is designed will be usable for the intended audience. Anthropometry can also be used to assist designers with sizing their products to either create a one size fits all product or supply them with the information needed to intelligently create different sizes by bracketing ranges of anthropometric values.
Within the hand, there are certain standardized terms and landmarks from which measurements are taken from. The distal tip of each digit is an important reference point for collecting information regarding total length. The joint between distal and middle phalanges is referred to as the distal interphalangeal (DIP) joint. The joint between the medial and proximal phalanges is referred to as the proximal interphalangeal (PIP) joint. Connecting the proximal phalanx with the metacarpal bone is the metacarpo-phalangeal (MCP) joint.

In addition to joint landmarks, there are a number of important landmarks on the skin itself used as reference points for taking anthropometric measurements. Figure 1 highlights the creases relevant to this study. Creases form at points of articulation to assist with movement by clearing out excess skin. Between each joint on the finger are creases, named similarly to the joints. Between the distal phalanx and the medial phalanx, there exists the DIP Crease, where there is only one crease at each joint. Between the medial phalanx and the proximal phalanx, there exists the PIP Crease, where there is a proximal and distal crease. The naming similarity ends between the proximal phalanx and the metacarpal/palm, where the crease is referred to as the Palmar Digit Crease. On the palm, there are there important creases to note, as can also be seen in Figure 1. While in anatomical position, the most inferior palmar crease is referred to as the Distal Transverse Palmar Crease. Just superior is the Proximal Transverse Palmar Crease. The Thenar Crease is located superior and runs more vertically. This crease allows for unrestricted movement of the first digit. Finally, the wrist crease serves as the dividing line separating the hand from the forearm.14
Background on Anthropometry Studies Used

Two major resources were used as a base of comparison in this study. One study was conducted by Thomas Greiner in 1988 and published in 1991 entitled “Hand Anthropometry of U.S. Army Personnel.” This is one of the largest hand anthropometry studies on record, as data from 1003 men and 1304 women were collected, with a total of 86 anthropometric measurements taken per hand. To collect all of these data points accurately, efficiently, and in a standardized manner, this group developed a hand photobox and a hand digitizing/dimensioning system. One unique and important aspect of the system was the light source. This system utilized collimated light, light rays that
run parallel, which allowed for clearly defined edges of the hand, limiting distortions and shadow variations.\textsuperscript{14} Images were then made digital and analyzed in that manner to obtain anthropometric measurements. It is important to note that this study did not utilize calipers to obtain measurements. The measurements taken from the digital hand images were shown to be consistently larger than those taken using traditional Vernier calipers, as the use of calipers inevitably applies some compressive force to the skin\textsuperscript{14}, thus introducing a source of error.

The other major resource used in this study was an anthropometric textbook by Pheasant entitled \textit{Bodyspace: Anthropometry, Ergonomics, and the Design of Work}. This textbook highlights anthropometric considerations for the workplace and for device design.\textsuperscript{15} The value of this work comes from the compilation of various anthropometric data into an easy to reference tabular format, from which it can be quickly found and compared to another data set. Measurement data from the hand, including measurements of the active hand such as maximum grip diameter, are included in this textbook,\textsuperscript{15} and are of value to this current study.

\textbf{Tests to Assess Glove Usage}

Not including tests that look to characterize the material properties of gloves, there are three well-known benchmark tests to assess how gloves affect dexterity, touch sensitivity, hand-eye coordination, etc. These tests are the: Crawford Small Parts Dexterity Test, Semmes-Weinstein Monofilament Test, and the Purdue Pegboard Test.\textsuperscript{16}

The Crawford Small Parts Dexterity Test is best used to assess one’s precise dexterity and coordination.\textsuperscript{16} In the first part of this test, the examinee is asked to use a
pair of forceps to insert small pins into well-fitting holes and to then place collars over the protruding region of the pin. The second part of this test involves placing and threading small screws using a screwdriver.\textsuperscript{17}

The Semmes-Weinstein Monofilament Test evaluates one’s tactile sensation.\textsuperscript{16} Though commonly used to test the severity of diabetic peripheral neuropathy, it can be adapted to evaluate how gloves can alter touch sensitivity. Typically, the Semmes-Weinstein Monofilament test involves touching a monofilament to the subject’s skin, at first to show how it feels. Then, with the subject’s eyes closed, the examiner touches the monofilament to the subject’s skin with just enough force for it to bend. The subject can either detect or miss a touch, which then can be used to determine the level of tactile sensation in the subject.\textsuperscript{18} In the context of sensation changes caused by donning surgical gloves, the monofilaments can be applied to the subject’s fingers, either testing for detection of a touch (the size of the monofilament can be changed) or discrimination of touch by applying two different sized monofilaments concurrently.\textsuperscript{16}

The Purdue Pegboard Test is another dexterity test but it also measures the speed related to hand-eye coordination.\textsuperscript{16} It is unique in that it is able to detect gross as well as fine movements as the user. Overall, the test is extremely simple. The subject uses a pair of forceps to take small pins from a concave cup and places them into small holes, then to remove the pins from the holes and return them to the cups.\textsuperscript{19} While wearing gloves, the rate at which this process can occur might be altered.
Glove Effects on Dexterity

It has been shown that various types of surgical gloves can negatively affect manual dexterity.\textsuperscript{7,16,20,21} Johnson et al. utilized the Purdue Pegboard Test to compare gloves of different thicknesses. Compared to bare hands, proper fitting gloves meant for different applications were tested. The only glove that showed a reduction in dexterity compared to bare hands were orthopedic gloves, due to their increased thickness.\textsuperscript{16} In another study that also used the Purdue Pegboard Test, Berger et al. noted a 10% decrease in dexterity while subjects were wearing nitrile gloves.\textsuperscript{21} Sawyer et al. determined that the materials the gloves are made from can also play a large role in dexterity, as they found that fine finger dexterity was 8.6% greater with latex gloves as opposed to nitrile exam gloves.\textsuperscript{22}

A study conducted by Drabek et al. took glove usage a step further. Instead of comparing proper fitting gloves only, they investigated what occurred when gloves that were a size too small or a size too large were worn, using the Purdue Pegboard Test to detect a difference.\textsuperscript{20} They found that proper fitting surgical gloves performed very similarly to bare hands but when a full size up or down was donned, there was a 7-10% decrease in the rate of completion of the Purdue Pegboard Test.\textsuperscript{20} Amongst those that participated in the study, many of the same complaints were made regarding the improperly fitting surgical gloves. With gloves that were one size too small, the participants felt they could not feel the pegs as well, and the decreased size limited their range of motion while also causing hand pain.\textsuperscript{20} With gloves that were one size too large, the participants felt they could not easily manipulate the pegs in their hands, that they
were clumsy, though comfortable.\textsuperscript{20} This study is extremely important in the context of surgical glove sizing. When gloves are too small, the results of this study indicate the surgeon and hospital staff in general, could experience musculoskeletal pain, fatigue easier, and see decreases in performance. With gloves that are too large, the surgeon and hospital staff might experience decreases in coordination and performance. Therefore, proper sizing metrics are essential to providing the best possible outcomes for both the health of the patient and the hospital staff caring for them.

