The Relationship Between Obesity and Mandible Size

in Children and Adolescents

BY

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THESIS

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This thesis is dedicated to Toby for his boundless love throughout every step of this journey.

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LIST OF ABBREVIATIONS

BMI	Body Mass Index
CDC	Center for Disease Control and Prevention
CPS	Chicago Public School
GH	Growth Hormone
GPA	Generalized Procrustes Analysis
LCR	Lateral Cephalometric Radiograph
NHANES	National Health Nutrition Examination Survey
PC	Principle Component
PCA	Principle Component Analysis
UIC	University of Illinois at Chicago
WHO	World Health Organization

SUMMARY

Obesity is a global public health epidemic. Obesity rates are on the rise across the board; no race, gender or age group is exempt (WHO, 2017). Obesity is known to cause a number of negative health effects including heart disease, respiratory dysfunction, and diabetes (Cole et al., 2000). In addition to those diseases, obesity in children is associated with increased secretion of growth hormone (Ohrn et al., 2002) and the early onset of puberty and the pubertal growth spurt (He and Karlberg, 2001). A high body mass index (BMI) in children has also been correlated with accelerated dental development and earlier tooth eruption timing (e.g., Hilgers et al., 2006; Sanchez-Perez et al., 2010; Must et al., 2012; Mack et al., 2013; Jaasari et al., 2016). It has also been reported that obesity in children and adolescents can result in increased dimensions of craniofacial structures, such as mandibular length (Ohrn et al., 2002).

The current study was performed using retrospective data collected from the orthodontics clinic at the University of Illinois at Chicago in Chicago, Illinois. Initial pre- treatment orthodontic records were reviewed for the presence of a lateral cephalometric radiograph (LCR), height and weight measurements. Patients with a medical history of any significant endocrine disorders, craniofacial anomalies, and cleft lip and/or palate were excluded from the sample. 181 total subjects, both male and female, were included the study. The subjects ranged from ages 9-19 years old.

The height and weight data was used to calculate a raw BMI score. Each subject's BMI percentile was then identified using the Center for Disease Control and Prevention (CDC) Age and

Sex specific growth charts. Subjects were then categorized as either underweight, normal weight, overweight or obese. 22 coordinate landmarks were identified and digitally marked on each lateral cephalometric radiograph. All chosen landmarks were skeletal points on the cranial base, maxilla, and mandible.

Geometric morphometrics software, tpsDigs2, was used to quantify and analyze the size and two-dimensional shape variation of the mandible and overall craniofacial complex. A series of Principal Component Analyses (PCA) were run. Normal parametric tests were performed in order to determine if BMI category was correlated to the shape variation of the mandible or overall facial morphology.

Results found that one principle component (PC) describing shape variance of the mandible, PC6, was approaching statistical significance across each of the three BMI categories: normal weight, overweight, and obese. This finding subtly suggests that as BMI increases, the mandibular corpus increases in height (superiorly-inferiorly).

This study failed to identify a significant relationship between obesity and mandible size in this sample population of Chicago youth. The limited sample size and diverse ethnic demographic likely contributed to this study's inability to support previous research (Ohrn et al.,2002). Existing literature on this relationship is extremely limited. The correlation of BMI to mandibular and craniofacial growth may not be as clear as previously thought (Olszewska et al., 2015).

1. INTRODUCTION

1.1 **Background**

Childhood obesity is a rising national and global public health concern. At nearly 25%, Chicago's childhood obesity rate is much higher than the national average of 18% (Healthy Chicago, 2013). Obesity negatively impacts the health of growing children in many ways, including cardiac and respiratory dysfunction. Childhood obesity is known to increase growth hormone levels and skeletal maturation as well as accelerate dental development (Ohrn et al., 2002; Mack et al., 2013). Obesity has also been documented to affect the timing of craniofacial growth (Ohrn et al., 2002). This study seeks to add to the limited existing literature on this relationship, specifically by providing data on mandibular growth in obese children.

