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The relationship between adiposity indices, dental development and skeletal maturation in orthodontics

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DISSERTATION

THE RELATIONSHIP BETWEEN ADIPOSITY INDICES, DENTAL DEVELOPMENT AND SKELETAL MATURATION IN ORTHODONTICS

by

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DEDICATION

I would like to dedicate this study to the Almighty God, thank you for the guidance, strength, power of mind, protection and skills and for giving me a healthy life.

I wholeheartedly dedicate this work to my patient and beloved parents Nawal and Said, my spouse and my siblings, who have been my source of inspiration and gave me strength when I thought of giving up, who continually provide their moral, spiritual, and emotional support.

Last but not least, I would also like to dedicate this work to my classmates and my colleagues who made it easier for me to recruit my candidates.

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ABSTRACT

Title: The Relationship between Adiposity Indices, Dental Development and Skeletal Maturation in Orthodontics.

Objectives: The aim of this study is to assess the association between different adiposity indices, dental development and skeletal maturation in children and adolescents.

Methods: A total of 115 patients who presented to the orthodontic clinics at Boston University were examined for their height, weight, skeletal maturation, and 10 different adiposity indices. Statistical analysis included chi-square, ANOVA, and multiple ordinal regression models.

Results: In the sample (59% female, 41% male) the mean age was 14 years, (SD:2.5), height 160 cm (SD:11.9), weight 61 kg (SD:19.1), and ethnicity was 31% African Americans, 31% Hispanics, 27% Caucasians, and 9% Asians. The Pearson correlation coefficient showed SMI was significantly correlated with (by order of correlation strength) CVMI (P<.01), dental development

according to Demirjian (P<.01), root completion (P<.01), eruption (P<.01), fat free mass (FFM) (P<.01), total body water (TBW) (P<.01), body adiposity index (BAI) (P<.01), BMI (P<.01), fat mass (P<.01), right subscapular skinfold (P<.01), BMI percentile (P<.01), fat percentage (P<.01), right triceps skinfold (P<.01), and waist/hip ratio (P<.01). For CVMI, it was significantly correlated in order of strength with SMI (P<.01), BMI % (P<.01), dental development (Demirjian) (P<.01), root completion (P<.01), eruption (P<.01), FFM (P<.01), TBW (P<.01), BAI (P<.01), waist/hip ratio (P<.01), BMI (P<.01), fat mass (P<.01) and right subscapular skinfold (P<.01). However, the Waist/Height ratio was not significantly related with either methods of skeletal assessment. Using the Chisquare test, we found that no adiposity index was statistically significant predictor of any dental outcome (i.e., dental development by Demirjian, root completion and eruption sequence) except for dental development (Demirjian) which was statistically significantly related with the waist/hip ratio. After controlling for other covariates (i.e., age and gender) for skeletal outcomes, all adiposity indices were statistically significant predictors for SMI including BMI percentile, BMI, BAI, fat percentage, fat mass, FFM, TBW, BIA, and waist/height ratio.

Conclusions: Children and adolescents with increased adiposity values (i.e., BMI percentile, BMI, BAI, fat percentage, fat mass, FFM, TBW, BIA, and waist/height ratio), had higher probability of being skeletally more mature as measured by SMI.

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INTRODUCTION

The optimal time to initiate orthodontic treatment has been widely researched and is highly debatable. The degree of dental development commonly determines the timing of treatment. Orthodontic treatment timing is based on the different concepts in craniofacial growth modifications during the individual's most somatic and facial growth period (Jang et al. 2005). A disturbance in dental maturity can impact oral health by affecting the individual's occlusion, crowding, temporomandibular joint, poor oral hygiene, periodontal disease, and dental caries (Must et al. 2012).

Chronological age and secondary sexual characteristics do not accurately correlate to the individual variation in skeletal growth and maturity (Pichai et al. 2014)(Hassel and Farman 1995). Radiographically, two methods have been developed for better assessment of skeletal age. Bjork introduced the hand wrist technique in the second decade of the 20th century. Greulich and Pyle modified Bjork's technique and published the Radiographic Atlas of Skeletal Development of the Hand and Wrist. Later on Lamparski created the cervical vertebral method as an alternative technique to accurately measure bone maturity ((US) et al. 2001).

A combination of several factors determines individual's body weight: genetic, metabolic, behavioral, environmental, cultural, and socioeconomic factors. Behavioral and environmental factors predominantly contribute to overweight and obesity (Dunger, Lynn Ahmed, and Ong 2005). Ultimately, obesity was found to affect the timing of puberty onset. Frisch and Revelle, in 1970, introduced the "Critical Mass Theory". It was thought that for puberty to progress, 22 percent body fat had to be reached (Martin et al. 2011). It was also found that before puberty, overweight children were likely to be significantly taller than their same age peers (Must et al. 2012).

BMI does not account for bone, muscle and fat mass. It measures only height and weight, ignoring the distribution of fat. Other obesity or adiposity measures such as waist to height ratio on the other hand, might be more representative and more accurate when related to growth and development. Therefore, our primary objective was assessing different types of adiposity indices other than BMI, on the skeletal and dental maturity since the amount of body fat is measured more exclusively in these techniques which also decreases the likelihood of misclassification.

BMI and BMI Percentile Limitations

BMI is defined as weight divided by the square of height; as a limitation, when BMI is calculated, weight is divided by a relatively small number for short individuals whereas a larger number for tall people. Short people are thus misled into thinking that they are more overweight than they are, and vice versa, which may imply that some individuals may be misclassified based on BMI. Most importantly, the definition of categories of BMI has been changing as the cut-off point for being obese or overweight has been updated continuously from 1985 to 1995. For example, the National Institute of Health has changed the cut-off point for overweight in 1985 from 27.3-27.8 to more than 25 in 1998.

For children, BMI percentile is used routinely instead of BMI in assessment of normality of weight and height ratio. It is not appropriate to use the BMI categories for adults to interpret the BMI of children and teens. The interpretation of BMI varies by age and sex. If the children are not the same age and the same sex, the interpretation of BMI has different meanings. For children of different age and sex, the same BMI could represent different BMI percentiles and possibly different weight status categories. After BMI is calculated for children and teens, it is expressed as a percentile which can be obtained from either a graph or a percentile calculator. (Centers for

Disease Control and Prevention n.d.) These percentiles express a child's BMI relative to children in the U.S. who participated in national surveys that were conducted from 1963-65 to 1988-94. Because weight and height change during growth and development, as does their relation to body fatness, a child's BMI must be interpreted relative to other children of the same sex and age. The BMI-for-age percentile growth charts are the most commonly used indicator to measure the size and growth patterns of children and teens in the United States. BMI-for-age weight status categories and the corresponding percentiles were based on expert committee recommendations and are shown in the following table (Table 1).

Table 1. BMI-for-age percentile growth chart.

Weight Status Category	**Percentile Range**
Underweight	Less than the 5th percentile
Normal or Healthy Weight	5th percentile to less than the 85th percentile
Overweight	85th to less than the 95th percentile
Obese	Equal to or greater than the 95th percentile

The prevalence of children and teens who are in the 95th percentile or greater who are considered as obese by the CDC growth charts has significantly increased over the past 40 years. Recently, however, this trend has leveled off and has even declined in certain age groups. (Centers for Disease Control and Prevention n.d.)

While BMI is not a perfect index for obesity, it is a valuable tool for public health because it measures weight in relation to height. Adults with a BMI between 18.5 and 24.9 are considered "normal," measurements between 25.0 and 29.9 are considered "overweight," those who measure 30 or more are considered "obese," and those with a measurement of 40 or more are considered "extremely obese." For children and adolescents, sex and age form the basis for BMI categorization; changes that occur during growth accounts for further division. The Centers for Disease Control and Prevention (CDC) developed children's BMI growth charts. Children and adolescents with a BMI between the 5th and 85th percentile are considered "healthy weight"; BMI values between the 85th and 94th percentiles are considered "overweight," and those with a BMI at 95th percentile or above are considered "obese". (Anon n.d.)

The U.S. Department of Health and Human Services reported that about one third of 6-19 years old children are reportedly overweight or obese, and more than 1 in 6 children aged in that age group are reportedly obese. In addition, among children aged between 2-19, about 32% are reportedly overweight or obese, and about 17% are obese. By gender, about 33% of boys are reportedly overweight or obese, compared with 30% of girls. Overall, about 19% of boys and 15% of girls are reportedly obese. By race, more than 2 in 5 black and Hispanic children are reportedly overweight or obese. Approximately 26% of black, 23% of Hispanic, and 15% of white children are reportedly obese. (Centers for Disease Control and Prevention n.d.)

National Health and Nutrition Examination Survey (NHANES)

Childhood obesity is a global public health concern. Data from the 2007–2008 NHANES show that the prevalence of obesity in the United States was approximately 17% among 2–19 years old children and reached as high as 29% in certain racial groups. In 2011-2012, almost 18% of 6-11 years old and 20.5% of 12-19 years old were obese (Must et al. 2012).

Hand wrist and Cervical Vertebrae Maturation

The assessment of bone age enables the recognition of normal growth deviations, determines the type of treatment, helps determine the appropriate time to begin treatment, and establishes prognosis and guides a retention strategy.

In order to assess the maturity of bones, hand-wrist radiographs were introduced to evaluate the appearance, size and shape of ossification centers, the width and the shape of growth cartilage, and the degree of fusion between diaphysis and epiphyses. Radiological examination of a hand wrist radiograph, a procedure commonly used for several years now, is more accurate in bone age assessment than the new proposed techniques (Martin et al. 2011). There is a considerable delay in the development of wrist bones compared with the bones of the upper limb. The ossification of cartilages begins after childbirth. Complete development of epiphyses and their fusion with diaphyses occur at puberty. Ossification happens earlier in females than in males (Mituś-Kenig 2013).

It is also possible to conduct bone age assessment by analyzing the morphological maturity of cervical vertebrae from cephalometric radiographs (Martin et al. 2011).

Center for Disease Control (CDC)

The 2013 National Youth Risk Behavior Survey indicates that 14% of U.S. high school students were obese. Obese children have a higher risk for type 2 diabetes, breathing problems, such as sleep apnea, and asthma; joint problems and musculoskeletal discomfort; fatty liver disease, gallstones, and gastro-esophageal reflux, and some cancers. They also tend to have more psychological stress such as depression, behavioral problems, issues in school, low self-esteem, impaired social, physical, and emotional functioning. A study showed that 70% of obese children had at least one cardiovascular disease (CVD) risk factor such as high blood pressure and high cholesterol, and almost 40% had more than one risk factor of CVD. Obese children were more likely to stay obese during adulthood. The epidemic of early childhood obesity threatens the future by increasing young children's chances of developing those diseases. (Centers for Disease Control and Prevention n.d.)

Epidemiology of Obesity

In the United States, childhood obesity rates have tripled over the past three decades. Today, one in three children in America is overweight or obese. Nearly 40% of African American and Hispanic children are overweight or obese. If this problem persists, 33% of all children born in the 21st century will suffer from diabetes at some point in their lives. Healthy People, a program sponsored by the CDC Office of Disease Prevention and Health Promotion, provides science-based 10-year national objectives for improving the health of all Americans. In 2010, they aimed for a reduction of overweight and obese children and adolescents to 5%, but have failed to achieve this goal. Since 1980, the obesity rate has more than doubled (from 5.0% to 12.4%) among children

aged 2-5 years old, almost tripled (6.5% to 17%) among children aged 6-11, and more than tripled (from 5.0% to 17.6%) in adolescents aged 12-19 years old. (Anon n.d.)