**Glove Effects on Touch Sensitivity**

Touch sensitivity is generally determined using a metric known as the pressure threshold. Pressure threshold is defined as the minimum applied force required to elicit a response.\textsuperscript{7} This metric has been very reliable in determining the effects of gloves. In a study evaluating both nitrile and latex gloves, it was determined through use of the Semmes-Weinstein Monofilament Test that the pressure threshold was significantly increased when gloved versus not gloved.\textsuperscript{23} These results are confirmed by numerous other studies. When using a dynamometer to measure pressure thresholds for dentists with and without latex gloves, a 36% decrease in sensitivity was noted when gloves were worn.\textsuperscript{24} Gnaneswaran et al. had performed another tactile test to evaluate gloves. They asked subjects to identify droplets of glue on a sponge when wearing gloves of various materials, compared to no gloves. It was determined that latex gloves outperformed vinyl in terms of their tactile sensitivity.\textsuperscript{25} In another study where different glove types were compared when conducting common nursing tasks, latex examination gloves performed superiorly to non-sterile latex, nitrile, and vinyl gloves,\textsuperscript{26} demonstrating the importance in
both glove quality of fit and material properties in completing tasks. Overall, touch sensitivity was found to be reduced in all nerves that innervate the hand, radial, median, and ulnar, when gloves are worn.\textsuperscript{16}

Though most studies seem to agree that surgical gloves decrease touch sensitivity, there was one study that claimed the opposite. In an anesthetist’s practice, wearing extra-thin latex gloves actually resulted in a reduced pressure threshold, thus improving touch sensitivity.\textsuperscript{27} These trends did not hold for traditional latex gloves, or those made from neoprene but it is interesting to note.

A common practice in surgery is double-gloving, as there is obvious benefit to adding another layer to separate the surgeon from the patient in preventing transmission of blood-borne pathogens. With respect to touch sensitivity, however, the increase in the number of layers of gloves has been shown to further increase the pressure threshold, and thus reduce sensitivity.\textsuperscript{28}

**Glove Effects on Grip Strength**

Handgrip strength is defined as the maximum power of voluntary contraction of all fingers.\textsuperscript{11} Gloves have been shown to alter the characteristic of grip strength in a fundamental manner, by reducing the efficiency of grip.\textsuperscript{7} The mechanism of interference is through the distortion of normal tactile cues.\textsuperscript{7} Information from the environment must travel through the glove’s material to reach the sensory receptors in the hand. This travel of information, however, is in a nonlinear manner\textsuperscript{7}, thereby skewing the perception of grasping.
When investigating the effects of latex gloves on grip force for precision grasping of dental tools, it was determined that gloves not only reduced the maximum attainable grip force, but also decreased the duration of grip at a given force level (decreased endurance). In general, it is agreed upon that gloves reduce overall grip strength, but electromyography activity observed in the muscles responsible for grip remains the same. Surgery is unique in that it involves maintaining grasp force for extended periods of time while donning gloves. Due to the reduced efficiency of grasping caused by gloves, the surgeon is exposed to greater levels of hand fatigue, which could have negative implications for long-term health.

**How Surgical Gloves are Currently Sized**

Each manufacturer of surgical gloves has a slightly different sizing chart but the principles of surgical glove sizing remains similar. Hand circumference, the distance around the knuckles, and hand length, the distance from the distal tip of the third digit (middle finger) to the wrist crease, is measured on both hands. The largest measurement on the dominant hand is the one used to determine what size surgical glove will be appropriate, from sizes 5.5 to 9. A study conducted by Kwon et al. supports this method to a degree, stating that the two measurements, hand length and circumference, are largely representative. Some manufacturers use hand width as a sizing metric instead of circumference alongside hand length, others use only hand circumference, and not hand length. When double-gloving, there are three different methods to don surgical gloves: the same size for both inner and outer gloves, the inner glove is the appropriate size while the outer glove is one half size larger, or the inner glove is one half size larger while the
outer glove is the appropriate size.\textsuperscript{31,32} Interestingly enough, the variation preferred by most surgeons is where the inner glove is one half size larger and the outer glove is the appropriate size.\textsuperscript{31,32} Comfort of fit, however, is only partially told by the sizing. The material properties of the gloves also play a large role. Comfort of fit tends to be proportion to glove elasticity, thus explaining why latex gloves are preferred by many whom are unaffected by latex allergies.\textsuperscript{7}
SPECIFIC AIMS

Previous studies regarding surgeon hand anthropometry are limited to largely to survey data where the metric used to determine general hand size is the preferred size surgical glove. Obviously, there can be differences in preference, where one surgeon prefers a tighter glove and one prefers a looser glove, so this metric has much inherent variation and does little to tell anything regarding actual surgeon hand sizes. These studies do show that surgeons have issues with the ergonomic design of the hand tools they must use, and many suffer from injury as a consequence of this.

The goal of this study is first and foremost to learn more about the physical characteristics of the surgeon’s hand, using a more standardized metric than preferred glove size. These measurements will then be evaluated against the general population, as reported by Greiner and Pheasant, to determine if there are any unique characteristics of the surgeon hand. Next, an attempt will be made to correlate hand anthropometric measurements to preferred glove size to determine which measurement is most influential in choosing a particular glove size. Additionally, male and female surgeon hand anthropometry and preferred glove sizes will be compared to each other to see where differences lie and how large those differences are. Then, grip distances on commonly used laparoscopic surgical stapling devices will be compared to a particular anthropometric measurement to determine widespread usability of the devices amongst the surgeon population. At the end of this study, ideal outcomes include: recommendations for new glove sizing metrics, and observations regarding the current size of laparoscopic hand tools and their general usability by the surgeon population.
METHODS

Background Literature Search

Several different pathways were followed during the literature review to create a comprehensive image of the problem at hand. Several PubMed MeSH terms were utilized to facilitate the limiting the number of hits to those that were deemed relevant to this study. Below is a list of the various MeSH terms used. These terms were used in different combinations to yield new search results.

- “Surgeons”[Mesh] OR “Physicians”[Mesh]
- “Gloves, Surgical”[Mesh]
- “Gloves, Surgical/History”[Mesh]
- “Hands”[Mesh] AND “Anthropometry”[Mesh]
- “Human Engineering”[Mesh]
- “Surgical Stapling”[Mesh]
- “Hand Strength”[Mesh]

Search results were limited to English language, human studies, published after the year 2000, unless insufficient evidence existed, in which case the publication year was expanded.

Study Selection

In total, 126 abstracts/articles were screened from the initial searches. From those 76 were excluded due to scope and 50 were kept and read in full. An additional 21 articles were extracted from the references sections of various articles, resulting in 71
total articles. From there, 46 were used in this study and the remaining 25 were excluded due to a lack of relevance. In terms of anthropometric studies where measurements could be taken from, only 2 studies, Greiner and Pheasant, were used in this study, as they are both extremely comprehensive and robust studies. In addition, studies correlating hand measurements to the practice of medicine are limited to survey data and glove size preferences, not actual numeric values.