1.2 **Objective**

To study whether a relationship exists between the size and shape of the mandible and body mass index (BMI) of children and adolescents.

1.3 **Null Hypotheses**

- There is no relationship between BMI and mandible size in children and adolescents.
- There is no relationship between BMI and mandible shape in children and adolescents.
- There is no relationship between BMI and craniofacial shape in children and adolescents.
- There is no relationship between BMI and craniofacial size in children and adolescents.

2. BACKGROUND

2.1 Childhood Obesity in the United States

In 2016, the World Health Organization reported 41 million overweight and obese children under the age of five globally (WHO, 2017). The United States' youth obesity prevalence rate has more than tripled in the last three decades (Hales et al., 2017). The cause of this rise in obesity prevalence is multifactorial. The combination of high caloric intake and decreased physical activity undoubtedly play a role (WHO, 2017). Limited access to healthy food options in certain communities is also a contributor (Frongillo and Bernal, 2014). There has also been a societal shift in what is perceived to be a normal body image and healthy weight. The studied trend in recent generations of women shows a decline in self-classification as overweight (Burke et al., 2010). These, along with other environmental factors, must be considered when analyzing the cause of increased childhood obesity rates.

The 2015-2016 National Health Nutrition Examination Survey (NHANES) reported that the prevalence of obesity among U.S. youth, ages 2-19 years, was 18.5 percent. Rates vary across age groups, gender, income levels, and race. Non-Hispanic Black and Hispanic youth are at a higher risk for obesity than Caucasians and Asians of the same age (Hales et al., 2017). Furthermore, obesity disproportionately affects children in low income households. The stressors related to poverty, such as community violence, housing insecurity, and discrimination (Dawson-McClureet al., 2014) are all contributing factors. Borell et al. (2016) published evidence of the link between childhood obesity and restricted access to physical activity in unsafe neighborhoods.

The Chicago Public School (CPS) population consists of an estimated 87% low-income households. These are families earning less than twice below the federal poverty line. The ethnicity composition of CPS is approximately 45% Hispanic and 42% non-Hispanic Black students (Healthy Chicago, 2013). When compared to the national reporting, Chicago's youth obesity rate is significantly greater overall, at 24.9%, and greater across every subgroup for age, gender and race. One in four CPS kindergarteners, sixth graders, and ninth graders is obese (Healthy Chicago, 2013).

Chicago's Cook County lawmakers recognized this public health issue plaguing its youth. In November 2016, the Cook County Board of Commissioners passed the Sweetened Beverage Tax Ordinance which imposed a tax rate of $0.01 per ounce on the retail sale of all sweetened beverages (Preckwinkle 2016). This piece of legislature was an attempt to decrease the consumption of sweetened beverages and encourage healthy dietary options. Although this tax was later repealed, it showed the willingness of public officials to take action against the rising obesity prevalence. Alternatively, more state and federal resources could be directed towards increasing safety in low-income communities as another means to combating childhood obesity.

2.2 **Effects of Obesity on Growth**

Several current methods exist for assessing obesity status, including skinfold thickness, waist-to-hip circumference ratio, biomarkers in blood or urine, bioelectrical impedance, and body mass index (BMI). BMI is an assessment of body composition derived from a calculation of a person's weight in kilograms divided by the square of their height in meters (kg/m^2). This measure is used to categorize individuals into weight statuses. Raw BMI scores are of no use in growing children due to varying age and sex related growth patterns. The Center for Disease Control and Prevention (CDC) produced age-and-sex specific growth charts for children which are widely used and accepted in healthcare (Kuczmarski et al., 2002). According to the charts, obesity in a child aged 2-20 years old is defined by a BMI score greater than or equal to the 95th percentile. A BMI between the 85th and 95th percentile is defined as overweight. A child is considered to be of normal weight with a BMI ranging anywhere from the 5th to 85th percentile. Any BMI lower than the 5th percentile is underweight (Kuczmarski et al., 2002).