Children nowadays have a sedentary lifestyle, as TV, video games, and the internet are replacing more physical activities. Diet is highly compromised because of fewer home-cooked meals and more snacking between meals. One in five school-age children has up to six snacks a day. Thirty years ago, one snack per day was common, whereas now having three snacks is the norm, adding 200 calories to the daily caloric intake. Portion size has increased two to five times bigger than the past years. Sweetened beverages were on average 13.6 oz. as compared to 20 oz. today. Americans are eating 31% more calories than 40 years ago, which includes 56% more fats and oils, and 14% more sugar and sweeteners. The average American now have 15 lb. more sugar a year than in 1970. Kids and adolescence now spend 7.5 hours/day on average using media entertainment. Only thirty three percent of high school students have the recommended physical activity levels. (Anon n.d.)

LITERATURE REVIEW

BMI, Dental Development, and Skeletal Maturation

Must et al. conducted a cross sectional study in the United States to examine the association between obesity and tooth eruption. NHANES data were combined from three consecutive cycles (2001–2006) with 5434 children between 5-14 years old accounting for their obesity status (BMI >95th percentile according to the CDC growth chart). Bivariate analyses revealed a significant association between number of erupted teeth and obesity status; on average, teeth of obese children erupt earlier than those of non-obese children. Obese children have on average 1.44 more teeth erupted than non-obese children at a given chronologic age. These findings have clinical significance in orthodontics that may increase the chances of malocclusions (Must et al. 2012).

Sánchez-pérez et al. conducted a prospective cohort study in Mexico to examine the association between caries and BMI and to explore the effect of BMI on tooth eruption on 110 elementary schoolchildren. Eighty-eight children completed the four-year follow-up. The CDC BMI growth chart was used. At baseline, children in the "overweight" category had 4.29 more teeth erupting on average than those classified as "thin." At age 11, the "overweight" group had 5 more teeth than the "thin" group. The "overweight" category had more erupted teeth and a lower caries index (Sánchez-Pérez, Irigoyen, and Zepeda 2010).

Fatemifar et al. conducted a prospective cohort study in the United Kingdom to establish a common pathway between primary tooth emergence and adiposity using the Avon Longitudinal Study of Parents and Children (ALSPAC). They used a sample of 2977 participants with a mean age of 17.8 years to measure the relationships between primary tooth emergence and anthropometric features in adolescence. "Quintiles of number of paired teeth" at 15 months positively related to height in males and fat mass at age 17. The associations with height and fat

mass were unaffected by adjustment for puberty onset. This suggests that primary tooth emergence and obesity could share similar factors, leading to the possibility that early primary tooth emergence might represent an unrecognized risk factor for obesity later in life. Confounders might be responsible for those associations due to the observational nature of the study. The sample represents a minority of the overall ALSPAC cohort, limiting the generalizability of their findings (Fatemifar, Evans, and Tobias 2014).

Mack et al. conducted a retrospective cohort study in the United States on a sample of 540 of 8-17-year-old to investigate the relationship between BMI percentile and skeletal and dental maturity in adolescent orthodontic patients. Dental age was assessed using Demirjian's method and weight status was assessed with the BMI percentile. They found more advanced cervical vertebral stage and dental age in individuals with a higher BMI percentile (MacK et al. 2013).

Costacurta et al. conducted a cross-sectional study in Italy to assess the skeletal maturation evaluated through CVM and dental age in normal weight, pre-obese and obese patients, using BMI and Dual energy X-ray Absorptiometry or DXA. DXA is a method of measuring bone mineral density, which can be used to measure total body composition and fat content with a high degree of accuracy. They used a sample of 107 patients between 6-12 years old. BMI-based classifications categorized participants as "underweight," "normal weight," "pre-obese," and "obese" by using "Italian specific growth charts." Dental age was assessed by using the Demirjian method. Dental age was found to be not significantly associated with BMI. (Journal et al. 2012).

Hilgers et al. conducted a retrospective cohort study in the United States to determine if elevated BMI was associated with an acceleration in dental development using the Demirjian method on 104 children between 8-15 years old. Dental development was significantly accelerated

with an increased BMI. The mean dental age acceleration for obese subjects was 1.53±1.28 years relative to chronological age (Hilgers et al. 2006).

Eid RM et al. conducted a retrospective cohort study in Brazil to apply Demirjian's method to 689 Brazilian children between 6-14 years old to obtain dental maturity curves for both sexes, to compare this data with that obtained by Demirjian, and to determine whether there was a significant correlation between dental maturity and BMI. Panoramic films, height and weight measurements were reviewed. Dental age was assessed using Demirjian's method. BMI was classified into five categories using the CDC reference growth chart. There was no significant association between dental age and BMI. Brazilian children were found to have more advanced dental maturity compared to Demirjian's French-Canadian sample, supporting the demand for population-specific standards. Demirjian assessment method tends to over-estimate dental age and does not accurately apply dental age in today's population (Eid et al. 2002).

BMI and Craniofacial Changes

Sadeghianrizi et al. conducted a cohort study in Sweden to examine craniofacial morphology in obese as compared to normal adolescents. The study used lateral cephalometric radiographs which showed that mandibular and maxillary dimensions for both genders were higher in the obese group. Maxillary and mandibular prognathism were noted in the obese group. The mandibular plane angle was smaller in the obese group. The obese group also exhibited a less convex soft tissue profile. In general, obesity was associated with bimaxillary prognathism and increased facial dimensions (Sadeghianrizi et al. 2005).

Ohrn et al. also conducted a cohort study in Sweden to examine whether craniofacial morphology is different between obese and normal weight children and adolescents. Comparison

of lateral cephalograms from 39 obese adolescents between 14–16 years of age to an equal number of matched controls revealed that the subjects in the obesity group had a larger mandibular length, prognathic jaws, and a reduced upper anterior face height compared to the control group. Obese adolescents also had low GH level with normal levels of insulin-like growth factor (IGF-1) (Ohrn K, Al-Kahlili B, Huggare J, Forsberg C-M, Marcus C 2002).

BMI and Puberty Timing

Dunger et al. and Marcovecchio et al. reviewed the literature on obesity and growth during childhood and puberty and came to the following conclusions: during puberty, obese children tended to be taller, but this disappeared due to a pubertal spurt that was reduced in magnitude. Abnormalities in the GH- IGF- 1 axis are common among obese children. During early life, obesity is a risk factor for an early onset of puberty, mainly in girls, with the associated consequences. In boys there are contradicting findings, with obesity being associated with delayed puberty in some studies and with advanced puberty in others. They also reported that rapid early postnatal gain in weight and subsequent increased risk for obesity may have profound effects on the velocity of childhood growth and puberty (Dunger et al. 2005)(Loredana Marcovecchio and Chiarelli 2013).

BMI and Obstructive Sleep Apnea

Maeda et al. conducted a study in Japan to compare the size of the dental arches in obese and non-obese obstructive sleep apnea (OSA) patients. Using a lateral cephalometric radiograph and study models, the tongue size and dental arches in 23 obese and 23 non-obese Japanese males were compared and matched for age, apnea hypopnea index (AHI) and maxillomandibular size. The sizes of the maxilla and the mandible, including dental arch width, dental arch length, overjet

and overbite were measured. The tongue size and both upper and lower dental arch widths were significantly larger in obese than in non-obese obstructive sleep apnea patients. These findings suggest an enlargement of the tongue and dental arches in obese patients under the same disease severity compared with non-obese patients. Fortunately, wider dental arches in obese OSA patients may help to balance the impact of the enlarged tongue on upper airway obstruction (Maeda et al. 2012).

Dental Development

Dental calcification, which is a continuous developmental process, is a better measure of physiological maturation than dental emergence. Demirjian, Goldstein and Tanner developed a widely used dental maturity scoring system for dental age on a large sample of Canadian children in 1973. (Demirjian, Goldstein, and Tanner 1973) Using this protocol, 7 mandibular teeth (left central incisor to left second molar) were scored based on 8 stages of tooth maturation and eruption. Scoring was based on criteria from crown calcification, root development, and apex characteristics. Scores were added together to give a dental maturity reading and then converted to a dental age using sex-specific tables. A maturity score of 100 indicates complete tooth development based upon the rate of development and calcification of tooth buds and their progressive sequence of eruption. This protocol was slightly modified; in girls, a maturity score of 100 indicates a dental age of 16 years, in boys, a maturity score of 98.4 indicates a dental age of 16 years (7 teeth on left side of mandible). The tooth calcification gives a valuable indication of dental maturation of the child. (Demirjian et al. 1973) This modification was followed in this study as shown in the figure below (Figure 1). (Wong et al. 2016)

Figure 1. Developmental stages of the permanent dentition.

Skeletal Maturation

Skeletal Maturity Index (SMI) (Radiograph Method)

Hand wrist skeletal maturity index (SMI) is measured by epiphyseal widening, ossification (appearance of adductor sesamoid), epiphyseal capping, and epiphyseal fusion according to Fishman et al. (Anon n.d.) The following table summarizes the stages of SMI maturity (Table 2).

Table 2. Skeletal Maturity Index (SMI)

SMI Stage	Description	Definition
SMI 1	When the third finger proximal phalanx shows equal width of ephiphysis and diaphysis	Initiation stage which means 85-100% pubertal growth is anticipated
SMI 2	When the width of epiphysis equal to that od diaphysis in the middle phalanx of the third finger	
SMI 3	When the width of epiphysis equal to that of diaphysis in the middle finger phalanx of fifth finger	Acceleration which means 65-85% pubertal growth is anticipated
SMI 4	The appearance of adductor sesamoid of the thumb	
SMI 5	Capping of epiphysis seen in distal phalanx of third finger	Transition stage which means 25-65% pubertal growth is anticipated
SMI 6	Capping of epiphysis seen in the middle phalanx of third finger	
SMI 7	Capping of epiphysis seen in middle phalanx of fifth finger	

SMI 8	Fusion of epiphysis and diaphysis in the distal phalanx of third finger	Deceleration which means 10-25% pubertal growth is anticipated
SMI 9	Fusion of epiphysis and diaphysis in the proximal phalanx of third finger	Maturation stage which means 5-10% pubertal growth is anticipated
SMI 10	Fusion of epiphysis and diaphysis in middle phalanx of third finger	
SMI 11	Fusion of epiphysis and diaphysis seen in the radius	Completion which mean 0% pubertal growth is anticipated

Cervical Vertebrae Maturation Index (CVMI) (Radiograph Method)

This method analyzes the cervical vertebrae C2 through C4 based on lower border concavity and vertebral body shape. Based on these criteria, a stage from 1 through 6 was assigned to each subject. (See Table 3) Initiation is CVMI 1 indicates the initiation stage of adolescent growth, whereas CVMI 2 indicates that acceleration of growth has occurred. CVMI 3 constitutes the transition stage, meaning that a moderate amount of adolescent growth is expected, Deceleration is at CVM 4 which indicates small amount of adolescent growth is expected. Maturation stage is indicated by CVMI 5, and CVMI 6 signifies completion of growth (Table 3).

Table 3. Cervical Vertebrae Maturation Index (CVMI).