**Hand Anthropometry of US Army Personnel to Excel**

The Greiner study from which over 1,000 men and 1,000 women were surveyed served as an extremely valuable tool in this study. The Pheasant textbook was also important for the study, surveying 300 men and 187 women in the British Army. These data were assumed to be representative of the general population as the study intended to create a working database for hand data and thus, were used as a comparator for the surgeon population. To use this data, a Microsoft Excel tool was developed. The mean and standard deviation for all 86 hand anthropometry measurements from the Greiner study and 20 hand anthropometry measurements from the Pheasant textbook were manually input into Excel. Another column was reserved for the measurement taken from the surgeon’s hand. The next column then utilized the mean, standard deviation and surgeon measurement to calculate the percentile of that surgeon’s particular hand measurement. It was also assumed that the anthropometric measurements from these studies are normally distributed. Therefore, to calculate the percentile of the surgeon’s hand for that measurement, the following function in Excel was used:

\[=\text{NORM.DIST}(x,\text{mean},\text{standard\_dev},\text{cumulative})\]

where \(x\) is the surgeon’s measurement,
mean is the mean from either the Greiner or Pheasant study, standard_dev is the standard deviation of the Greiner or Pheasant study, and cumulative is TRUE to return the cumulative distribution function. **Table 1** shows an excerpt of the tool developed for men from the Greiner study.

**Table 1: Excerpt of the hand measuring tool developed.** The first column is the identification number given to each anthropometric measurement. The second column is the formal name for the measurement. The third, fourth, fifth, and sixth columns are the mean, standard deviation, minimum and maximum values reported by Greiner. Column seven is where the user inputs the collected measurement and column eight is where the percentile is displayed, based on a normal distribution.

<table>
<thead>
<tr>
<th>ID</th>
<th>Measurement from ANSUR Male Data, Greiner 1991</th>
<th>Mean</th>
<th>St Dev</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Measure</th>
<th>Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Digit 1 Length*</td>
<td>6.97</td>
<td>0.48</td>
<td>5.50</td>
<td>8.60</td>
<td>7.00</td>
<td>52.5%</td>
</tr>
<tr>
<td>2</td>
<td>Digit 1 Height*</td>
<td>10.03</td>
<td>0.74</td>
<td>7.60</td>
<td>12.60</td>
<td>10.50</td>
<td>73.7%</td>
</tr>
<tr>
<td>3</td>
<td>Digit 1 Tip to Wrist Crease</td>
<td>13.79</td>
<td>0.87</td>
<td>11.20</td>
<td>17.00</td>
<td>13.00</td>
<td>18.2%</td>
</tr>
<tr>
<td>4</td>
<td>Digit 1 Interphalangeal Breadth*</td>
<td>2.40</td>
<td>0.13</td>
<td>2.00</td>
<td>2.80</td>
<td>2.50</td>
<td>77.9%</td>
</tr>
<tr>
<td>5</td>
<td>Digit 1 Interphalangeal Circumference*</td>
<td>7.23</td>
<td>0.29</td>
<td>6.30</td>
<td>8.10</td>
<td>7.23</td>
<td>50.0%</td>
</tr>
<tr>
<td>6</td>
<td>Digit 1 Link Length*</td>
<td>12.34</td>
<td>0.72</td>
<td>10.30</td>
<td>14.60</td>
<td>12.00</td>
<td>31.8%</td>
</tr>
<tr>
<td>7</td>
<td>Digit 1 Metacarpal Link Length</td>
<td>8.23</td>
<td>0.71</td>
<td>6.10</td>
<td>11.00</td>
<td>8.50</td>
<td>64.8%</td>
</tr>
<tr>
<td>8</td>
<td>Digit 1 Proximal Phalanx Link Length</td>
<td>2.11</td>
<td>0.30</td>
<td>1.20</td>
<td>3.10</td>
<td>2.50</td>
<td>90.3%</td>
</tr>
<tr>
<td>9</td>
<td>Digit 1 Distal Phalanx Link Length</td>
<td>3.45</td>
<td>0.26</td>
<td>2.70</td>
<td>4.50</td>
<td>4.00</td>
<td>98.3%</td>
</tr>
</tbody>
</table>

**Surgeon Measurements**

Various general surgeons (51 men, 8 women) were invited to the Medtronic Minimally Invasive Therapies Group in North Haven, CT for customer labs for numerous reasons, one of which being to learn their opinions on current or future products. While the surgeons were checking in, they filled out a brief survey indicating sex, dominant hand, preferred glove size, whether they double gloved and the corresponding sizes. The limited measurements taken from each surgeon included: hand circumference, maximum
grip diameter, Digit 2 link length (distance from the Digit 2 MCP joint to tip), Digit 1 length (from MCP joint to tip), and the Digit 2 distance from Digit 2 MCP Joint to DIP Joint. The Digit 2 distal phalanx length measurement was extrapolated from the data points collected (see below). Figure 2 provides a visual summary of the measurements taken.
Figure 2: Hand anthropometry measurements summary. Digit 1 Length (red arrow) is taken from the distal tip of the thumb to the palmar digit 1 crease. Digit 2 Link Length (green arrow) is the distance from the distal tip of the index finger to the MCP Joint, measured using the proximal transverse palmar crease. Digit 2 Distal Phalanx Length (orange arrow) is the distance from the distal tip of digit 2 to the DIP Joint, measured using the DIP Crease. In this study, this measurement was extrapolated by subtracting the Digit 2 Distance from D2 MCP Joint to DIP Joint form the Digit 2 Link Length. Digit 2 Distance from D2 MCP Joint to DIP Joint (purple arrow) is the distance from the D2 MCP Joint to DIP Joint using the Proximal Transverse Palmar Crease. Maximum Grip Diameter (light blue arrow) is taken by having the subject touch the distal tips of the first and third digits together and slide them over a cone until the two digits can no longer touch. Hand Circumference (curved blue arrows) is taken around the widest part of the palm, typically around the breadth of the knuckles.

Extrapolating Data Points

The measurement, Digit 2 Distance from D2 MCP Joint to DIP Joint, is not a reported anthropometric measurement by Greiner. Therefore, in order to compare the surgeon population surveyed to the general population as reported by Greiner, some
manipulations were necessary. To preface this, these measurements were recorded from the perspective of a medical device company and thus, focused on device usability. The Digit 2 Distance from D2 MCP Joint to DIP Joint was designed to serve as a functional measurement for gripping ability. It roughly approximates the effective trigger distance, depending on the size and shape of the instrument. Distances greater than this measurement will make operating the instrument challenging and might require the user to reposition their hand, whereas distances shorter than this measurement will not pose these issues. Since hand anthropometry measurements are distributed normally across the population, the mean and variance of two measurements can be summed. In the Greiner study, the length of the middle phalanx, taken as the distance between the DIP Crease and the PIP Crease, and the length of the proximal phalanx, taken as the distance between the PIP Crease and the Proximal Transverse Palmar Crease, together make up the Digit 2 Distance from D2 MCP Joint to DIP Joint.

Additionally, the Digit 2 Distal Phalanx Length was not measured, but rather extrapolated by subtracting the Digit 2 Link Length from the Digit 2 Distance from D2 MCP Joint to DIP Joint. The Digit 2 Distal Phalanx Length is a measurement recorded by Greiner so the analysis conducted thereafter was conducted the same as other measurements.

**Surgical Stapler Measurements**

Two commonly used laparoscopic surgical staplers are the Medtronic Endo GIA™ Ultra Universal Stapler and the Ethicon ECHELON FLEX™ ENDOPATH® Stapler. A photo of each handle was taken using a tripod to ensure the same scale in each
(Figure 3A, C), along with an additional image for reference lengths (not shown). Then, using ImageJ, an image processing software, measurements of the grips were taken at the most proximal and distal regions to provide the maximum and minimum lengths between the trigger and the handle at the time of device operation (Figure 3B, D).