Using BMI as an assessment of health has its flaws, which have been pointed out by other scholars. The calculation does not account for variations in physical characteristics such as body frame. It does not differentiate between fat mass and lean muscle mass which weighs less than adipose tissues (Burkhauser and Cawley, 2008). For instance, the BMI of an athletically-fit individual may be inaccurately categorized as overweight due to their high muscle mass. The most accurate measure of obesity is a DXA scan which requires exposing the patient to additional radiation. Alternatively, BMI and age-and-sex specific BMI percentiles provide a noninvasive, inexpensive, and readily accessible method of assessment. Daniels et al. (1997) showed BMI to be an accurate measure of obesity in children.

Obesity is an associated risk factor for heart disease and other chronic illnesses including hypertension, diabetes, obstructive sleep apnea, and hyperlipidemia (Cole et al., 2000). Obese children are also at a greater risk of psychological and emotional stress due to their appearance

(Voelker, 2015). In addition to those risks listed above, there are a number of effects on growth and development.

Obesity in children has been implicated in causing the early onset of puberty, including earlier pubertal growth spurts (He and Karlberg, 2001). A decrease in testosterone levels (Allan and Mclachlan, 2010) and growth hormone (GH) secretion are frequently found in obese individuals (Ohrn et al., 2002). Despite low growth hormone levels, obese children are reported to exhibit faster linear growth compared to those of normal weight. During childhood they are taller and larger, but are of normal stature in late adolescence and adulthood (Ohrn et al., 2002).

There is a significant association between early dental development/tooth eruption and increased BMI (e.g., Hilgers et al., 2006; Sanchez-Perez et al., 2010; Must et al., 2012; Mack et al., 2013; Jaasari et al., 2016; for a summary, see Nicholas et al., 2018). The overweight children and adolescents studied by Hilgers et al. (2006) were found to have an average of a year and a half of advancement in dental development. These researchers also found that both males and females who were overweight or obese had precocious dental development (Hilgers et al., 2006). Literature also supports that tooth eruption occurs earlier in children with a large body mass index (Must et al., 2012).

2.3 Skeletal Relationships and Normal Mandibular Growth

In 1890, Edward H. Angle was the first to describe the classifications of dental malocclusion (Angle 1897). The classifications are based on the relationship of the mesiobuccal cusp of the maxillary first molar and the buccal groove of the mandibular first molar. Normal occlusion is defined by the position of the mesiobuccal cusp of the maxillary first molar aligning with the buccal groove of the mandibular first molar. A Class I malocclusion has a normal molar relationship but crowding, malalignment, spacing, and/or transverse discrepancies exist. In a Class II malocclusion, the molar relationship presents with the mesiobuccal cusp of the maxillary first molar in a mesial position to the buccal groove of the mandibular first molar. The Class II malocclusion is further categorized into two subdivisions which describe the position of the anterior teeth. Lastly, a Class III malocclusion is characterized by a molar relationship in which the mesiobuccal cusp of the maxillary first molar is distal to the buccal groove of the mandibular first molar. An objective of most comprehensive orthodontic treatment plans is to maintain or achieve a normal Class I molar relationship (Angle 1897).

Additional treatment objectives are typically set with respect to Lawrence Andrews' 6 Keys to normal occlusion (Andrews, 1972). In 1972, Andrews studied the dental casts of 120 subjects with normal occlusion who had never been treated orthodontically. He was able to identify six commonalities across all of the untreated subjects which he concluded to be the necessary characteristics of a normal, harmonious, and stable occlusion. The first key is the same normal molar relationship detailed by Angle. The other five keys include specific crown angulations, crown inclinations, a flat occlusal plane, tight interproximal dental contacts, and no unfavorable tooth rotations (Andrews 1972).

Enlow and Harris (1964) helped to describe and summarize normal mandibular growth in humans. The overall growth and structural change occurs through the process of bone deposition and resorption on its various component surfaces. For example, the ramus experiences deposition along the posterior and resorption on the anterior border. During growth, the mandibular condyle structure itself grows in a superior and posterior direction towards the base of the skull. This results in displacement of the entire mandible in a downward and forward direction relative to its cranial base articulation at the glenoid fossa (Enlow and Harris, 1964).