CVMI Stage	Description	Definition
CVMI 1	Initiation; which indicated a very significant amount of adolescence growth expected, it is when C2, C3 and C4 inferior vertebral body borders are flat, and superior vertebral borders are tapered posterior to anterior	Peak mandibular growth will occur in 2 years
CVMI 2	Acceleration; where there is significant amount of adolescent growth is expected, this is when concavities developing in lower borders of C2 and C3, lower border of C4 vertebral body is flat, and C3 and C4 are more rectangular in shape	Mandibular growth peaks a year after
CVMI 3	Transition; which is moderate amount of adolescent growth is expected, which is visible as distinct concavities in lower borders of C2 and C3, C4 developing concavity in lower border of body, and C3 and C4 are rectangular in shape	Pubescent growth spurt occurs
CVMI 4	Deceleration; which indicates small amount of adolescent growth is expected, this is visible as distinct concavities in lower border od C2, C3, and C4, and C3 and C4 are nearly square in shape	Peak mandibular growth occurred 1-2 years ago

CVMI 5	Maturation; indicating insignificant amount of adolescence growth expected, accentuated concavities of inferior vertebral body borders of C2, C3, and C4. C3 and C4 are square in shape	Peak growth ended 1 year ago
CVMI 6	Completion; which indicated that adolescent growth is completed, deep concavities are present for inferior vertebral body borders of C2, C3, and C4. C3 and C4 heights are greater than width.	Peak growth ended 2 years ago

Adiposity Indices:

1. **Body Mass Index (BMI)**

BMI percentile gives a more specific weight status in growing children and teens than the BMI alone. BMI-for-age percentile shows how a given child's weight compares to other children of the same age and sex. It could be used as a screening tool for body fat but it is not diagnostic. Individuals with the same BMI may have different measurements of body fat.

2. **Body Fat Percentage (BFP)**

The body fat percentage is a measure of fitness level, since it is the only body measurement which directly calculates a person's relative body composition without taking height or weight into consideration.

3. **Body Adiposity Index (BAI)**

Based on population studies, the BAI is almost equal to the percentage of body fat for adults of both genders of differing ethnicities. BAI is calculated using hips circumference compared to the height of the person without measuring body weight, unlike BMI as BAI can be measured without weighing, which may render it useful in settings where measuring accurate body weight is problematic (Bergman et al. 2012).

4. **Waist Circumference (WC)**

Waist circumference reflects abdominal obesity, which is a risk factor for diseases related to chronic obesity. The National Heart, Lung, and Blood Institute (NHLBI) classified the risk of obesity-related diseases as high if men have a waist circumference greater than 102 cm / 40 inches

and women have a waist circumference greater than 88 cm / 35 inches. Koning et al. published a study in 2007 and showed that waist circumference and waist-hip ratio were predictors of cardiovascular events.

5. Waist-Hip Ratio (WHpR)

It measures the proportion of fat distribution around the torso by calculating waist measurement divided by hip measurement (W/H). Waist–hip ratios of 0.7 for women and 0.9 for men have shown a strong correlation with general health and fertility.

People who have metabolic syndrome typically have apple-shaped bodies, meaning they have larger waists and a lot of their weight is around the abdomens. It is thought that having a pear-shaped body, which is having a narrower waist and carrying more of your weight around your hips puts a person at a lower risk of developing diseases and complications of metabolic syndrome.

6. Waist-Height Ratio (WHtR)

In 2010, a systematic review of published studies concluded "WHtR may be advantageous because it avoids the need for age-, sex- and ethnic-specific boundary values." For people under 40, the critical value was 0.5; for people aged 40–50, the critical value was between 0.5 and 0.6, and for people over 50, the critical values start at 0.6 (Browning, Hsieh, and Ashwell 2010).

A 2010 study of 11,000 subjects who were followed up to 8 years established that WHtR is a better tool for measuring the risk of heart attack, stroke, or death compared to BMI (Schneider et al. 2010). Another study was conducted in 2011 on 60,000 subjects followed up to 13 years found that WHpR was better in predicting ischemic heart disease mortality than WHtR. WHtR is not a

predictor for the onset of diabetes mellitus (Mørkedal, Romundstad, and Vatten 2011). Height was measured using a stadiometer. WHtR correlates with abdominal obesity. (Man et al. 2008)

7. Skin Calipers

The skinfold estimation methods are based on a skinfold measured by a caliper at several standardized points on the body to quantify subcutaneous fat layer thickness. Measurements are then converted to an estimated body fat percentage by various equations. (Wilson and Durnin 1995) Some formulas require as few as two measurements, while others use as many as ten. Skinfold thicknesses may be measured in duplicate or triplicate at the left side of the body to the nearest 0.1 mm. In this study it was measured in triplicate on the left side of the body.

8. Bioelectrical Impedance Analysis (BIA)

Essential body fat is crucial to maintain life and reproductive functions. The essential body fat percentage for women is greater than it is for men, because women need to nourish a fetus and then a baby from their own reserves. The National Academy of Sports Medicine reported the percentage of essential fat is 3–5% in men, and 8–12% in women.

Bioelectrical impedance are scales used for measuring the body composition. These scales send electrical impulses through the body to measure their speed of return. Muscles conduct electrical impulses quicker than fat; a faster response time correlates with a lean muscular physique. Hydration levels, meal times, and workouts may alter the results by under or over-estimations of the values.

Evidence Table

In examining the association between obesity and dental development, all the papers available looked at BMI for measuring obesity. However, none of the authors used any adiposity indices to measure body fat, which are hypothesized to reveal a much better predictive ability for obesity than BMI because it measures fat. Looking at the following table it is seen that most of the papers found an association between BMI & dental development. Four of them looked at skeletal maturation measured by CVMI while the rest looked at the Demirjian method for dental development (Table 4).

Table 4. Evidence table.

Author/ Study Design/ Country	Sample Size/ Age	Obesity	Dental / skeletal Development	Results	Conclusion
Akridge et al, 2005 *Cross-sectional* **USA**	104 Subjects 8-15 years old	**BMI**	Demirjian / SMI	Statistically significant differences were observed among the groups as for skeletal age	Obese children have accelerated dental maturity
Akridge et al, 2007 *Cross-sectional* **USA**	107 Subjects 9-16 years old	**BMI**	Demirjian	No statistically significant differences were observed among the groups as for dental age	Obese children do not have accelerated dental maturity
Costacurta M et al, 2012 *Cross-sectional study* **Italy**	107 Subjects 6 - 12 years old	**BMI**	Demirjian / CVM	No statistically significant differences were observed among the groups as for chronological, dental and skeletal age	Obese children do not have accelerated dental/skeletal maturity

K. Mack et al, 2013 *Retrospective cohort study* **USA**	540 Subjects 8 - 17 years old	**BMI**	Demirjian / CVM	Statistically significant differences were observed among the groups as for chronological, dental and skeletal age	Obese children have accelerated dental development only
Hedayati et al, 2014 *Cross-sectional* **USA**	95 Subjects 6-15 years old	**BMI**	Demirjian / CVM	Statistically significant differences were observed among the groups as for chronological, dental and skeletal age	Obese children have accelerated dental not skeletal maturity
DuPlessis et al, 2016 *Retrospective cohort study* **USA**	197 subjects 7-14 years old	**BMI**	Demirjian/ CVM	Statistically significant differences were observed among the groups as for chronological, dental and skeletal age	Obese children have accelerated dental/skeletal maturity

Summary of the Literature

The literature establishes an association between childhood obesity and dental development. However, contradicting results exist between the association of childhood obesity and dental age using Demirjian assessment method. Accelerated dental maturation can affect orthodontic treatment timing and treatment options. Therefore, at an earlier age, early orthodontic consultation, serial extraction timing and growth appliances can help avoid later complications.

STUDY OBJECTIVES

Objectives:

- To test the association between the different adiposity indices and dental development (Demirjian) in children and adolescence.
- To test the association between the different adiposity indices and skeletal maturation (CVMI and SMI) in children and adolescence.
- To test the association between the different adiposity indices and dental age (root completion timing and sequence of eruption) in children and adolescence.

MATERIALS AND METHODS

Data Source and Study Population

The goal for the sample size was set at 129 new patients treated at Boston University Henry M. Goldman School of Dental Medicine department of Orthodontics post-graduate clinics. This was estimated as adequate to ensure sufficient numbers of subjects in each cervical vertebral maturation stage, in each degree of fusion between diaphysis and epiphyses of the hand wrist, and to provide distribution across different levels of the adiposity indices, the sample size for each group was based on an $\alpha = 0.05$ and a $\beta = 0.1$ to achieve 90% power. Using previous studies, we calculated the effect size and beta of 80% at alpha .05 and concluded that we need 129 subjects. We were able to obtain 115 individuals within the given timeframe.

Eligibility Criteria

The eligibility criteria for each subject was the availability of pretreatment panoramic, lateral cephalometric, and hand wrist radiographs of adequate diagnostic quality. Anthropometric measurements such as height, weight, waist circumference, hip circumference, skinfold and bioelectrical impedance were collected from each patient to complete the adiposity indices. The study included both genders between the ages 6-18 years old. All data collected are from within a month from the initial visit.

The exclusion criteria included a history of past orthodontic treatment; congenital anomalies; or undiagnostic radiographs. Pregnancy is also excluded, as hormones may alter growth.

1. Exposure Variables

Obesity and Adiposity Indices

Body composition is related to the ratios of body fat, muscle, bone, and connective tissue. Dozens of methods for measuring body composition are available ranging from simple and quick methods to more detailed comprehensive techniques. For example, Hydrostatic Weighing, (DEXA) Dual-Energy X-Ray Absorptiometry and Air-Displacement Plethysmography are detailed and highly accurate in recording body composition. However, these techniques require expert training in a hospital-based setting. In this study, I have chosen simple and accurate ways to measure body composition in a clinical setting. (Combest, Howard, and Andrews 2017) In this study we measured BMI percentile and BAI each by an equation. The BIA -bioelectrical impedance analysis- measured BMI, BMR, fat percentage, fat mass, fat free mass, total body water. Waist circumference, hip circumference, waist/hip ratio, waist/height ratio, triceps, and subscapular skinfold was all measure manually.

Table 5. List of adiposity indices.

Index Type	Measurement Needed	Measurement Type	Citation
BMI Percentile	Weight / Height / Age / Gender	Formula	1000+
Body Fat Percentage	Weight / Height / Age / Gender	Formula	1000+
Body Adiposity Index	Height / Hip	Formula	100+
Waist Circumference	Waist	Linear in mm	1000+
Waist-Hip Ratio	Weight / Hip	Formula	100+
Waist-Height Ratio	Weight / Height	Formula	100+
Skinfold Thickness	Skin Calipers (3-10 Sites)	Average (3-10 sites)	1000+
Bioelectrical Impedance Analysis	Scale	%	1000+

1. Body Mass Index (BMI)

Body Mass Index (BMI) is a person's weight in kilograms divided by the square of height in meters. BMI is an easy and inexpensive method to screen for weight categories that may cause health problems. The CDC has defined BMI into four categories, underweight (<18.5), healthy (18.5-24.9), Overweight (25-29.9), and above Obese (>=30).

For children and teens, the CDC BMI-for-age growth charts use specific age and gender percentiles to compare where the child stands with respect to the population standard. A child with a BMI percentile less than 5 is considered underweight, a child with a percentile of 5 through 84 falls in the healthy weight category, one with a percentile of 85 through 94 is under the overweight category, and one at percentile 95 or greater is considered obese. The BMI-for-age percentile growth charts are the primary used indicator to measure the size and growth patterns of children and adolescents in the United States.

BMI percentile gives a more specific weight status in growing children and teens than the BMI alone. BMI-for-age percentile shows how your child's weight compares to other children of the same age and sex. It could be used as a screening tool for body fat but it is not diagnostic. Individuals with the same BMI may have different measurements of body fat.

2. Body Adiposity Index (BAI)

The body adiposity index (BAI) is a method of measuring the amount of body fat.

$$\frac{100 \times \text{hip circumference in m}}{\text{height in m} \times \sqrt{\text{height}}} - 18$$

3. Waist Circumference (WC)

Waist circumference was measured by using a tape according to NHANES Anthropometry Procedures Manual and it is measured at a level midway between the lowest rib and the iliac crest.