Statistical Methods

Hand measurement data was input into Microsoft Excel and Minitab 17 for analysis. Pearson’s correlations and linear regression analysis were made for each measurement and glove size in addition to determining how well each hand measurement correlated with the others. Additionally, 2-sample t-tests were used to compare the general population taken from the Greiner and Pheasant study to the surgeon population that was measured. Median values with Median Absolute Difference (MAD) values were
reported to provide a more comprehensive view of the measurements. The data comparing the populations were plotted in Excel. P-values less than 0.05 were determined to be significant.
RESULTS

Surgeon Hand Anthropometry Compared to Average Population

Data can be found summarized in Table 2. The general population includes the mean and standard deviation reported by Greiner and Pheasant. Of the measurements, grip diameter came from the Pheasant study, all else came from Greiner. For men in the general population, average measurements are: 21.39 ± 0.98 cm hand circumference, 5.20 ± 0.43 cm grip diameter, 10.83 ± 0.69 cm D2 link length, 8.34 ± 0.64 cm distance from D2 MCP to DIP joint (extrapolated), 2.84 ± 0.23 D2 distal phalanx length, 6.97 ± 0.48 cm D1 length. For male surgeons, average measurements are: 7.5 ± 0.50 glove size, 21.35 ± 0.95 cm hand circumference, 5.05 ± 0.32 cm grip diameter, 9.98 ± 0.53 cm D2 link length, 7.20 ± 0.51 cm distance from D2 MCP to DIP joint, 2.78 ± 0.21 D2 distal phalanx length(extrapolated), 7.13 ± 0.51 cm D1 length. Male surgeon percentiles comparing means of the general population to the surgeons can also be found in Table 2, along with median and MAD values for the surgeons.

For women in the general population, average measurements are: 18.65 ± 0.86 cm hand circumference, 4.80 ± 0.31 cm grip diameter, 10.02 ± 0.64 cm D2 link length, 7.76 ± 0.57 cm distance from D2 MCP to DIP joint (extrapolated), 2.55 ± 0.21 D2 distal phalanx length, 6.35 ± 0.48 cm D1 length. For female surgeons, average measurements are: 6.0 ± 0.25 glove size, 18.95 ± 1.03 cm hand circumference, 4.63 ± 0.40 cm grip diameter, 9.14 ± 0.62 cm D2 link length, 6.58 ± 0.50 cm distance from D2 MCP to DIP joint, 2.56 ± 0.16 D2 distal phalanx length(extrapolated), 6.44 ± 0.59 cm D1 length.
Female surgeon percentiles comparing means of the general population to the surgeons can also be found in Table 2, along with median and MAD values for the surgeons.

**Table 2: Data summary.** All measurement data collected was summarized and inserted into this table. Male and female measurements were separated. The measurement data for the general population and surgeon population is included in addition to percentile data comparing the surgeon measurements to the general population. Mean and median values were included for the data collected during this study, reported with standard deviation (Stdev) and median absolute difference (MAD), respectively. The asterisks next to the Distance from D2 MCP to DIP Joint and D2 Distal Phalanx Length indicate data that were extrapolated and included only for completeness, despite potential inaccuracies.

<table>
<thead>
<tr>
<th>Male</th>
<th>General Population</th>
<th>Surgeon Measurements</th>
<th>Surgeon Percentiles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (Stdev)</td>
<td>Mean (Stdev)</td>
<td>Mean (Stdev)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Median (MAD)</td>
<td>Median (MAD)</td>
</tr>
<tr>
<td>Glove Size</td>
<td>N/A</td>
<td>7.55 (0.48)</td>
<td>N/A</td>
</tr>
<tr>
<td>Hand Circumference (cm)</td>
<td>21.39 (0.98)</td>
<td>21.35 (0.95)</td>
<td>49.97 (27.91)</td>
</tr>
<tr>
<td>Grip Diameter (cm)</td>
<td>5.20 (0.43)</td>
<td>5.05 (0.32)</td>
<td>40.14 (24.69)</td>
</tr>
<tr>
<td>D2 Link Length (cm)</td>
<td>10.83 (0.69)</td>
<td>9.98 (0.53)</td>
<td>16.63 (16.84)</td>
</tr>
<tr>
<td>Distance from D2 MCP to DIP Joint (cm)</td>
<td>8.34 (0.64)</td>
<td>7.20 (0.51)</td>
<td>8.15 (11.12)</td>
</tr>
<tr>
<td>D2 Distal Phalanx Length (cm)</td>
<td>2.84 (0.23)</td>
<td>2.78 (0.21)</td>
<td>42.85 (25.47)</td>
</tr>
<tr>
<td>D1 Length (cm)</td>
<td>6.97 (0.48)</td>
<td>7.13 (0.51)</td>
<td>58.40 (29.76)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Female</th>
<th>General Population</th>
<th>Surgeon Measurements</th>
<th>Surgeon Percentiles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (Stdev)</td>
<td>Mean (Stdev)</td>
<td>Mean (Stdev)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Median (MAD)</td>
<td>Median (MAD)</td>
</tr>
<tr>
<td>Glove Size</td>
<td>N/A</td>
<td>6.06 (0.50)</td>
<td>N/A</td>
</tr>
<tr>
<td>Hand Circumference (cm)</td>
<td>18.65 (0.86)</td>
<td>18.95 (1.03)</td>
<td>57.51 (26.76)</td>
</tr>
<tr>
<td>Grip Diameter (cm)</td>
<td>4.80 (0.31)</td>
<td>4.63 (0.40)</td>
<td>32.75 (34.32)</td>
</tr>
<tr>
<td>D2 Link Length (cm)</td>
<td>10.02 (0.64)</td>
<td>9.14 (0.62)</td>
<td>16.23 (20.61)</td>
</tr>
<tr>
<td>Distance from D2 MCP to DIP Joint (cm)</td>
<td>7.76 (0.57)</td>
<td>6.58 (0.50)</td>
<td>6.00 (9.18)</td>
</tr>
<tr>
<td>D2 Distal Phalanx Length (cm)</td>
<td>2.55 (0.21)</td>
<td>2.56 (0.16)</td>
<td>50.68 (25.79)</td>
</tr>
<tr>
<td>D1 Length (cm)</td>
<td>6.35 (0.48)</td>
<td>6.44 (0.59)</td>
<td>57.89 (32.95)</td>
</tr>
</tbody>
</table>
Figure 4: General population men vs women. Mean and standard deviation values are compared. Asterisks indicate statistically significant differences. Carrots indicate extrapolated data points.

Figure 5: Male surgeons vs female surgeons. Mean and standard deviation values are compared. Asterisks indicate statistically significant differences. Carrots indicate extrapolated data points.
Figure 6: General population men vs male surgeons. Mean and standard deviation values are compared. Asterisks indicate statistically significant differences. Carrots indicate extrapolated data points.