When compared to other craniofacial structures, the mandible is the last of the two jaw bones to complete its growth and is far behind the neuro-cranial bones which complete most of their growth near age seven (Evans, 2002). The growth pattern of the mandible most closely mimics that of general body tissues (skeletal bones, muscle, viscera). The growth pattern of these somatic tissues are described by Scammon's growth curve. The "S-shaped" graphs the slowing rate during childhood and an acceleration at puberty. On average, the growth spurt of the jaws occurs at the same time as the growth spurt in height (Proffit and Fields, 2012). It is also important to note that there are variations in the velocity of height growth between boys and girls. Girls typically will reach their growth spurt sooner than boys. However, boys tend to grow larger and for a longer duration of time (Evans, 2002). Obesity is thought to affect the timing of the statural growth spurt (Shalitin and Phillip, 2003). Therefore, we might anticipate that it will also affect the timing of mandibular growth.

It has been hypothesized that obesity in children leads to more precocious maturation of the maxilla and mandible which has a fundamental significance in dentofacial orthopedics (Olszewska et al., 2015). The impact of obesity on craniofacial morphology was studied in a Swedish population of adolescents (Ohrn et al., 2002). The results found that the obese subjects had a more intense skeletal growth activity. They showed increased mandibular length, prognathic jaws, and a reduced upper anterior face height when compared to the sex- and age-matched controls (Ohrn et al., 2002). This is in spite of the fact that other studies have documented low GH levels in obese children, which would have perhaps suggested that they would have subdued, not accelerated, growth.

A similar and supporting conclusion can be made of the Guevara et al. (2016) study of a Puerto Rican population. The dental casts of 47 individuals, aged 11-25, were analyzed using three dimensional coordinate data. The coordinate landmarks were regressed against BMI to determine if any patterns existed in the dental arches that could be related to increased BMI. The results overwhelmingly found Class III malocclusion dental arch patterns in those subjects with an increased BMI (Guevara et al., 2016).

Both dental development and skeletal growth are fundamentally useful in orthodontics to determine diagnosis, timing of intervention, and identification of treatment modalities. Accelerated or disproportionate dentofacial development in obese children may alter the orthodontic treatment considerations (Olszewska et al., 2015). We have only begun to uncover the extent to which obesity affects the craniofacial complex. There is a need for further investigation of the association with mandibular prognathism.

This relationship has yet to be studied in a population as ethnically and racially diverse as the one at the University of Illinois at Chicago (UIC). Childhood obesity in the United States disproportionately affects low-income, Black, and Hispanic youth. Given that those most at risk comprise a significant portion of the patient population at UIC, there is potential to contribute to this field of research in a unique and impactful way.

3. METHODS AND MATERIALS

3.1 Subjects

Retrospective records of patients who presented to the University of Illinois at Chicago (UIC) Orthodontic Clinic for treatment were reviewed (IRB: 2018-0716). Initial pre-treatment records captured between January 1, 2000 and October 16, 2018 were reviewed for eligibility. There was no power analysis performed prior to data collection due to a lack of comparable studies of this topic (Ohrn et al., 2002 and Guevara et al., 2016 both employed different metrics than those used in this study). 206 subjects were identified has having complete pre-treatment orthodontic records which included a lateral cephalometric radiograph (LCR), height, and weight measurements.

The criteria for inclusion and exclusion in this study were as follows:

3.1.1 Inclusion Criteria

- Male and female subjects age 9-19 years old at the time of presentation for initial records
- Initial lateral cephalometric radiograph must be available
- Height and weight data must have been recorded within three months of the date the cephalometric radiograph was taken

3.1.2 Exclusion Criteria

- Subjects with craniofacial anomalies
- Subjects with a cleft lip and/or palate

- Subjects with syndromes or disorders that potentially affect growth and development
- Medical history of any significant endocrine disorders
- Any significant history of medication that would affect physical development and growth
- Subjects who have previously undergone orthodontic treatment
- Distorted or missing lateral cephalometric radiographs

181 total subjects remained following the application of the exclusion criteria (80 male and 101 female). The height and weight measurements along with the LRC of each subject were de-identified and assigned a randomized unique identifying number. Each subject's self-reported sex, race, ethnicity, and age at the time of initial records was also recorded.