4. Waist-Hip Ratio (WHpR)

Waist–hip ratio or waist-to-hip ratio (WHR) is the ratio of the waist circumference to the hip's circumference in mm. In a lean person, the waist is measured at its narrowest point, while for a convex waist; it is measured at around one inch above the navel. The hip may be measured at its widest portion of the buttocks for lean figures, and at the greater trochanters for a heavier figure. Hip circumference was measured by using a tape according to NHANES Anthropometry Procedures Manual.

Waist-hip ratio was divided by gender into 2 different categories, healthy category was defined as females having a waist/hip ratio of 0.85 or less for women and was defined as overweight if it was more, while it was defined healthy for males if it was 0.9 or less and overweight if more.

5. Waist-Height Ratio (WHtR)

A person's waist-to-height ratio (WHtR) measures the distribution of body fat, measured by calculating the individual's waist circumference divided by their height.

6. Skin Calipers

Skin calipers measures the thickness of the skinfold in mm from a minimum of three to seven body sites to estimate body composition. Each individual's different body fat distribution

must be taken into consideration in order not to get under or over-estimated values. In this study it was measured in triplicate on the left side of the body.

Skinfold thickness was measured by using a skin caliper (Seko USA Lange Skinfold Caliper) according to The Tufts University Nutrition Collaborative (TNC) and Center for Drug Abuse and AIDS Research (CDAAR) from Tufts, Brown, and Johns Hopkins Anthropometry protocol adapted from: Anthropometric Standardization Reference Manual. TG Lohman, AF Roche and R Martorell (Eds.) 1988; Human Kinetics Book, Champaign Il (Book 1988). This caliper provides a constant standard pressure of 10 grams/per square millimeter over the entire operating range, with a scale that measures up to 60 millimeters. The caliper was calibrated daily.

7. Bioelectrical Impedance Analysis (BIA)

Bioelectrical impedance analysis and weight were measured by using a digital scale from Tanita (Tokyo, Japan) (BC-418 Segmental Body Composition Analyzer). Instead of relying on weight, age, and gender, Tanita's proprietary formula considers Fat Free Mass, which provides a higher level of precision compared to current BMR. Eight polar electrodes are used, Tanita BC-418 Segmental Body Composition Analyzer can show separate body mass readings for the right arm, left arm, trunk, right leg and left leg. It also prints out a complete body composition profile: including Weight, Body Fat Percentage (the body fat percentage (BFP) of a human is the total mass of fat divided by total body mass; body fat includes essential and storage body fat), body fat mass, Body Mass Index (BMI), fat free mass, estimated muscle mass, total body water and Basal Metabolic Rate (BMR). BC-418 is perfect for use in limited, dedicated spaces. All professional models use a single-point load cell weighing system in the scale platform.

2. Outcome Variables

Table 6. List of outcome variables.

Type of Measurement	Measurement Technique
Dental development	Demirjian Assessment Method (DAM)
Skeletal maturation	1. Skeletal Maturity Index (SMI) 2. Cervical Vertebrae Maturation Index (CVMI)
Dental Age	1. Root completion 2. Normal eruption pattern

Dental Development

For dental development, the panoramic radiograph is used for carrying out the Demirjian index to obtain a dental maturity score and corresponding dental age. The subjects' chronologic ages were then subtracted from their dental ages to produce a "dental age difference." Negative differences reflected a delay, while positive differences reflected acceleration in dental development. Dental ages extracted using the Demirjian method for subjects were compared with each adiposity index.

Skeletal Maturation

Skeletal Maturity Index (SMI) (Radiograph Method)

A radiograph of the hand and wrist can be used to assess skeletal age by comparing the degree of ossification of the bones of the wrist, hand, and finger to plates in a standard atlas of hand wrist development.

In this study, SMI was divided into 6 Categories, Initiation (1-2), Acceleration (3-4), Transition (5-6), Deceleration (7-8), Maturation (9-10), and Completion (11). It was also grouped into 3 categories: pre-peak (initiation and acceleration), peak (transition and deceleration), and post-peak (maturation and completion).

Cervical Vertebrae Maturation Index (CVMI) (Radiograph Method)

The lateral cephalometric radiograph was used to analyze the cervical vertebral maturation according to Baccetti's method. (Baccetti, Franchi, and McNamara 2005)

In this study CVMI was grouped into 3 different categories, CVMI 1 and 2 were considered acceleration, CVMI 3 and 4 were considered high growth, and CVMI 5 and 6 were considered deceleration.

Dental Age

In addition to the dental development by the Demirjian method, we also characterized the dental age of each subject according to a chart developed by the American Academy of Pediatric Dentistry (AAPD). (Logan WHG 2003) We assigned a number according to each root completion age in order, on the left side are the numbers that were followed. Dental eruption sequence was also determined from the panoramic radiograph, which is assigned in order (numbers between parenthesis on the right side in the following table) with each dental age. Dental ages by means of root completion and eruption were compared with each adiposity index. (Table 7).

Table 7. Age at which roots are completed and eruption sequence (Logan WHG 2003).

Permanent Dentition					
	Calcification begins at	Crown (enamel) complete at	Roots complete at	Eruption* Maxillary	Mandibular
Central incisiors	3-4 mo	4-5 y	(1) 9-10 y	7-8 y (3)	6-7 y (2)
Lateral incisors	Maxilla: 10-12 mo	4-5 y	(3) 11 y	8-9 y (5)	7-8 y (4)
	Mandible: 3-4 mo	4-5 y	(2) 10 y		
Canines	4-5 mo	6-7 y	(6) 12-15 y	11-12 y (11)	9-11 y (6)
First premolars	18-24 mo	5-6 y	(4) 12-13 y	10-11 y (7)	10-12 y (8)
Second premolars	24-30 mo	6-7 y	(5) 12-14 y	10-12 y (9)	11-13 y (10)
First molars	Birth	30-36 mo	(1) 9-10 y	5.5-7 y (1)	5.5-7 y (1a)
Second molars	30-36 mo	7-8 y	(7) 14-16 y	12-14 y (12)	12-14 y (12a)
Third molars	Maxilla: 7-9 y			17-30 y (13)	17-30 y (13a)
	Mandible: 8-10 y				

Variables of Interest (Covariates)

Covariates included age in years and gender.

V) Statistical Analysis

The statistical analyses were performed using the SPSS software (version 24; IBM, Armonk, NY). Descriptive statistics for all the baseline measurements were reported as means and standard deviation for each continuous variable and proportion and percentage for the categorical ones. Pearson correlation coefficient was used to assess the associations between the outcome measures and all adiposity indices. Correlation strength was indexed as: 0-0.19 very weak, 0.2-0.39 weak, 0.4-0.59 moderate, 0.6-0.79 strong, 0.8-1 very strong. Bivariate analysis was performed using Chi-square testing and T-test or ANOVA. Tukey HSD post-hoc test was used for further pairwise comparison after ANOVA. Finally, a regression analysis (linear, logistic, ordinal logistic) was carried out to show any confounder or effect measure modifiers that could affect the relationships and associations.

RESULTS

The mean age in our sample of 115 was 14 years old (range: 8-18). The mean BMI (continuous variable) was 23.26 (range: 13.6-42.1) placing them within the healthy category of BMI which ranged between 18.5-24.9. The mean BMI percentile (continuous variable) was 70.64% (range: 1-99) indicating that our sample mean is within the healthy group which ranged between the 5 and 85 percentile. Our norms are not comparable to the population, because our sample is between 8-18 and fat indices are continuously changeable due to growth. For children, other adiposity indices except for BMI percentile norms were not available in the literature. (Table 8).

1. Descriptive Statistics of the Study Population

Table 8. Anthropometric characteristics of the study population (continuously).

Parameter	N	Minimum	Maximum	Mean	SD
Demirjian (Development)	115.00	8.00	16.00	14.46	2.03
Dental Age (Root method)	115.00	1.00	7.00	5.86	1.74
Dental age (eruption)	115.00	1.00	13.00	11.15	2.23
Age	115.00	8.00	18.00	13.66	2.49
Height (Cm)	115.00	127.00	188.00	159.83	11.88
Weight (Kg)	115.00	24.50	133.90	60.37	18.77
BMI %	115.00	1.00	99.00	70.64	29.22
BMI (kg/m^2)	115.00	13.60	42.10	23.26	5.54
Body Adiposity Index	115.00	37.90	87.88	57.18	8.84
BMR (Kcal)	115.00	992.00	8678.00	1990.36	1494.41
Fat %	115.00	6.30	52.30	26.91	8.64
Fat Mass (Kg)	115.00	4.20	57.70	17.07	9.78
Fat free Mass (Kg)	115.00	19.50	89.90	43.28	11.81

Total body water (Kg)	115.00	8.20	65.80	31.35	8.79
Bioelectrical Impedance Analysis	115.00	450.00	980.00	682.01	108.61
Waist (Cm)	115.00	56.00	121.00	79.00	12.78
Hip (Cm)	115.00	64.00	136.00	95.15	12.82
Waist/Hip Ratio	115.00	68.75	100.00	82.96	5.67
Waist/Height Ratio	115.00	36.05	72.78	49.45	7.22
Triceps (Cm)	115.00	4.00	40.00	16.46	7.39
Subscapular (Cm)	115.00	0.00	38.00	14.97	7.74
SMI	108.00	0.00	11.00	8.21	3.43
CVMI	114.00	1.00	6.00	3.48	1.28

The majority of our sample were females (59.13%). African American (30.43%), Caucasians (26.96%), and Hispanics (33.91%) each accounted for about one third of our sample. Asians were (8.70%) of the sample. Based on the CDC norms for children and adolescents,(Centers for Disease Control and Prevention n.d.) using BMI percentile as a categorical variable, showed that 50% of our patient were within the healthy category, while Overweight (25.22%) and obese (23.48%) accounted for most of the rest. Based on adult norms (i.e. as there are no children and adolescence norms found in the literature for waist/hip ratio) reported in the literature,(World Health Organization 2011)(Campagnolo PD, Hoffman DJ 2011) the majority of the study population were within the healthy category for Waist/Hip measurement (73.04%) and Waist/Height ratio (61.74%) (Izze et al. 2014) (Table 9).

Table 9. Demographic and anthropometric measurements (categorically).

Parameter	Category	Count	Percentage (%)
Dental development according to Demirjian (Categorical) (development)	6-11	8.00	6.96
	12-14	27.00	23.48
	15-17	80.00	69.57
Age (Categorical)	6-11	27.00	23.48

	12-14	41.00	35.65
	15-17	40.00	34.78
	18	7.00	6.09
Gender	Female	68.00	59.13
	Male	47.00	40.87
Ethnicity	Asian	10.00	8.70
	AA	35.00	30.43
	Caucasian	31.00	26.96
	Hispanic	39.00	33.91
Physical activity	Athletic	7.00	6.09
	Standard	108.00	93.91
BMI % (Cat)	Underweight	2.00	1.74
	Healthy	57.00	49.57
	Overweight	29.00	25.22
	Obese	27.00	23.48
BMI (Cat)	Underweight	23.00	20.00

	Healthy	54.00	46.96
	Overweight	26.00	22.61
	Obese	12.00	10.43
Waist/Hip Ratio (Cat)	Healthy	84.00	73.04
	Overweight	31.00	26.96
Waist/Height Ratio (Cat)	Healthy	71.00	61.74
	Overweight	44.00	38.26

Table 10. Distribution of athletic versus sedentary children in our sample.

Characteristics (n=110)	Percentage (%)
Athletic (Works out 3 times or more/week)	6.09
Sedentary	93.91

2. Correlation Analysis

CVMI and SMI had a very strong positive correlation coefficient and this association was statistically significant. Correlations between the CVMI with BMI percentile, dental development by both the Demirjian method, and the root completion method were strongly positive and these associations were statistically significant. Correlations between the CVMI and the Body Adiposity Index, Body Mass Index, Fat Mass and Right Subscapular were weakly positive but statistically significant.