Figure 7: General population women vs female surgeons. Mean and standard deviation values are compared. Asterisks indicate statistically significant differences. Carrots indicate extrapolated data points.
Anthropometric Measurement Correlations amongst Surgeons

Each anthropometric measurement taken from surgeons, and the measurement that was extrapolated, were compared to each other to assess correlation. Table 3 shows correlations of all measurements from both male and female surgeons together. Table 4 shows correlations of all measurements from only male surgeons. Table 5 shows correlations of all measurements from only female surgeons. For both male and female surgeons, the measurements with the highest correlations are: D2 Link Length and Distance from D2 MCP to DIP Joint, Grip Diameter and D2 Link Length, and D2 Link Length and D1 Link Length. For male surgeons only, measurements with the highest correlations are: D2 Link Length and Distance from D2 MCP to DIP Joint, Grip Diameter and D2 Link Length, and D2 Link Length and D1 Link Length. For female surgeons only, measurements with the highest correlations are: D2 Link Length and Distance from D2 MCP to DIP Joint, D1 Length and Distance from D2 MCP to DIP Joint, and D2 Link Length and D1 Link Length.

Table 3: Surgeon hand anthropometry measurement correlations. All measurements, even those extrapolated were correlated to one another using Pearson’s Correlation test. Asterisks indicate a p-value less than 0.05. n = 56

<table>
<thead>
<tr>
<th></th>
<th>Hand Circumference</th>
<th>Grip Diameter</th>
<th>D2 Link Length</th>
<th>Distance from D2 MCP to DIP Joint</th>
<th>D2 Distal Phalanx Length</th>
<th>D1 Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand Circumference</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grip Diameter</td>
<td>0.519*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D2 Link Length</td>
<td>0.574*</td>
<td>0.773*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance from D2 MCP to DIP Joint</td>
<td>0.454*</td>
<td>0.693*</td>
<td>0.937*</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D2 Distal Phalanx Length^</td>
<td>0.503*</td>
<td>0.432*</td>
<td>0.455*</td>
<td>0.116</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>D1 Length</td>
<td>0.447*</td>
<td>0.649*</td>
<td>0.770*</td>
<td>0.682*</td>
<td>0.451*</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 4: Male surgeon hand anthropometry measurement correlations. All measurements, even those extrapolated were correlated to one another using Pearson’s Correlation test. Asterisks indicate a p-value less than 0.05. n = 48

<table>
<thead>
<tr>
<th>Hand Circumference</th>
<th>Grip Diameter</th>
<th>D2 Link Length</th>
<th>Distance from D2 MCP to DIP Joint</th>
<th>D2 Distal Phalanx Length^</th>
<th>D1 Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand Circumference</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grip Diameter</td>
<td>0.347*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D2 Link Length</td>
<td>0.395*</td>
<td>0.718*</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance from D2 MCP to DIP Joint</td>
<td>0.283*</td>
<td>0.629*</td>
<td>0.920*</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>D2 Distal Phalanx Length^</td>
<td>0.336*</td>
<td>0.228*</td>
<td>0.296*</td>
<td>-0.102</td>
<td>1</td>
</tr>
<tr>
<td>D1 Length</td>
<td>0.275*</td>
<td>0.583*</td>
<td>0.689*</td>
<td>0.578*</td>
<td>0.341*</td>
</tr>
</tbody>
</table>

Table 5: Female surgeon hand anthropometry measurement correlations. All measurements, even those extrapolated were correlated to one another using Pearson’s Correlation test. Asterisks indicate a p-value less than 0.05. n = 8

<table>
<thead>
<tr>
<th>Hand Circumference</th>
<th>Grip Diameter</th>
<th>D2 Link Length</th>
<th>Distance from D2 MCP to DIP Joint</th>
<th>D2 Distal Phalanx Length^</th>
<th>D1 Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand Circumference</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grip Diameter</td>
<td>0.449</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D2 Link Length</td>
<td>0.384</td>
<td>0.736*</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance from D2 MCP to DIP Joint</td>
<td>0.259</td>
<td>0.672</td>
<td>0.982*</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>D2 Distal Phalanx Length^</td>
<td>0.681</td>
<td>0.753*</td>
<td>0.805*</td>
<td>0.679*</td>
<td>1</td>
</tr>
<tr>
<td>D1 Length</td>
<td>0.086</td>
<td>0.540</td>
<td>0.834*</td>
<td>0.871*</td>
<td>0.506</td>
</tr>
</tbody>
</table>

Anthropometric Measurements to Glove Size Selection

Correlations of hand measurements and preferred glove size can be found in Table 6. The highest correlations were seen with hand circumference, followed by D2 link length. For female surgeons only, the top correlations were seen with hand circumference, D2 distal phalanx length (extrapolated), and D2 Link Length. For male surgeons only, the highest correlations were seen with hand circumference, distance from D2 MCP to DIP joint, and D2 link length.
Table 6: Glove size to hand measurement correlation. The preferred glove size of male and female surgeons both individually and together were tested against each measurement to determine which measurements most likely correlated with a particular glove size. The carrot indicates an extrapolated measurement. Asterisks indicate statistical significance (p-value < 0.05).

<table>
<thead>
<tr>
<th></th>
<th>Glove Size (M+F)</th>
<th>Glove Size (F)</th>
<th>Glove Size (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand Circumference</td>
<td>0.799*</td>
<td>0.818*</td>
<td>0.579*</td>
</tr>
<tr>
<td>Grip Diameter</td>
<td>0.512*</td>
<td>0.494</td>
<td>0.308*</td>
</tr>
<tr>
<td>D2 Link Length</td>
<td>0.631*</td>
<td>0.685*</td>
<td>0.414*</td>
</tr>
<tr>
<td>Distance from D2 MCP to DIP Joint</td>
<td>0.594*</td>
<td>0.608</td>
<td>0.45*</td>
</tr>
<tr>
<td>D2 Distal Phalanx Length^</td>
<td>0.304*</td>
<td>0.755*</td>
<td>-0.024</td>
</tr>
<tr>
<td>D1 Length</td>
<td>0.523*</td>
<td>0.311</td>
<td>0.326*</td>
</tr>
</tbody>
</table>

Linear regression analysis comparing preferred glove size to hand anthropology measurements can be found in Table 7. The highest $R^2$ values were observed for hand circumference, followed by D2 link length, indicating that these measurements have the greatest predictive value for selecting a preferred glove size.

Table 7: Glove size to hand measurement linear regression. The preferred glove size of male and female surgeons both individually and together were tested against each measurement to determine which measurements most likely predicted a particular glove size. The carrot indicates an extrapolated measurement. Asterisks indicate statistical significance (p-value < 0.05).

<table>
<thead>
<tr>
<th></th>
<th>Glove Size (M+F) $R^2$ (%)</th>
<th>Glove Size (F) $R^2$ (%)</th>
<th>Glove Size (M) $R^2$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand Circumference</td>
<td>63.9*</td>
<td>66.9*</td>
<td>33.5*</td>
</tr>
<tr>
<td>Grip Diameter</td>
<td>26.2*</td>
<td>24.4</td>
<td>9.5*</td>
</tr>
<tr>
<td>D2 Link Length</td>
<td>39.9*</td>
<td>47.0</td>
<td>17.1*</td>
</tr>
<tr>
<td>Distance from D2 MCP to DIP Joint</td>
<td>35.3*</td>
<td>37.0</td>
<td>20.2*</td>
</tr>
<tr>
<td>D2 Distal Phalanx Length^</td>
<td>9.3*</td>
<td>57.1</td>
<td>0.1</td>
</tr>
<tr>
<td>D1 Length</td>
<td>27.3*</td>
<td>9.7</td>
<td>10.7*</td>
</tr>
</tbody>
</table>
Hand Size Comparisons

Men of the general population had statistically significantly greater hand measurements than women of the general population (Table 8, Figure 4). This trend held true for male and female surgeons as well (Table 8, Figure 5).