3.2 **Body Mass Index Calculation**

The height and weight of each subject was captured using a Health O Meter® Digital Physicians Scale 500 x 0.2lbs, w/Height Rod (Sunbeam Procuts Inc, Boca Raton, FL). Height and weight measurements were used to calculate each subject's raw body mass index (BMI) score. BMI is calculated using the following equation: 703 x [weight (lbs) / [height (in)^2] (Kuczmarski et al., 2002). The BMI percentile for each subject was then determined using the Center for Disease Control and Prevention (CDC) age-and-sex specific growth charts (Figure 1). The resultant BMI percentile was then used to identify the weight status of each subject as either underweight (<5th percentile), normal weight (5th – 84th percentile), overweight (85th – 94th percentile), or obese (>95th percentile) (Kuczmarski et al., 2002).

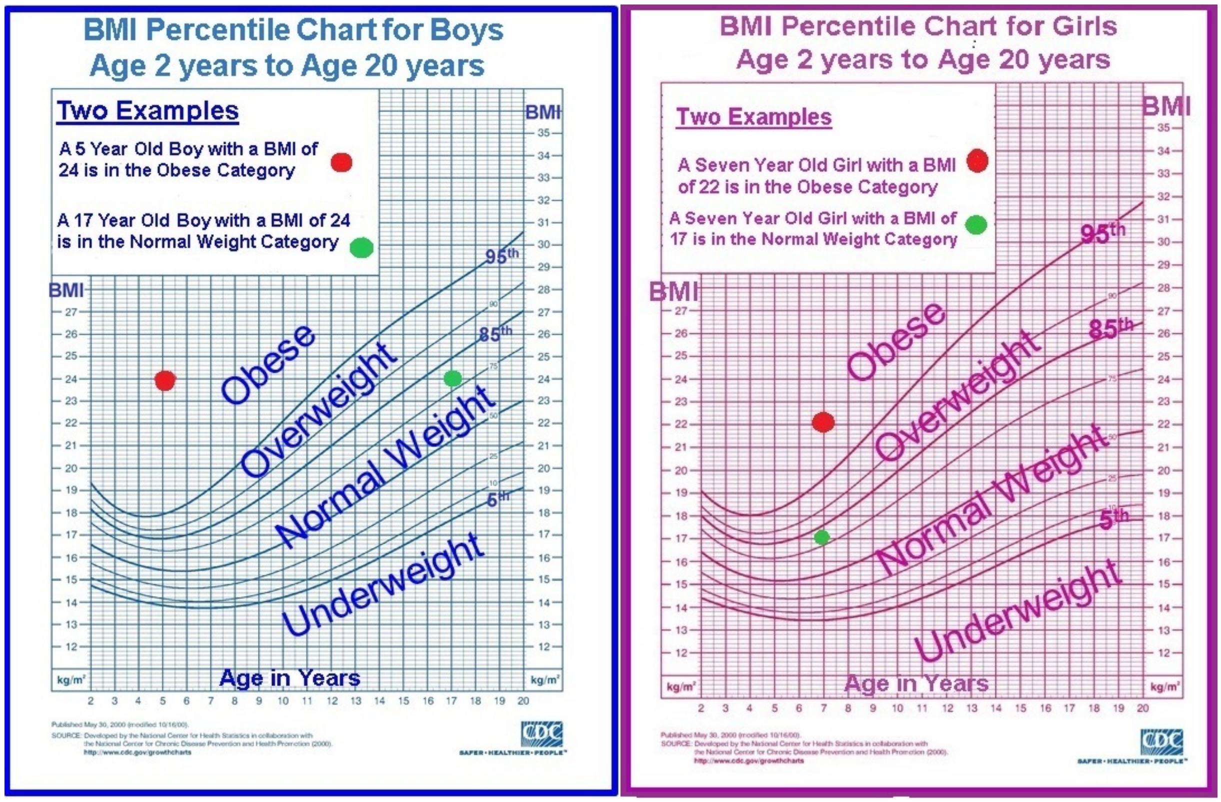

Figure 1. CDC example charts of height/weight depicting the cut-offs for underweight, normal, overweight, and obese children (left: boys, right: girls). [Kuczmarski et al., 2002]

3.3 **Digital Landmark Identification**

Twenty-two coordinate landmarks were chosen to be identified on each subject's lateral cephalometric radiograph (LCR) (Figure 2, Table I). The digital landmarking was completed using the tpsDig2 version 2.31 (Rohlf, 2016) computer software. The landmarking of each subject's LCR was completed by a single investigator. Intra- reliability testing was performed previously. Inter-reliability testing was performed using a second investigator. The ruler present in each LCR was used to measure one centimeter. This measurement was used to calibrate the scale in each subject's LCR thus correcting for variances in magnification.