Correlations between the SMI and the Fat Free Mass, dental development by the Demirjian, root completion and by eruption methods were strongly positive and statistically significant. Correlations between the SMI with BMI Percentile, Right Subscapular skinfold thickness, Fat percentage and Right Triceps skinfold thickness were weakly positive but statistically significant (Table 11).

Table 11. The relationship between CVMI / SMI and different adiposity indices.

Adiposity indices	**CVMI**		**SMI**	
	r	**Level of Correlation**	**r**	**Level of Correlation**
BMI percentile	.711**	Strong	.315**	Weak
Fat Free Mass	.509**	Moderate	.612**	Strong

Body Adiposity Index	.393**	Weak	.576**	Moderate
Total Body Water	.485**	Moderate	.58**	Moderate
Body Mass Index	.306**	Weak	.49**	Moderate
Fat Mass	.294**	Weak	.461**	Moderate
Right Subscapular	.245**	Weak	.393**	Weak
Fat Percentage	.12	No significant correlation	.296**	Weak
Right Triceps	.17	No significant correlation	.255**	Weak
Waist/Height ratio	.03	No significant correlation	.18	No significant correlation
Waist/Hip ratio	-.33**	Weak	-.251**	Weak
SMI	.847**	Very strong		

CVMI			.847**	Very strong
Demirjian	.711**	Strong	.703**	Strong
Root Completion	.636**	Strong	.657**	Strong
Eruption	.587**	Moderate	.653**	Strong

**Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

Dental development by Demirjian and by root completion methods were strongly and positively correlated and this association was statistically significant. Correlations between dental development by the Demirjian method and Body Adiposity Index, Body Mass Index, Fat Mass and Right Subscapular skinfold thickness were weak but positive, and these associations were statistically significant (Table 12).

Table 12. The relationship between dental development and different adiposity indices.

Adiposity indices	**Demirjian**	
	r	**Level of Correlation**
BMI %	.04	No significant correlation
Fat Free Mass	.520**	Moderate
Body Adiposity Index	.385**	Weak

Total Body Water	.488**	Moderate
Body Mass Index	.318**	Weak
Fat Mass	.299**	Weak
Right Subscapular	.230*	Weak
Fat %	.08	No significant correlation
Right Triceps	.09	No significant correlation
Waist/Height ratio	.05	No significant correlation
Waist/Hip ratio	-.267**	Weak
CVMI	.711**	Strong
SMI	.703**	Strong
Root Completion	.848**	Very strong
Eruption	.754**	Strong

**Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

Root completion and dental development according to Demirjian were very strongly and positively correlated and this association was statistically significant. There was only a weakly positive correlation between root completion and Body Adiposity Index, Body Mass Index, Fat Mass and Right Subscapular skinfold thickness but this association was statistically significant (Table 13).

The correlation between dental eruption and SMI, dental development according to Demirjian, and root completion was strongly positive and this association was statistically significant. The correlation between dental eruption and Body Adiposity Index, Body Mass Index, Fat Mass and Right Subscapular skinfold thickness was weakly positive and this association was statistically significant (Table 13).

Table 13. The relationship between root completion and different adiposity indices.

Adiposity indices	**Root Completion**		**Eruption**	
	r	**Level of Correlation**	**r**	**Level of Correlation**
BMI %	.06	No significant correlation	.10	No significant correlation
Fat Free Mass	.492**	Moderate	.520**	Moderate

Body Adiposity Index	.389**	Weak	.325**	Weak
Total Body Water	.458**	Moderate	.408**	Moderate
Body Mass Index	.345**	Weak	.293**	Weak
Fat Mass	.341**	Weak	.284**	Weak
Right Subscapular	.279**	Weak	.223*	Weak
Fat %	.15	No significant correlation	.13	No significant correlation
Right Triceps	.14	No significant correlation	.12	No significant correlation
Waist/Height ratio	.07	No significant correlation	.08	No significant correlation

Waist/Hip ratio	-250**	Weak	-.14	No significant correlation
CVMI	.636**	Strong	.587**	Moderate
SMI	.657**	Strong	.653**	Strong
Demirjian	.848**	Very strong	.754**	Strong
Eruption	.741**	Strong	.741**	Strong

**Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

3. ANOVA

Dental development stage according to Demirjian was found to be statistically significantly different from body mass index, body adiposity index, fat mass, fat free mass, total body water, waist circumference, hip circumference and waist/hip ratio.

Tukey HSD post-hoc test for the significant predictors:

Bivariate analysis of the association between dental development groups and adiposity indices with Tukey HSD post-hoc analysis is reported in Table 14.

Table 14. Bivariate analysis (ANOVA) for dental development groups and adiposity indices.

Parameter	Demirjian groups		Tukey HSD post-hoc*	N	Mean	SD	Minimum	Maximum	P-value
BMI %	Group 1	(6-11) yrs	-	8.00	65.50	34.23	13.00	99.00	0.88
	Group 2	(12-14) yrs	-	27.00	71.33	30.54	1.00	99.00	
	Group 3	(15-17) yrs	-	80.00	70.93	28.60	1.00	99.00	
BMI	Group 1	(6-11) yrs	3	8.00	19.73	4.67	14.40	26.10	0.02
	Group 2	(12-14) yrs	3	27.00	21.53	4.58	13.60	34.30	
	Group 3	(15-17) yrs	1,2	80.00	24.21	5.68	14.60	42.10	
Body Adiposity Index	Group 1	(6-11) yrs	3	8.00	49.86	8.92	38.57	59.77	0.00
	Group 2	(12-14) yrs	3	27.00	53.62	7.69	37.90	69.31	
	Group 3	(15-17) yrs	1,2	80.00	59.12	8.53	44.45	87.88	
BMR	Group 1	(6-11) yrs	-	8.00	1302.13	282.58	992.00	1615.00	0.09
	Group 2	(12-14) yrs	-	27.00	1606.37	798.16	1033.00	5427.00	
	Group 3	(15-17) yrs	-	80.00	2188.78	1693.43	1159.00	8678.00	
Fat %	Group 1	(6-11) yrs	-	8.00	24.60	5.29	17.70	33.30	0.59

	Group 2	(12-14) yrs	-	27.00	26.11	7.74	15.10	43.60	
	Group 3	(15-17) yrs	-	80.00	27.42	9.20	6.30	52.30	
Fat Mass (Kg)	Group 1	(6-11) yrs	3	8.00	10.49	5.66	4.50	17.80	0.01
	Group 2	(12-14) yrs	-	27.00	14.11	7.43	5.50	35.00	
	Group 3	(15-17) yrs	1	80.00	18.73	10.34	4.20	57.70	
Fat free Mass (Kg)	Group 1	(6-11) yrs	3	8.00	29.80	9.91	19.50	40.70	0.00
	Group 2	(12-14) yrs	3	27.00	37.43	8.80	23.10	59.00	
	Group 3	(15-17) yrs	1,2	80.00	46.61	11.22	28.10	89.90	
Total body water (Kg)	Group 1	(6-11) yrs	3	8.00	21.83	7.25	14.30	29.80	0.00
	Group 2	(12-14) yrs	3	27.00	27.39	6.45	16.90	43.20	
	Group 3	(15-17) yrs	1,2	80.00	33.63	8.56	8.20	65.80	
Bioelectrical Impedance Analysis	Group 1	(6-11) yrs	-	8.00	721.25	105.25	617.00	866.00	0.28
	Group 2	(12-14) yrs	-	27.00	700.67	107.44	509.00	952.00	
	Group 3	(15-17) yrs	-	80.00	671.79	108.91	450.00	980.00	
Waist (Cm)	Group 1	(6-11) yrs	3	8.00	70.63	13.22	56.00	93.00	0.02
	Group 2	(12-14) yrs	-	27.00	75.56	10.90	58.00	102.00	

	Group 3	(15-17) yrs	1	80.00	81.01	12.88	57.00	121.00	
Hip (Cm)	Group 1	(6-11) yrs	3	8.00	80.75	13.77	64.00	95.00	0.00
	Group 2	(12-14) yrs	3	27.00	88.89	11.00	68.00	109.00	
	Group 3	(15-17) yrs	1,2	80.00	98.70	11.56	78.00	136.00	
Waist/Hip Ratio	Group 1	(6-11) yrs	3	8.00	87.49	6.46	79.35	100.00	0.00
	Group 2	(12-14) yrs	3	27.00	84.95	5.11	76.74	97.75	
	Group 3	(15-17) yrs	1,2	80.00	81.83	5.42	68.75	97.46	
Waist/Height Ratio	Group 1	(6-11) yrs	-	8.00	50.06	6.99	42.11	65.03	0.95
	Group 2	(12-14) yrs	-	27.00	49.17	6.62	39.19	66.67	
	Group 3	(15-17) yrs	-	80.00	49.49	7.51	36.05	72.78	
Triceps (Cm)	Group 1	(6-11) yrs	-	8.00	15.25	6.39	8.00	25.00	0.30
	Group 2	(12-14) yrs	-	27.00	14.74	6.05	5.00	31.00	
	Group 3	(15-17) yrs	-	80.00	17.16	7.84	4.00	40.00	
Subscapular (Cm)	Group 1	(6-11) yrs	-	8.00	11.63	5.85	5.00	20.00	0.08
	Group 2	(12-14) yrs	-	27.00	12.81	6.62	5.00	29.00	
	Group 3	(15-17) yrs	-	80.00	16.03	8.07	0.00	38.00	

*Numbers refers to Demirjian groups that are significantly different in the Tukey HSD post-hoc analysis

All adiposity indices were statistically significantly related with CVMI. Only the waist/height ratio was not statistically significant with CVMI.

Tukey HSD post-hoc test for the significant predictors:

Bivariate analysis of the association between CVMI groups and adiposity indices with Tukey HSD post-hoc analysis is reported in Table 15.

Table 15. Bivariate analysis (ANOVA) for CVMI and adiposity indices.