When comparing men of the general population to male surgeons, hand circumference measurements were not statistically different. Men of the general population had a greater grip diameter, D2 link length, distance from D2 MCP to DIP joint (extrapolated for general population), and D2 distal phalanx length (extrapolated for surgeons), but were statistically shorter with respect to D1 length. These results can be found in Table 8 and Figure 6.

When comparing women of the general population to female surgeons, hand circumference measurements were greater in the female surgeons. There was no difference in grip diameter, D2 distal phalanx length (extrapolated for surgeons), and D1 length. Female surgeons had significantly greater D2 link lengths and distance from D2 MCP to DIP joint (extrapolated for general population). These results can be found in Table 8 and Figure 7.
Table 8: Group comparisons p-values. All groups were compared. Men and women are those from the Greiner and Pheasant studies. P-values less than 0.05 indicate statistical significance. The carrot indicates extrapolated data points. If the statistically significant p-value has an asterisk next to it, it means the surgeon was statistically significantly larger than the general population. If there is no asterisk, it means the general population was larger than the surgeon. Men were larger than women with respect to all measurements.

<table>
<thead>
<tr>
<th></th>
<th>Male Surgeon vs Men</th>
<th>Female Surgeons vs Women</th>
<th>Men vs Women</th>
<th>Male Surgeons vs Female Surgeons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glove Size</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>&gt;0.001</td>
</tr>
<tr>
<td>Hand Circumference</td>
<td>0.777</td>
<td>0.009*</td>
<td>&gt;0.001</td>
<td>&gt;0.001</td>
</tr>
<tr>
<td>Grip Diameter</td>
<td>0.003</td>
<td>0.269</td>
<td>&gt;0.001</td>
<td>0.022</td>
</tr>
<tr>
<td>D2 Link Length</td>
<td>&gt;0.001</td>
<td>0.005</td>
<td>&gt;0.001</td>
<td>0.007</td>
</tr>
<tr>
<td>Distance from D2 MCP to DIP</td>
<td>&gt;0.001</td>
<td>&gt;0.001</td>
<td>&gt;0.001</td>
<td>0.010</td>
</tr>
<tr>
<td>D2 Distal Phalanx Length</td>
<td>0.06</td>
<td>0.865</td>
<td>&gt;0.001</td>
<td>0.006</td>
</tr>
<tr>
<td>D1 Length</td>
<td>0.038*</td>
<td>0.680</td>
<td>&gt;0.001</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Figure 8: Histogram of preferred glove size vs gender. 48 male and 8 female general surgeons had their preferred glove size recorded. The sizes were normally distributed amongst men and women. The numbers over the bar indicate amount of men and women at that particular size.
Laparoscopic Stapler Measurements

The Medtronic Endo GIA™ Ultra Universal Stapler in “Fire Mode” had a proximal grip distance of 5.13 cm and a distal grip distance of 9.75 cm. The Ethicon ECHELON FLEX™ ENDOPATH® Stapler in “Fire Mode” had a proximal grip distance of 6.83 cm and a distal grip distance of 13.59 cm. These measurements can be found in Table 9. As mentioned above, the distance from the D2 MCP to DIP Joint was developed to provide an estimate for effective trigger distance. Based on a normal distribution of the mean and standard deviation values reported above in Table 2 for male and female surgeons, nearly all male surgeons and 99.8% of female surgeons will be able to use the Endo GIA™ Ultra Stapler ergonomically. For the ECHELON FLEX™ Stapler, 78.2% of male surgeons and 30.9% of female surgeons will be able to use it ergonomically (Figure 9).

Table 9: Stapler handle grip span measurements. Common laparoscopic staplers, as seen in Figure 3, were measured on the most proximal (top arrow in Figure 3B, D) and distal (bottom arrow in Figure 3B, D) on of the handle.

<table>
<thead>
<tr>
<th>Medtronic Endo GIA™ Ultra Universal (Fire Mode) Stapler</th>
<th>Ethicon ECHELON FLEX™ ENDOPATH® Stapler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal Grip Distance (cm)</td>
<td>Distal Grip Distance (cm)</td>
</tr>
<tr>
<td>5.13</td>
<td>9.75</td>
</tr>
</tbody>
</table>
Figure 9: Laparoscopic stapler handle length compared to Distance from D2 MCP to DIP Joint. The bars are the mean measured male and female surgeon’s distance from D2 MCP to DIP Joint with standard deviation. The red reference line is the proximal grip distance on the Ethicon ECHELON FLEX™ ENDOPATH® Stapler. The blue reference line is the proximal grip distance on the Medtronic Endo GIA™ Ultra Universal Stapler. These locations are typically where the index finger would be located during firing of the surgical stapler.
DISCUSSION

Measurement Interpretations

The data from Greiner\textsuperscript{14} and Pheasant\textsuperscript{15} shows that the mean hand size measurement for men is greater than the corresponding mean measurement for women, as seen in Figure 4, where all measurements for men were statistically greater than for women. The data collected in this study confirms these results, as the male surgeons have statistically larger hands than the female surgeons. Men also had a median glove size of 7.5, whereas women had a median glove size of 6.0. Figure 8 shows a histogram of the distribution of glove sizes broken out by gender, demonstrating where men and women fall with respect to preferred glove size. The vast majority of men have a glove size greater than 7.0, but only a minority of women wear gloves size 7.0 and above.

Compared to men of the general population, male surgeons had a smaller grip diameter, smaller D2 link length, yet a larger D1 length. Based on these outcomes and the schematic diagram presented in Figure 2, it appears that the male surgeons surveyed have shorter second and third digits. Female surgeons, compared to women in the general population had a larger hand circumference but shorter D2 link lengths. Female surgeons might also have shorter fingers, which is similar to the male surgeons. The effects of shorter fingers can be felt in many aspects of the practice of medicine.
Recommendations for Glove Sizing

According to previous studies, hand length and hand circumference measurements are largely representative metrics to encompass the majority of the population. These metrics are in fact how gloves are typically sized today, by choosing the larger of the two measurements, as explained above. This method, however, fails to take into the account the subtle variations in hand sizes, thus preventing an “ideal fit.” Though this current study is missing very valuable measurements for sizing surgical gloves, it agrees with previous research that hand circumference is a very influential factor in selecting a glove. This measurement had the highest correlation and linear regression to preferred glove size compared to any other measurement collected. Index finger length was second but it was not as strong of a correlation as hand circumference (0.799 vs 0.631), nor regression (63.9% vs 39.9%). If it is true that most surgeons choose a glove based on hand circumference, and yet have shorter digit lengths, this could be problematic. To ensure a wider range of sizes, surgical glove manufacturers might consider adding more variation to the finger lengths on the gloves, to create a two-metric sizing system. This would allow for those with wider palms and shorter fingers and those with narrower palms and longer fingers to find an ideal fitting surgical glove. Additionally, correlations differed between men and women. Whereas women glove size selection correlated very strongly to hand circumference (0.818), men did not correlate as strongly with this measurement (0.579). Therefore, gloves made specifically for each sex could also improve fit and comfort.
**Implications of Performing Surgery with Particular Hand Size**

Numerous studies to date have been surveys and thus have not collected actual hand measurements from surgeons. Instead, these studies have relied on preferred glove size as a metric to gain a rough idea of hand size. Nevertheless, the results are quite compelling and support the data gathered in this study. In general surgery, there is an increased emphasis on performing procedures laparoscopically. This method, however, has many flaws ergonomically. Poor ergonomics of the instruments used can result in an increase in forearm muscle EMG activity and undesirable wrist motion during laparoscopic surgery, ultimately increasing the amount of stress felt at the level of the forearm, wrist, and hand. This stress leads to fatigue and injury as a direct result of the additive adverse effects of overuse. Musculoskeletal pain in these areas, in addition to the upper extremity, shoulders, back and neck, is commonly reported by surgeons, which can decrease productivity and shorten careers.