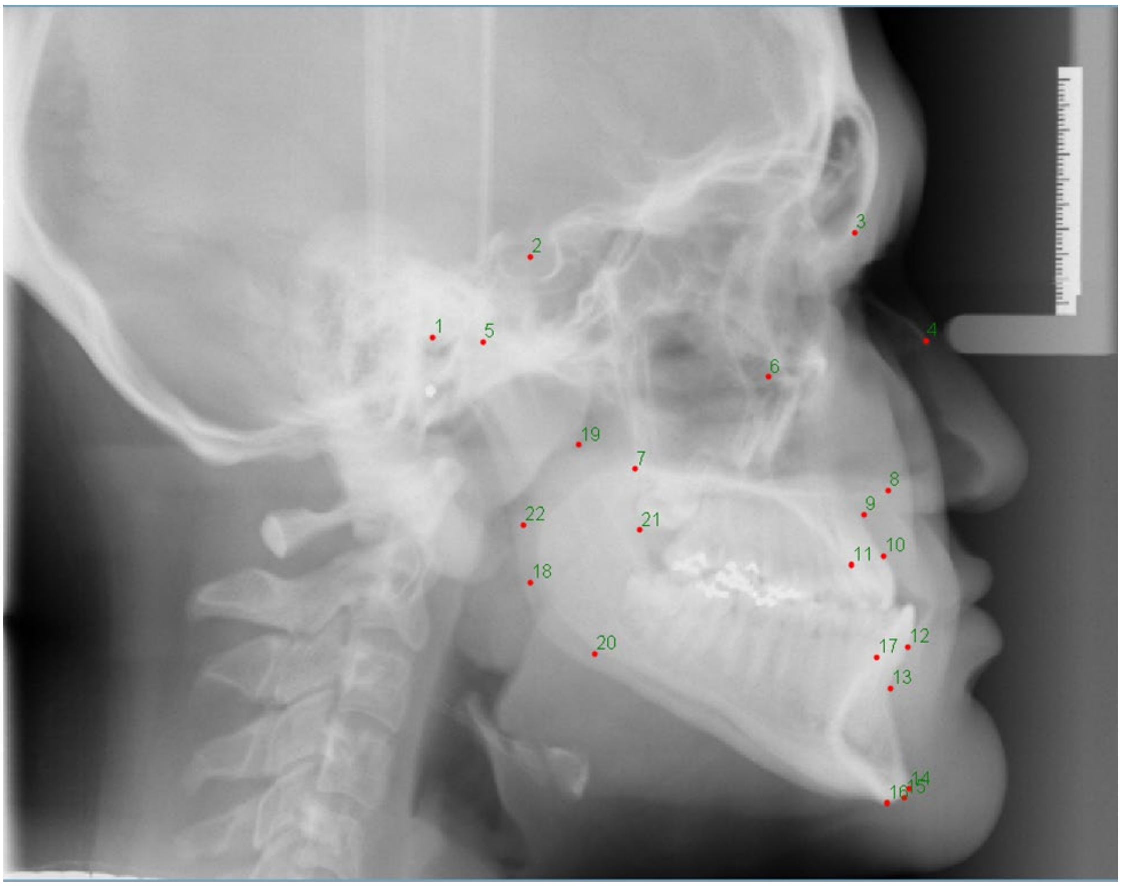

Figure 2. Sample lateral cephalometric radiograph with selected digital landmarks

TABLE I

SELECTED LANDMARKS AND DESCRIPTIONS

1	Porion (Po)	Most superior point of the right external auditory meatus
2	Sella (S)	The center of sella turcica
3	Nasion (N)	The most anterior point on the frontonasal suture
4	Rhinion	The most inferior anterior point of the nasal bone
5	Condylion (Co)	The most posterior superior point of the right condyle
6	Orbitale (Or)	Lowest point of the floor of the right orbit, the most inferior point of the external border of the orbital cavity
7	Posterior Nasal Spine (PNS)	
8	Anterior Nasal Spine (ANS)	Tip of the anterior nasal spine
9	A-point, Subspinale (Ss)	The innermost point on the contour of the maxilla between the anterior nasal spine and the incisor
10	Prosthion, Supradentale (Pr)	Labial cemento –enamal junction of the upper incisor
11	Upper Incisor Lingual Gingival Border	Lingual cemento –enamal junction of the upper incisor
12	Inferior Prosthion, Infradentalale (Id)	Labial cemento –enamal junction of the lower incisor
13	B- point, Supramentale (Sm)	The innermost point on the contour of the mandible between the incisor and the bony chin
14	Pogonion (Pg)	The most anterior point on the chin The point on the curvature of the angle of the mandible located by bisecting the angle formed by the lines tangent to the posterior ramus and the inferior border of the mandible
15	Gnathion (Gn)	The lowest, most anterior midline point on the symphysis of the mandible (midway between the menton and the pogonion)
16	Menton (Me)	The most inferior point on the mandibular symphysis in the midline
17	Lower Incisor Lingual Gingival Border	Lingual cemento –enamal junction of the lower incisor
18	Gonion (Go)	The point on the curvature of the angle of the mandible located by bisecting the angle formed