Parameter	CVMI Category		Tukey HSD post-hoc*	N	Mean	SD	Minimum	Maximum	P-value
BMI %	1	Acceleration	2	26.00	58.04	35.37	1.00	99.00	0.01
	2	High Growth	1	62.00	77.69	24.30	7.00	99.00	
	3	Deceleration	-	26.00	66.12	29.81	1.00	99.00	
BMI	1	Acceleration	2,3	26.00	19.32	3.87	13.60	26.10	0.00
	2	High Growth	1	62.00	24.76	5.60	17.00	42.10	
	3	Deceleration	1	26.00	23.74	5.12	14.60	38.30	
Body Adiposity Index	1	Acceleration	2,3	26.00	49.93	7.16	37.90	62.02	0.00
	2	High Growth	1	62.00	59.59	8.71	45.22	87.88	
	3	Deceleration	1	26.00	58.71	6.95	44.45	74.87	
BMR	1	Acceleration	3	26.00	1672.65	1188.96	992.00	5849.00	0.00
	2	High Growth	3	62.00	1693.81	615.20	1092.00	6017.00	
	3	Deceleration	1,2	26.00	3037.73	2523.68	1172.00	8678.00	
Fat %	1	Acceleration	2	26.00	23.73	6.59	15.10	39.90	0.03

	2	High Growth	1	62.00	28.79	9.60	9.00	52.30	
	3	Deceleration	-	26.00	25.70	7.16	6.30	38.80	
Fat Mass (Kg)	1	Acceleration	2,3	26.00	10.60	5.30	4.50	22.70	0.00
	2	High Growth	1	62.00	19.72	10.65	5.10	57.70	
	3	Deceleration	1	26.00	17.42	8.36	4.20	44.10	
Fat free Mass (Kg)	1	Acceleration	2,3	26.00	32.01	7.45	19.50	46.50	0.00
	2	High Growth	1	62.00	45.75	9.48	24.90	71.20	
	3	Deceleration	1	26.00	48.84	13.44	28.10	89.90	
Total body water (Kg)	1	Acceleration	2,3	26.00	23.43	5.45	14.30	34.00	0.00
	2	High Growth	1	62.00	32.87	7.41	8.20	52.10	
	3	Deceleration	1	26.00	35.75	9.84	20.60	65.80	
Bioelectrical Impedance Analysis	1	Acceleration	2	26.00	741.92	101.18	574.00	952.00	0.00
	2	High Growth	1	62.00	659.69	89.30	485.00	848.00	
	3	Deceleration	-	26.00	675.62	138.15	450.00	980.00	
Waist (Cm)	1	Acceleration	2,3	26.00	70.31	9.46	56.00	93.00	0.00
	2	High Growth	1	62.00	82.17	12.34	60.00	115.00	

	3	Deceleration	1	26.00	80.54	13.18	57.00	121.00	
Hip (Cm)	1	Acceleration	2,3	26.00	82.58	10.27	64.00	98.00	0.00
	2	High Growth	1	62.00	98.84	11.58	74.00	136.00	
	3	Deceleration	1	26.00	98.96	10.20	78.00	127.00	
Waist/Hip Ratio	1	Acceleration	3	26.00	85.20	4.83	75.56	100.00	0.03
	2	High Growth	-	62.00	82.98	5.53	69.66	97.75	
	3	Deceleration	1	26.00	81.03	5.98	68.75	95.28	
Waist/Height Ratio	1	Acceleration	-	26.00	47.71	5.88	39.19	65.03	0.13
	2	High Growth	-	62.00	50.73	7.82	36.05	72.78	
	3	Deceleration	-	26.00	48.35	6.66	36.54	64.71	
Triceps (Cm)	1	Acceleration	2	26.00	13.42	5.51	5.00	22.00	0.06
	2	High Growth	1	62.00	17.47	8.28	4.00	40.00	
	3	Deceleration	-	26.00	17.08	6.24	8.00	35.00	
Subscapular (Cm)	1	Acceleration	2,3	26.00	10.62	5.25	5.00	21.00	0.00
	2	High Growth	1	62.00	16.39	8.38	0.00	38.00	
	3	Deceleration	1	26.00	16.00	6.96	8.00	32.00	

*Numbers refers to CVMI groups that are significantly different in the Tukey HSD post-hoc analysis

BMI Percentile, Body Mass Index, Body Adiposity Index, Fat Percentage, Fat Mass, Fat free Mass, Total body water, Bioelectrical Impedance Analysis, Waist Circumference, Hip circumference, Waist/Hip Ratio, Waist/Height Ratio, Triceps and Subscapular were statistically significant with SMI. The waist/height ratio and waist/hip ratio were not statistically significant with SMI.Waist/Height Ratio and Waist/Hip Ratio were not statistically significant with SMI.

Bivariate analysis of the association between SMI groups and adiposity indices with Tukey HSD post-hoc test is reported in Table 16.

Table 16. Bivariate analysis (ANOVA) for SMI and adiposity indices.

Parameter	SMI Category		Tukey HSD post-hoc*	N	Mean	SD	Minimum	Maximum	P-value
BMI %	1	Pre-peak	3	21.00	52.43	31.87	2.00	99.00	0.00
	2	Peak	-	21.00	65.76	35.06	1.00	99.00	
	3	Post-peak	1	66.00	76.50	23.79	1.00	99.00	
BMI	1	Pre-peak	2,3	21.00	18.43	3.32	13.90	26.10	0.00
	2	Peak	1,3	21.00	21.78	5.06	13.60	34.30	
	3	Post-peak	2,3	66.00	24.95	5.22	17.60	42.10	
Body Adiposity Index	1	Pre-peak	2,3	21.00	48.37	6.18	37.90	59.77	0.00
	2	Peak	1,2	21.00	54.19	7.16	39.30	69.31	
	3	Post-peak	2,3	66.00	60.35	7.64	48.17	87.88	
BMR	1	Pre-peak	-	21.00	1745.00	1316.26	992.00	5849.00	0.40
	2	Peak	-	21.00	1638.81	697.39	1033.00	4498.00	
	3	Post-peak	-	66.00	2045.11	1493.10	1172.00	8678.00	
Fat %	1	Pre-peak	3	21.00	21.70	4.40	15.10	33.30	0.01

	2	Peak	-	21.00	26.14	8.67	13.30	43.60	
	3	Post-peak	1	66.00	28.32	8.76	6.30	52.30	
Fat Mass (Kg)	1	Pre-peak	3	21.00	8.94	3.80	4.50	17.80	0.00
	2	Peak	-	21.00	14.72	8.02	5.50	35.00	
	3	Post-peak	1	66.00	19.83	9.95	4.20	57.70	
Fat free Mass (Kg)	1	Pre-peak	2,3	21.00	31.17	7.88	19.50	46.50	0.00
	2	Peak	1,3	21.00	39.15	8.41	23.10	54.80	
	3	Post-peak	2,3	66.00	48.18	10.71	28.50	89.90	
Total body water (Kg)	1	Pre-peak	2,3	21.00	22.81	5.76	14.30	34.00	0.00
	2	Peak	1,3	21.00	28.71	6.24	16.90	40.10	
	3	Post-peak	2,3	66.00	34.67	8.35	8.20	65.80	
Bioelectrical Impedence Analysis	1	Pre-peak	3	21.00	745.38	97.52	605.00	891.00	0.00
	2	Peak	-	21.00	698.43	121.34	529.00	980.00	
	3	Post-peak	1	66.00	658.73	102.59	450.00	941.00	
Waist (Cm)	1	Pre-peak	3	21.00	68.38	8.95	56.00	93.00	0.00
	2	Peak	-	21.00	75.95	11.31	57.00	102.00	

	3	Post-peak	1	66.00	82.66	12.42	62.00	121.00	
Hip (Cm)	1	Pre-peak	2,3	21.00	80.38	9.43	64.00	95.00	0.00
	2	Peak	1,3	21.00	90.48	9.49	69.00	108.00	
	3	Post-peak	2,3	66.00	100.58	10.18	83.00	136.00	
Waist/Hip Ratio	1	Pre-peak	-	21.00	85.13	5.22	75.56	100.00	0.07
	2	Peak	-	21.00	83.73	6.05	73.08	97.75	
	3	Post-peak	-	66.00	81.93	5.73	68.75	97.46	
Waist/Height Ratio	1	Pre-peak	-	21.00	46.78	5.56	39.19	65.03	0.14
	2	Peak	-	21.00	48.46	7.59	36.54	66.67	
	3	Post-peak	-	66.00	50.20	7.39	36.05	72.78	
Triceps (Cm)	1	Pre-peak	3	21.00	12.90	4.65	5.00	22.00	0.04
	2	Peak	-	21.00	15.38	7.10	5.00	31.00	
	3	Post-peak	1	66.00	17.24	7.29	4.00	40.00	
Subscapular (Cm)	1	Pre-peak	3	21.00	9.19	4.31	5.00	20.00	0.00
	2	Peak	-	21.00	14.14	7.07	6.00	29.00	
	3	Post-peak	1	66.00	16.48	7.72	0.00	38.00	

*Numbers refers to SMI groups that are significantly different in the Tukey HSD post-hoc analysis

There was no association between BMI percentile and dental development predictors (Table 17).

Table 17. ANOVA for the association between BMI Percentile and dental development.

Parameter	BMI%		N	Mean	SD	Minimum	Maximum	P-value
Dental development (Demirjian)	1	Underweight	2.00	14.40	2.26	12.80	16.00	0.97
	2	Healthy	57.00	14.38	2.20	8.00	16.00	
	3	Overweight	29.00	14.60	1.57	10.00	16.00	
	4	Obese	27.00	14.46	2.17	8.10	16.00	
Dental Age (Root completion)	1	Underweight	2.00	5.00	2.83	3.00	7.00	0.75
	2	Healthy	57.00	5.74	1.74	1.00	7.00	
	3	Overweight	29.00	6.00	1.54	3.00	7.00	
	4	Obese	27.00	6.04	1.95	1.00	7.00	
Dental age (eruption)	1	Underweight	2.00	12.00	0.00	12.00	12.00	0.70
	2	Healthy	57.00	10.91	2.21	5.00	13.00	
	3	Overweight	29.00	11.41	2.24	1.00	13.00	
	4	Obese	27.00	11.30	2.33	3.00	13.00	

There was a statistically significant association between BMI and all dental development predictors (Table 18).

Table 18. ANOVA for the association between BMI and dental development.

Parameter	BMI		Tukey HSD post-hoc	N	Mean	SD	Minimum	Maximum	P-value
Dental Development (Demirjian)	1	Underweight	4	23.00	13.60	2.80	8.00	16.00	0.02
	2	Healthy	-	54.00	14.38	1.90	8.10	16.00	
	3	Overweight	-	26.00	14.82	1.55	9.50	16.00	
	4	Obese	1	12.00	15.68	0.74	13.70	16.00	
Dental Age (Root Completion)	1	Underweight	4	23.00	5.17	2.06	1.00	7.00	0.01
	2	Healthy	-	54.00	5.67	1.81	1.00	7.00	
	3	Overweight	-	26.00	6.35	1.32	2.00	7.00	
	4	Obese	1	12.00	7.00	0.00	7.00	7.00	
Dental age (Eruption)	1	Underweight	4	23.00	10.04	2.85	5.00	12.00	0.02
	2	Healthy	-	54.00	11.19	2.22	1.00	13.00	
	3	Overweight	-	26.00	11.50	1.73	5.00	13.00	
	4	Obese	1	12.00	12.33	0.49	12.00	13.00	

*Numbers refers to BMI groups that are significantly different in the Tukey HSD post-hoc analysis

T-test analysis for all dental development predictors:

There was a statistically significant difference between the mean of dental development (Demirjian), root completion and eruption for healthy children as compared to overweight, where the healthy category had a higher mean than the overweight category. This is mainly due to the variation difference seen between those groups. T-test analysis to investigate the significance of the mean difference between healthy and overweight groups in dental development is reported in Table 19.

Only the dental development according to Demirjian was statistically significant with Waist/Hip Ratio (Table 19)

Table 19. T-test for Waist/Hip Ratio and dental development.

Parameter	**Waist/Hip Ratio**		**N**	**Mean**	**SD**	**Minimum**	**Maximum**	**P-value**
Dental Development (Demirjian)	1	Healthy	84.00	14.74	1.73	9.50	16.00	0.01
	2	Overweight	31.00	13.68	2.54	8.00	16.00	
Dental Age (Root Completion)	1	Healthy	84.00	5.99	1.59	1.00	7.00	0.20
	2	Overweight	31.00	5.52	2.08	1.00	7.00	
Dental age (Eruption)	1	Healthy	84.00	11.20	2.15	1.00	13.00	0.67
	2	Overweight	31.00	11.00	2.45	5.00	13.00	

There was no association between the weight/height ratio for all dental development predictors (Table 20)

Table 20. T-test for Waist/Height Ratio and dental development.

Parameter	Waist/Height Ratio		N	Mean	SD	Minimum	Maximum	P-value
Dental Development (Demirjian)	1	Healthy	71.00	14.47	2.12	8.00	16.00	0.92
	2	Overweight	44.00	14.43	1.88	8.10	16.00	
Dental Age (Root Completion)	1	Healthy	71.00	5.85	1.69	1.00	7.00	0.90
	2	Overweight	44.00	5.89	1.85	1.00	7.00	
Dental age (Eruption)	1	Healthy	71.00	11.01	2.38	1.00	13.00	0.42
	2	Overweight	44.00	11.36	1.95	3.00	13.00	

All dental developmental ages were significantly associated with CVMI, where the deceleration group consistently had the highest mean in dental development, as shown in Table 21.