Those that often suffer from injury are those with glove sizes of 6.5 or smaller, and although this number is independent of sex, the average glove size for women is approximately 6.5, which is in full agreement with the results from this current study. Men on the other hand, have an average glove size of approximately 7.5. Men and women of East Asian descent have smaller hand sizes, further compounding the issue. Japanese women have an average glove size of 6.0 and Japanese men have an average size of 7.0. Historically, surgery was a field dominated by men, and thusly, devices were designed to fit their hands. Today, however, more women are entering the field and are having a difficult time using the instruments. At this point in time, there
exists a large percentage of the surgeon population that must use instrumentation that does not fit their hands. Hand size is known to have a large influence on the ability to learn how to use surgical instrumentation and perform procedures, and issues with having small hands exist through the duration of one’s career, as adaptation does not occur. The “Learning Effect,” as reported by Uhrich et al., does not occur. Figure 9 is an overlaid plot that shows the distance from the D2 MCP to DIP Joint for the surgeon population measured. The horizontal lines are the grip distances for the ECHELON FLEX™ Stapler (red line) and the Endo GIA™ Ultra Stapler (blue line). As mentioned above, the distance from the D2 MCP to DIP Joint was developed to serve as a representative measurement of effective trigger distance for that user. The red line is greater than the average distance from D2 MCP to DIP Joint for female general surgeons surveyed, implying the majority of women, and some smaller handed men, will be unable to use this instrument in an ergonomic position and will either have to adjust their grip on the handle or use two hands to fire the device. Based on a normal distribution, nearly all male surgeon and 99.8% of female surgeons will be able to use the Endo GIA™ Ultra Stapler ergonomically. For the ECHELON FLEX™ Stapler, 78.2% of men and 30.9% of women will be able to use it ergonomically. This helps to explain why more women turn to a two-handed firing method when using laparoscopic staplers than do men and report that they are difficult to use, in addition to a host of other factors. Many note the importance of hand/glove size on the ability to use surgical instruments, where small hands/glove correlates with an increased difficulty using these devices. It has also been demonstrated in the literature that women typically have a lower maximum grip
strength than do men,\textsuperscript{10,40,41} further compounding the problem. Small hands with a lower grip strength makes instrument usage with one hand very difficult, especially when considering that such a great proportion of women don’t have hands large enough to use a common laparoscopic surgical stapler ergonomically as is.

Figure 8 shows the distribution of glove sizes of the surgeons surveyed during this study. As shown by numerous studies, ease of use of laparoscopic medical devices is proportional to glove size.\textsuperscript{33,39} As can be seen in Figure 8, below, the smaller-sized end of the spectrum is dominated by female surgeons and the larger-sized end of the spectrum is dominated by men. Therefore, men have an easier time using laparoscopic medical devices purely as a result of their hand size, a factor that is independent of medical knowledge. Historically, manually operated surgical stapler handles were designed based on the mechanical needs of the device. To be possible to fire, various parts must be a certain dimension, so the mechanics of the device were first assessed. After that, end users (surgeons) were asked to evaluate the device to assess the clinical acceptability and operability of the device by the majority of the user population tested. Future iterations of the device largely followed the same footprint of the predicate, with minor changes made each time to improve functionality. It is also important to note that most surgeons at the time of device development were men, so the devices were designed for them. Now, more and more women are entering the field, and find themselves at a disadvantage due to having a smaller hand size. If possible, medical device manufacturers such as Medtronic and Ethicon should look to develop an adjustable trigger handle with a locking pin mechanism for their manual stapling platforms to accommodate individuals with
different hand sizes so the device is comfortable and usable for all members of the surgeon population. In addition, for future devices, large hand anthropometry databases should be consulted to gain a more comprehensive view of the entire population.

Poor ergonomics can have numerous other negative implications. To reiterate, since stapler ease of use is proportional to glove size, and since women have significantly smaller hands than men, they have a much more difficult time, on average, using these devices. This difficulty has been linked to a decreased sense of confidence and increased levels of stress, especially for those with small glove size and weak grip force. In addition, those with a preferred glove size of 6.5 or less experience more musculoskeletal pain. More female surgeons experience pain than men, and more women receive treatment for their hands than do men. As shown in this study, female surgeons are significantly smaller than male surgeons in every measurement recorded. The discrepancy between hand sizes of surgeons and devices they use should be a cause for concern, especially when considering the physical and emotional challenges posed by poorly sized and ergonomically designed devices.

Consequences of Wearing Improperly Sized Surgical Gloves

As mentioned above, gloves are sized largely by using hand circumference and hand length measurements, where the user selects the larger of the two. That length, in inches, corresponds to the size of the glove. Most surgeons, however, only loosely use this guide and select a glove size based purely on comfort and feel. Each manufacturer uses a different set of specifications so a size 7 of one manufacturer might actually be different than the same size from a different manufacturer, which introduces variability in
the study. This variability, however minimal it is, may skew the results of this study, namely the correlation and regression analysis comparing glove size to hand anthropometry measurements.

To review, compared to bare hands, gloves can reduce tactile sensitivity,\(^{44-46}\) reduce dexterity as defined by score on the Purdue Pegboard Test,\(^{20,45}\) reduce handgrip strength,\(^{46}\) change pinch force sensitivity,\(^{45}\) and increase forearm muscle activity levels as defined by EMG activity.\(^{44-46}\) Most of these findings occurred with the subject’s preferred size surgical glove, and, as mentioned above, wearing improperly sized surgical gloves can further increase the negative effects of glove use.\(^{20}\) The challenge in glove sizing comes from the variability of hands, which can come in countless shapes and sizes. Based on the correlations above (Tables 3-5), it can be seen that all measurements correlated positively with one another to varying degrees, indicating variability in size between different parts of the hand on each individual. Excluding the extrapolated measurement that was only included for completeness (D2 Distal Phalanx Length), and measurements that share a digit (such as D2 Link Length and Distance from D2 MCP to DIP Joint), correlation strength is weakly to moderately positive. D1 and D2 link lengths display the strongest correlations, grip diameter has a few moderate correlations, and hand circumference has only weakly positive correlations to the other measurements. When investigating the correlation and regression analysis of these hand measurements with preferred glove size, (Table 6, 7), again there exists a range values. Highest correlations and \(R^2\) values exist when paired with the hand circumference measurement and D2 Link Length. Aside from those measurements, the correlation strengths and \(R^2\)
values are only weakly positive. This indicates that most surgeons, especially female surgeons, choose preferred glove size based on hand circumference while perhaps compromising quality of fit for their other measurements. Since most of the muscles that control the digits are located in the forearm and hand, with tendons passing through the palm on the posterior and anterior surfaces, a proper fitting glove in this part of the hand is essential to avoid early fatiguing and hand pain during tissue dissection. Therefore, it is reasonable to assume that some surgeons will experience tightness in their fingers or bunching of material at the tips while wearing their gloves, thus limiting tactile sensitivity and fine manipulation, respectively. These effects might reduce operating efficiency by increasing the difficulty of tissue dissection and lengthening the time needed for closure, as these processes require a delicate touch and fine movements. Having more flexibility in terms of how surgical gloves are sized is essential to ensure long-term health of the surgeons and effectiveness in practice