		by the lines tangent to the posterior ramus and the inferior border of the mandible
19	R1 Point	The deepest point on the curve of the anterior border of the ramus of the mandible
20	R2 Point	Point located on the posterior border of the ramus of the mandible directly lateral to R1 point
21	R3 Point	Point located at the center and most inferior aspect of the sigmoid notch
22	R4 Point	Point on the border of the mandible directly inferior to R3 point.

3.4 **Geometric Morphometrics**

Geometric Morphometrics was used in order to quantify and analyze the differences in shape and size of our subjects' mandibles. Morphometrics is a branch of mathematical shape analysis. It provides a quantitative method of understanding complex shape comparisons and can localize where changes in shape occur. Geometric shape analysis provides an effective means of visualization, interpretation, and communication of results (Zelditch et al., 2012).

Shape is defined by all geometric information that remains when location, scale, and rotational effects are filtered out from an object (Kendall, 1977). By removing the differences between two or more configurations which are attributed to their differences in location, scale, and orientation this leaves only the differences in shape.

There are many contexts in which to discuss the concept of size. For the purposes of this study we will describe “centroid size” and how it relates to shape. Centroid size is calculated using the measurements of boarder landmarks to the center of a shape configuration (Zelditch et al., 2012).

Generalized Procrustes Analysis (GPA) is a mathematical superimposition method which uses three operations: translating, scaling, and rotation in order to calculate an average shape. That average shape is used as a reference to calculate differences in shape from the reference (Zelditch et al., 2012).