Table 21. The association between CVMI and dental development predictors.

Parameter	**CVMI**		**Tukey HSD post-hoc**	**N**	**Mean**	**SD**	**Minimum**	**Maximum**	**P-value**
Dental Development (Demirjian)	1	Acceleration	2,3	26.00	12.27	2.30	8.00	16.00	0.00
	2	High Growth	1,3	62.00	14.87	1.59	8.10	16.00	
	3	Deceleration	1,2	26.00	15.66	0.61	14.40	16.00	
Dental Age (Root Completion)	1	Acceleration	2,3	26.00	4.08	1.98	1.00	7.00	0.00
	2	High Growth	3	62.00	6.21	1.43	1.00	7.00	
	3	Deceleration	1	26.00	6.77	0.65	4.00	7.00	

Dental age (Eruption)	1	Acceleration	2,3	26.00	9.15	3.45	1.00	12.00	0.00
	2	High Growth	1	62.00	11.55	1.42	6.00	13.00	
	3	Deceleration	1	26.00	12.15	0.37	12.00	13.00	

*Numbers refers to CVMI groups that are significantly different in the Tukey HSD post-hoc analysisAll dental developmental ages were significantly associated with SMI, where the post-peak group consistently had the highest mean in dental development, as shown in Table 22.

Table 22. The association between SMI 3 and dental development.

Parameter	SMI 3 Categories		Tukey HSD post-hoc	N	Mean	SD	Minimum	Maximum	P-value
Dental Development (Demirjian)	1	Pre-peak	2,3	21.00	12.04	2.45	8.00	16.00	0.00
	2	Peak	1,3	21.00	13.90	2.04	8.10	16.00	
	3	Post-peak	1,2	66.00	15.33	1.04	11.20	16.00	
Dental Age (Root Completion)	1	Pre-peak	2,3	21.00	3.95	1.88	1.00	7.00	0.00
	2	Peak	1,3	21.00	5.33	2.06	1.00	7.00	
	3	Post-peak	1,2	66.00	6.62	0.94	3.00	7.00	
Dental age (Eruption)	1	Pre-peak	2,3	21.00	8.33	3.55	1.00	12.00	0.00
	2	Peak	1	21.00	11.14	1.71	6.00	12.00	
	3	Post-peak	1	66.00	11.97	0.72	8.00	13.00	

*Numbers refers to SMI 3 categorical groups that are significantly different in the Tukey HSD post-hoc analysis

4. Chisquare

No adiposity indices were statistically significantly related with SMI when divided into three categories (pre-peak, peak, and post-peak) except for BMI categorical, as shown in Table 23.

Table 23. Chisquare analysis between SMI (3) with adiposity indices

Parameter		**SMI (3)**			**Total**	
		Pre-peak	**Peak**	**Post-peak**		**P-value**
BMI % (Cat)	**Underweight**	0	1	1	2	0.214
	Healthy	16	10	30	56	
	Overweight	3	4	20	27	
	Obese	2	6	15	23	
Total		21	21	66	108	
BMI (Cat)	**Underweight**	12	6	4	22	0.000
	Healthy	8	10	34	52	
	Overweight	1	3	20	24	

	Obese	0	2	8	10	
Total		21	21	66	108	
Waist/Hip Ratio (Cat)	**Healthy**	15	13	50	78	0.465
	Overweight	6	8	16	30	
Total		21	21	66	108	
Waist/Height Ratio (Cat)	**Healthy**	17	12	40	69	0.185
	Overweight	4	9	26	39	
Total		21	21	66	108	

Only the categorical BMI index was statistically significantly related with SMI in 6 categories (Table 24).

Table 24. Chisquare analysis between SMI (6) with adiposity indices.

Parameter		**SMI (6)**						**Total**	
		Initiation	**Acceleration**	**Transition**	**Deceleration**	**Maturation**	**Completion**		**P-value**
BMI % (Cat)	**Under-weight**	0	0	1	0	0	1	2	0.394
	Healthy	8	8	4	6	9	21	56	
	Over-weight	1	2	1	3	9	11	27	
	Obese	2	0	3	3	4	11	23	
Total		11	10	9	12	22	44	108	
BMI (Cat)	**Under-weight**	7	5	3	3	0	4	22	0.000
	Healthy	3	5	4	6	15	19	52	

	Over-weight	1	0	2	1	7	13	24	
	Obese	0	0	0	2	0	8	10	
Total		11	10	9	12	22	44	108	
Waist/Hip Ratio (Cat)	**Healthy**	7	8	5	8	15	35	78	0.625
	Over-weight	4	2	4	4	7	9	30	
Total		11	10	9	12	22	44	108	
Waist/Height Ratio (Cat)	**Healthy**	8	9	5	7	13	27	69	0.535
	Over-weight	3	1	4	5	9	17	39	
Total		11	10	9	12	22	44	108	

Only the categorical BMI measurement was statistically significantly associated with CVMI (Table 25).

Table 25. Chisquare analysis between CVMI with adiposity indices.

Parameter		**CVMI (3)**			**Total**	
		Acceleration	**High Growth**	**Deceleration**		**P-value**
BMI % (Cat)	**Underweight**	1	0	1	2	0.339
	Healthy	15	26	15	56	
	Overweight	6	17	6	29	
	Obese	4	19	4	27	
Total		26	62	26	114	
BMI (Cat)	**Underweight**	12	7	4	23	0.006
	Healthy	11	29	13	53	
	Overweight	3	16	7	26	
	Obese	0	10	2	12	
Total		26	62	26	114	
Waist/Hip Ratio (Cat)	**Healthy**	16	44	23	83	0.082
	Overweight	10	18	3	31	

Total		26	62	26	114	
Waist/Height Ratio (Cat)	**Healthy**	17	34	19	70	0.247
	Overweight	9	28	7	44	
Total		26	62	26	114	

The categorical waist/hip ratio was statistically significantly related with dental development using the Demirjian method (Table 26).

Table 26. Chisquare analysis between dental development (Demirjian) with adiposity indices.

Parameter		**Demirjian (Cat) (dental development)**			**Total**	
		6-11	**12-14**	**15-17**		**P-value**
BMI % (Cat)	**Underweight**	0	1	1	2	0.864
	Healthy	4	13	40	57	
	Overweight	1	8	20	29	
	Obese	3	5	19	27	
Total		8	27	80	115	
BMI (Cat)	**Underweight**	4	6	13	23	0.205
	Healthy	3	15	36	54	
	Overweight	1	5	20	26	
	Obese	0	1	11	12	
Total		8	27	80	115	
Waist/Hip Ratio (Cat)	**Healthy**	3	18	63	84	0.030
	Overweight	5	9	17	31	
Total		8	27	80	115	
Waist/Height Ratio (Cat)	**Healthy**	5	15	51	71	0.750
	Overweight	3	12	29	44	
Total		8	27	80	115	

SMI is significantly associated with the BMI percentile, BMI, body adiposity index, fat percentage, fat mass, fat free mass, total body water, bioelectrical impedance analysis, and waist/height ratio (Table 27).

5. Multivariate Ordinal Regression Analysis

Table 27. Multivariate regression models for dental and skeletal outcomes using different adiposity indices controlling for age and gender.

Parameter (Independent)		**Dependent**				
		Ordinal regression		**Linear Regression**		
		CVMI (Cat) P-value	**SMI 3 (Cat) P-value**	**Demirjian P-value**	**Root Completion P-value**	**Eruption P-value**
Controlled for in all analyses	**Age**	*	*	*	*	*
	Gender=0	*	*	NS	NS	NS
BMI Percentile Cat		NS	NS	NS	NS	NS
BMI Percentile		NS	*	NS	NS	NS
BMI Cat		NS	NS	NS	NS	NS
BMI		NS	*	NS	NS	NS
BAI		NS	*	NS	NS	NS
BMR		NS	NS	NS	NS	NS

Fat Percent	NS	*	NS	NS	NS
Fat Mass (KG)	NS	*	NS	NS	NS
FFMKG	NS	*	NS	NS	NS
TBWKG	NS	*	NS	NS	NS
BIA	NS	*	NS	NS	NS
Waist Hip Ratio	NS	NS	NS	NS	NS
Waist Hip Cat	NS	NS	NS	NS	NS
Waist Height Ratio	NS	*	NS	NS	NS
Waist Height Cat	NS	NS	NS	NS	NS

* Correlation is significant at the 0.05 level

Using a multivariate ordinal regression model, it was found that SMI categories was significantly associated with BMI percentile. In the parameter estimate table 28, BMI percentile (continuous), age, and gender are all statistically significant. Given that all other variables in the model are held constant, for BMI percentile, a 1-unit increase in BMI percentile the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 1.06 ($e^{0.063}$) greater. For a one-unit increase in age, the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 8.14 ($e^{2.098}$) greater. For Gender, compared to males, females have increased odds ($e^{4.273}$=71.73) of higher SMI stage 3 versus stage 1 and 2.

Table 28. Multivariate regression model for SMI categories and BMI percentile controlling for age and gender.

Variables	**Coefficient**	**Standard Error**	**Wald**	**P.value**
Dependent				
SMI 1	30.129	5.72	27.8	0.000
SMI 2				
SMI 3	Ref.	Ref.	Ref.	Ref.
Independent				
BMI percentile (continuous)	0.063	0.016	28.309	0.000
Age	2.098	0.394	28.304	0.000
Gender				
Female	4.273	0.93	21.11	0.000
Male	Ref.	Ref.	Ref.	Ref.

Using a multivariate ordinal regression model, it was found that SMI categories was significantly associated with BMI. In the parameter estimate table 29, BMI (continuous), age, and gender are all statistically significant. Given that all other variables in the model are held constant, for BMI, a 1 unit increase in BMI the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 1.31 ($e^{0.272}$) greater. For a one unit increase in age, the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 4.47 ($e^{1.498}$) greater. For Gender, compared to males, females have increased odds ($e^{3.406}$=30.14) of higher SMI stage 3 versus stage 1 and 2.

Table 29. Multivariate regression model for SMI categories and BMI controlling for age and gender.

Variables	Coefficient	Standard Error	Wald	P.value
Dependent				
SMI 1	24.118	4.264	31.998	0.000
SMI 2	27.217	4.662	34.089	0.000
SMI 3	Ref.	Ref.	Ref.	Ref.
Independent				
BMI (continuous)	0.272	0.085	10.148	0.001
Age	1.498	0.275	29.777	0.000
Gender				
Female	3.406	0.768	19.674	0.000
Male	Ref.	Ref.	Ref.	Ref.

Using a multivariate ordinal regression model, it was found that SMI categories was significantly associated with BAI. In the parameter estimate table 30, BAI, age, and gender are all statistically significant. Given that all other variables in the model are held constant, for BAI, a 1 unit increase in BAI the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 1.19 ($e^{0.174}$) greater. For a one unit increase in age, the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 4.08 ($e^{1.407}$) greater. For Gender, compared to males, females have increased odds ($e^{3.308}$=27.33) of higher SMI stage 3 versus stage 1 and 2.

Table 30. Multivariate regression model for SMI categories and BAI controlling for age and gender.

Variables	Coefficient	Standard Error	Wald	P.value
Dependent				
SMI 1	26.509	4.679	32.098	0.000
SMI 2	29.627	5.074	34.095	0.000
SMI 3	Ref.	Ref.	Ref.	Ref.
Independent				
BAI	0.174	0.053	10.933	0.001
Age	1.407	0.264	28.287	0.000
Gender				
Female	3.308	0.769	18.524	0.000
Male	Ref.	Ref.	Ref.	Ref.