**Study Limitations**

This study is limited in that there were minimal anthropometric measurements taken. Coming from the perspective of a surgical stapling company, these measurements were geared towards usability of the products, not learning more about the physical characteristics of the surgeon’s hand. Sample size was also limiting, as only eight female surgeons were surveyed. Due to this limited data set, the results of this study may not be generalizable to the whole population of surgeons. Also, this limitation sheds light on the smaller numbers of women in the field of general surgery but should still be noted. Next, various glove manufacturers might use slightly different sizing metrics, introducing
variability to the study. Additionally, the resource used that served as a base of comparison to the surgeon population from the Greiner study is dated, as the measurements were taken in 1988 and 1989.

Conclusions

This study is unique in that it took actual anthropometric measurements of the surgeon hand and correlated it to preferred glove size. It found that there were minimal correlations between each hand measurement, yielding a large variety of hand sizes. It also showed that most surgeons choose a preferred glove size based on their hand circumference. This leaves variability as to how the glove will fit in the finger region, and how that could negatively impact both health and effectiveness of the surgeon during their medical practice. In addition, it showed statistically significant differences between the hands of surgeons and those of the general population, perhaps creating a need for new sizing metrics for surgical gloves. In the meantime, surgeons should look to match glove size to hand circumference in order to minimize musculoskeletal strain of having gloves that are too tight, unless touch sensitivity is more important for that particular case, in which hand length should be matched. This study also demonstrated, through the use of a novel hand measurement, that some commonly used laparoscopic staplers are too large to be used ergonomically by a large portion of intended users. Medical device manufacturers should look to create adjustable trigger handles, perhaps through a rotating locking pin mechanism, to allow ergonomic usability for all intended operators. Future devices should be designed with the help of large anthropometric databases.
LIST OF JOURNAL ABBREVIATIONS

Am J Nurs.  The American Journal of Nursing

Acta Anaesthesiol Scand  Acta Anaesthesiologica Scandinavica


Appl Ergon  Applied Ergonomics

Bull Hist Med  Bulletin of the History of Medicine

Can J Anaesth  Canadian Journal of Anesthesia

Dig Dis Sci  Digestive Diseases and Sciences

Ergonomics  The Official Journal of the Chartered Institute for Ergonomics and Human Factors

Hum Factors  The Journal of the Human Factors and Ergonomics Society

Interact Cardiovasc Thorac Surg  Interactive Cardiovascular and Thoracic Surgery

Int J Ind Ergon  International Journal of Industrial Ergonomics

J Am Coll Surg  Journal of the American College of Surgeons

J Clinic Gastroenterol  Journal of Clinical Gastroenterology

J Hand Surg  Journal of Hand Surgery

J Hand Surg Eur Vol  Journal of Hand Surgery (European Volume)

J Hum Kinet  Journal of Human Kinetics

J Occup Environ Hyg  Journal of Occupational and Environmental Hygiene

J R Soc Promot Health  Journal of the Royal Society for the Promotion of Health

Man Ther  Manual Therapy Journal
REFERENCES


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(860) 384-3616
michael.stellon@gmail.com
Year of birth: 1992

EDUCATION

Graduate Education: Boston University School of Medicine, Boston, MA
   (Sept. 2014 – May 2016)
   Masters of Science in Medical Sciences GPA: 3.88/4.00

Undergraduate Education: University of Connecticut, Storrs, CT
   (August 2010 – May 2014)
   Honors in Biomedical Engineering, Magna Cum Laude GPA: 3.86/4.00
   Concentrations: Biomaterials / Pre-medicine
   Minors in Mathematics and Materials Science & Engineering

EXTRACURRICULAR ACTIVITIES

Literacy Volunteers of Greater Hartford Mathematics Tutor
   Aug. 2015 – Present
   • Provide one-on-one assistance to those attempting to earn their GED by teaching mathematics

Alpha Eta Mu Beta BME Honor Society, UCONN Chapter (President)
   Aug. 2012 – April 2014
   • Enriched BME experience through organizing trips to conferences and seminars
   • Raised money to become a self-sufficient society

Biomedical Engineering Society, UCONN Chapter (Vice President)
   Sept. 2010 – April 2014
   • Founder of the UCONN BME Mentoring Program
   • Invited professors and company representatives to meetings to present new research

Hartford Hospital Mobility Program Volunteer
   May 2012 - Jan. 2013
   • Assisted patients in the healing process by providing physical therapy
   • Trained additional mobility aides

INTERNSHIPS

Medical Affairs Intern: Medtronic, New Haven, CT
   Aug. 2015 – Present
Internship Preceptor: Christine Mauro, Md, MMSc.
   • Function as a member of a multidisciplinary team to participate in post-market vigilance of products
   • Work in the development and review of human clinical trials
• Support clinically-oriented topics such as: device use, patient safety in, and generation of clinical evidence to support products

**Biomedical Engineer: Covidien Surgical Solutions, North Haven, CT**  
May 2011 – Aug 2014

Internship Preceptors: Dwight Bronson, MS., Andrew Miesse, MS., Marisha Godek, PhD.

• Researched and developed testing protocols to determine the effects of tension across a stapled anastomosis (published results)
• Created and validated a semi-automated test apparatus to pressurize stapled anastomotic samples by applying pressure inside the lumen while applying tension across the anastomosis
• Collaborated with external companies to develop artificial tissue for the validation of medical devices
• Developed and executed testing protocols to compare surgical staplers
• Developed extensive surgical lab experience to execute testing protocols
• Tested performance of powered vs manually activated surgical staplers

**Research Assistant: Biomolecular and Biomimetic Engineering Laboratory**  
Univ. of Connecticut and Penn State Univ.  

Internship Preceptor: Yong Wang, PhD.

• Designed a microfluidic system to selectively capture and safely release circulating tumor cells
• Developed a method for the dynamic capture of circulating tumor cells using an aptamer-functionalized hydrogel and release using DNA sequences complementary to the aptamer (published results)

**SENIOR CAPSTONE PROJECT**

**UCONN Department of Biomedical Engineering, Storrs, CT**  
September 2013 – May 2014

Advisor: Donald Peterson, PhD.

• Worked in a collaborative, multidisciplinary team to redesign the personal epinephrine auto-injector
• Utilized SolidWorks to design individual mechanical components of the auto-injector
• Developed skills in: advanced machining/manufacturing, fluid dynamics, computer programming
• Learned Xcode to develop an iPhone application
• Gained familiarity with basic circuitry and Bluetooth protocols

**PUBLICATIONS**

**Abstracts**

1. Andrew M Miesse, **Michael A Stellon**, Ross Segan, Emily Miesse, Dwight G Bronson: *Investigating the Effects of Tension on a Stapled Anastomosis*. Surgical Endoscopy, Vol. 27 (Supplemental 1); April 2013, pages S1-527.


**INVITED PRESENTATIONS**