Using a multivariate ordinal regression model, it was found that SMI categories was significantly associated with fat percentage. In the parameter estimate table 31, fat percentage, age, and gender are all statistically significant. Given that all other variables in the model are held constant, for fat percentage, a 1 unit increase in fat percentage the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 1.11 ($e^{0.113}$) greater. For a one unit increase in age, the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 4.53 ($e^{1.511}$) greater. For Gender, compared to males, females have increased odds ($e^{2.557}$=12.89) of higher SMI stage 3 versus stage 1 and 2.

Table 31. Multivariate regression model for SMI categories and fat percentage controlling for age and gender.

Variables	**Coefficient**	**Standard Error**	**Wald**	**P.value**
Dependent				
SMI 1	21.019	3.666	32.689	0.000
SMI 2	23.744	3.966	35.841	0.000
SMI 3	Ref.	Ref.	Ref.	Ref.
Independent				
Fat percentage	0.113	0.051	4.854	0.028
Age	1.511	0.256	34.833	0.000
Gender				
Female	2.557	0.804	10.120	0.001
Male	Ref.	Ref.	Ref.	Ref.

Using a multivariate ordinal regression model, it was found that SMI categories was significantly associated with fat mass. In the parameter estimate table 32, fat mass, age, and gender are all statistically significant. Given that all other variables in the model are held constant, for fat mass, a 1 unit increase in fat mass the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 1.15 ($e^{0.145}$) greater. For a one unit increase in age, the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 4.17 ($e^{1.429}$) greater. For Gender, compared to males, females have increased odds ($e^{2.846}$=17.21) of higher SMI stage 3 versus stage 1 and 2.

Table 32. Multivariate regression model for SMI categories and fat mass controlling for age and gender.

Variables	Coefficient	Standard Error	Wald	P.value
Dependent				
SMI 1	19.251	3.401	32.039	0.000
SMI 2	22.146	3.730	35.257	0.000
SMI 3	Ref.	Ref.	Ref.	Ref.
Independent				
Fat mass	0.145	0.054	7.247	0.007
Age	1.429	0.257	30.857	0.000
Gender				
Female	2.846	0.757	14.141	0.000
Male	Ref.	Ref.	Ref.	Ref.

Using a multivariate ordinal regression model, it was found that SMI categories was significantly associated with fat free mass. In the parameter estimate table 33, FFM, age, and gender are all statistically significant. Given that all other variables in the model are held constant, for FFM, a 1 unit increase in FFM the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 1.23 ($e^{0.211}$) greater. For a one unit increase in age, the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 3.33 ($e^{1.204}$) greater. For Gender, compared to males, females have increased odds ($e^{5.132}$=169.35) of higher SMI stage 3 versus stage 1 and 2.

Table 33. Multivariate regression model for SMI categories and fat free mass controlling for age and gender.

Variables	Coefficient	Standard Error	Wald	P.value
Dependent				
SMI 1	23.679	4.248	31.064	0.000
SMI 2	27.369	4.764	32.999	0.000
SMI 3	Ref.	Ref.	Ref.	Ref.
Independent				
FFM	0.211	0.053	16.217	0.000
Age	1.204	0.277	18.971	0.000
Gender				
Female	5.132	1.000	26.358	0.000
Male	Ref.	Ref.	Ref.	Ref.

Using a multivariate ordinal regression model, it was found that SMI categories was significantly associated with total body water. In the parameter estimate table 34, TBW, age, and gender are all statistically significant. Given that all other variables in the model are held constant, for TBW, a 1 unit increase in TBW the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 1.2 ($e^{0.183}$) greater. For a one unit increase in age, the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 3.86 ($e^{1.353}$) greater. For Gender, compared to males, females have increased odds ($e^{4.384}$=80.15) of higher SMI stage 3 versus stage 1 and 2.

Table 34. Multivariate regression model for SMI categories and total body water controlling for age and gender.

Variables	Coefficient	Standard Error	Wald	P.value
Dependent				
SMI 1	22.231	3.956	31.583	0.000
SMI 2	25.394	4.339	34.245	0.000
SMI 3	Ref.	Ref.	Ref.	Ref.
Independent				
TBW	0.183	0.050	13.310	0.000
Age	1.353	0.268	25.481	0.000
Gender				
Female	4.384	0.865	25.665	0.000
Male	Ref.	Ref.	Ref.	Ref.

Using a multivariate ordinal regression model, it was found that SMI categories was significantly associated with BIA. In the parameter estimate table 35, BIA, age, and gender are all statistically significant. Given that all other variables in the model are held constant, for BIA, a 1 unit increase in BIA the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 0.98 ($e^{-0.014}$) greater. For a one unit increase in age, the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 5.31 ($e^{1.67}$) greater. For Gender, compared to males, females have increased odds ($e^{5.32}$=200.3) of higher SMI stage 3 versus stage 1 and 2.

Table 35. Multivariate regression model for SMI categories and BIA controlling for age and gender.

Variables	Coefficient	Standard Error	Wald	P.value
Dependent				
SMI 1	11.710	3.486	11.286	0.001
SMI 2	15.144	3.78	16.052	0.000
SMI 3	Ref.	Ref.	Ref.	Ref.
Independent				
BIA	-0.014	0.004	14.487	0.000
Age	1.670	0.304	30.163	0.000
Gender				
Female	5.327	1.039	26.288	0.000
Male	Ref.	Ref.	Ref.	Ref.

Using a multivariate ordinal regression model, it was found that SMI categories was significantly associated with waist/height ratio. In the parameter estimate table 36, waist/height ratio, age, and gender are all statistically significant. Given that all other variables in the model are held constant, for waist/height ratio, a 1 unit increase in WHtR the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 1.13 ($e^{0.128}$) greater. For a one unit increase in age, the odds of higher SMI stage 3 versus the combined SMI stage 1 and 2 categories are 4.93 ($e^{1.596}$) greater. For Gender, compared to males, females have increased odds ($e^{3.39}$=29.66) of higher SMI stage 3 versus stage 1 and 2.

Table 36. Multivariate regression model for SMI categories and waist/height ratio controlling for age and gender.

Variables	**Coefficient**	**Standard Error**	**Wald**	**P.value**
Dependent				
SMI 1	25.824	4.950	27.222	0.000
SMI 2	28.607	5.247	29.729	0.000
SMI 3	Ref.	Ref.	Ref.	Ref.
Independent				
Waist/Height ratio	0.128	0.052	6.031	0.014
Age	1.596	0.273	34.120	0.000
Gender				
Female	3.390	0.741		0.000
Male	Ref.	Ref.	Ref.	Ref.

DISCUSSION

In this cross-sectional study we explored the relationship between different adiposity indices and dental development and skeletal maturation.

The literature that assessed skeletal maturation and dental age in childhood obesity used the BMI index and often reported contradicting results (Akridge et al., 2007; Basaran et al., 2007; Chen et al., 2010; Eid et al., 2002; Hilgers et al., 2006). The explanation for these contradicting results could be explained by the misclassification of BMI categories as body composition is not controlled for.

Measuring dental age was performed by the Demirjian method, which is one of the most frequently used systems and is considered highly accurate. It is less accurate than skeletal, somatic, or sexual measures to identify the peak height velocity, but no other method of determining the dental age is currently accepted in US children. Although there has been some criticism of the accuracy of the method of Demirjian et al, no other widely accepted systematic method is available that has been validated across different ethnic and racial groups.

Age was significantly associated with CVMI (categorical), SMI (categorical), dental development, root completion, and eruption while gender was significantly associated with CVMI (categorical) and SMI (categorical) only. Furthermore, our study included majority of relevant adiposity indices which could be carried out in clinical settings. In the multiple regression analysis, we confirmed that there is no significant association between CVMI and all adiposity indices used. However, in the multiple regression analysis, SMI was significantly associated with BMI percentile (continuous), BMI (continuous), BAI, fat percentage, fat mass, FFM, TBW, BIA, and waist/height ratio. No other studies reported such associations. In a clinical setting, this would indicate that children with higher SMI will have a higher adiposity index score, which means that

adiposity indices might be a good tool to use in predicting skeletal maturation. Although this might be complex in terms of identifying the specific skeletal stage, it might enable clinicians to identify patients with accelerated skeletal maturity.

Neeley (Neeley and Gonzales, 2007) states that "orthodontic therapy can be affected by obesity", given the probability for obese patients to show irregular pubertal development. This is due to the hormonal changes associated with obesity, a different bone metabolism (leading to changes in growth and development or tooth movement), and specific craniofacial features (increased mandibular length, shorter upper face height, flatter or more concave profiles).

It is possible that higher BMI values may be related to advanced development, while lower BMI values may be related to delayed development. Despite that, Flores-Mir et al found that there is no statistically significant difference for the skeletal maturation or the dental development stages according to nutritional status (determined by BMI status) (Flores-mir et al. 2005).

Childhood BMI norms changes with age significantly. At birth, the median is 13 kg/m^2— to 17 at age 1, to 15.5 at age 6, and to 21 at age 20. The age-related increases in BMI during both late childhood and adolescence can be related primarily to increases in fat-free tissue rather than fat.

Advanced dental maturation might affect treatment timing and treatment options. Patients who are overweight may require earlier orthodontic consultation. Serial extraction timing may be adjusted, as may space maintenance and growth modification. Furthermore, when permanent teeth erupt early in children, caries incidence may increase if they have not developed good oral hygiene practices.

Options for treatment such as growth modification are most successful when used right before peak height velocity growth. This study has shown that obesity and skeletal maturation are

significantly associated. Thus, orthodontists may need to consider such additional factors as the patient's BMI/Adiposity status in addition to sex when deciding among various treatment options. In fact, the BMI/Adiposity status (i.e., particularly BMI percentile) can aid clinicians in determining whether the patient will exhibit delayed or accelerated skeletal maturation.

This is the first study to assess the relationship between adiposity indices and dental development and skeletal maturation in children and adolescents. There are no similar studies in the literature that analyzed adiposity indices with dental development and skeletal maturation to compare our results with.

All analyses were done by all possible data shapes as a continuous and categorical data using correlation, ANOVA, Chisquare and multivariate ordinal regression models. After controlling for age and sex, this study found that with a one unit increase in certain adiposity indices (i.e., BMI percentile, BMI, BAI, fat percentage, fat mass, FFM, TBW, BIA, and waist/height ratio), there is a significant increase in the probability of being more skeletally mature in this study sample, as measured by SMI.

Study significance

This study was carried out to establish the relationship between body fat composition and dental development and skeletal maturation. The results could guide clinicians towards the proper timing of orthodontic treatment and encourage them to use alternative diagnostic techniques.

Study limitations

This is a cross-sectional study, and therefore conclusions about causal associations cannot be made. Socioeconomic information was not available for analysis. Also, subjects were selected

from a patient base treated within a dental school in an urban area which might affect generalizability. A nationally representative sample would validate our findings.

Future considerations

Future well-designed studies are needed to test the association of adiposity indices with dental development and skeletal maturation in a longitudinal study design where participants are followed up annually. Furthermore, additional covariates that include socioeconomic status are needed in a larger population to determine whether SES in coordination with obesity has an effect on dental development and skeletal maturation.

CONCLUSIONS

Children and adolescents with increased adiposity values (i.e., BMI percentile, BMI, BAI, fat percentage, fat mass, FFM, TBW, BIA, and waist/height ratio), had higher probability of being skeletally more mature as measured by SMI. Orthodontists should consider the effect of obesity and fat on the maturity of their patients and its effect on the timing of orthodontic treatment. Further well designed prospective longitudinal studies are needed to confirm these results.

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