A Principle Component Analysis (PCA) is a tool fir simplifying descriptions of variance among individual. PCA produces a set of complex variables, Principle Components (PC). PCA is useful because most variation in a sample can be described by very few PCs. For example, PC1 accounts for the largest proportion of shape variation followed by PC3, then PC3 and so on (Zelditch et al., 2012).

Allometry describes size-related shape differences. Biomechanically, organisms are expected to change shape as they change in size. Without this change in shape, they would likely lose their ability to perform vital functions such as respiration, feeding, and locomotion (Zelditch et al., 2012). Growth and size related shape changes are occurring in children and adolescents during this study’s target age range of 9 to 19 years old. Therefore, we would expect to find evidence of allometry in this population of subjects.

4. RESULTS

4.1 Descriptive Statistics

51% of the total sample size was of normal weight (BMI between the 5th and 85th percentile). There were 53 normal weight females and 40 normal weight males. 45% of our study population was overweight or obese having a BMI above the 85th percentile. 25.97% of subjects were overweight (20 female, 27 male). 35 subjects were obese (25 female, 10 male), accounting for 19.34% of the sample. We found 6 of the subjects (2 female, 4 male) to be underweight with a BMI below the 5th percentile (Table II).

TABLE II

DESCRIPTION OF SAMPLE BROKEN DOWN BY BMI CATEGORY AND SEX

	Male	Female	Total
Normal BMI	40	53	**93**
Overweight	27	20	**47**
Obese	10	10	**35**
Underweight	4	2	**6**
Total	**80**	**101**	**181**

Five different ethnic groups were included and identified in the study. The subgroups included African-American, Asian, Caucasian Non-Hispanic, Caucasian Hispanic, and Multiracial.

Those subjects who did not self-report any ethnicity information were included and grouped in a separate subgroup. Obesity was highest among African-Americans and lowest among Asians (Table III).

TABLE III

DESCRIPTION OF SAMPLE BROKEN DOWN BY BMI AND ETHNICITY

	Normal	Overweight	Obese	Underweight	Total	% Overweight/Obese
African-American	7	3	9	1	20	60%
Asian	6	1	1	1	9	22.22%
Caucasian:						
Hispanic	53	25	27	1	106	49.06%
Non-Hispanic	19	4	5	-	28	32.14%
Multiracial	-	2	1	-	3	100%
Unknown	8	-	4	3	15	26.67%
Total	**93**	**35**	**47**	**6**	**181**	**45.3%**

The self-reported racial information revealed 111 total Hispanic subjects. Of those, 106 were Caucasian Hispanic, 1 Hispanic multiracial, and 4 Hispanic with no race listed (Table IV). The remaining 70 subjects in our total same either reported to be Non-Hispanic or no racial information was listed at all.

TABLE IV

DESCRIPTION OF SAMPLE BROKEN DOWN BY RACE

	Number of Subjects
Non-Hispanic/No Information	70
Hispanic:	111
Hispanic White	106
Hispanic Multiracial	1
Hispanic No Listed Race	4

4.2 **Statistical Analysis of Facial Morphology**

An initial Principal Component Analysis (PCA) was performed which yielded 44 Principal Components (PCs). The first four PCs each represented greater than five percent of the overall facial shape variation (Table V).

TABLE V

FIRST SIX PRINCIPLE COMPONENTS YIELDED FROM PRINCIPAL COMPONENT ANALYSIS OF FACIAL SHAPE VARIATION

	PC1	PC2	PC3	PC4	PC5	PC6
Standard Deviation	0.03858	0.03709	0.02523	0.01869	0.01572	0.01471
Proportion of Variance	0.24782	0.22907	0.10598	0.05818	0.04113	0.03603
Cumulative Proportion	0.24782	0.47689	0.58287	0.64105	0.68218	0.71822

The study's sample population included 6 underweight individuals. It appeared that these potential outliers may be affecting the normal distribution of the data (Figure 3). Therefore, the decision was made to remove all six underweight subjects from the sample.

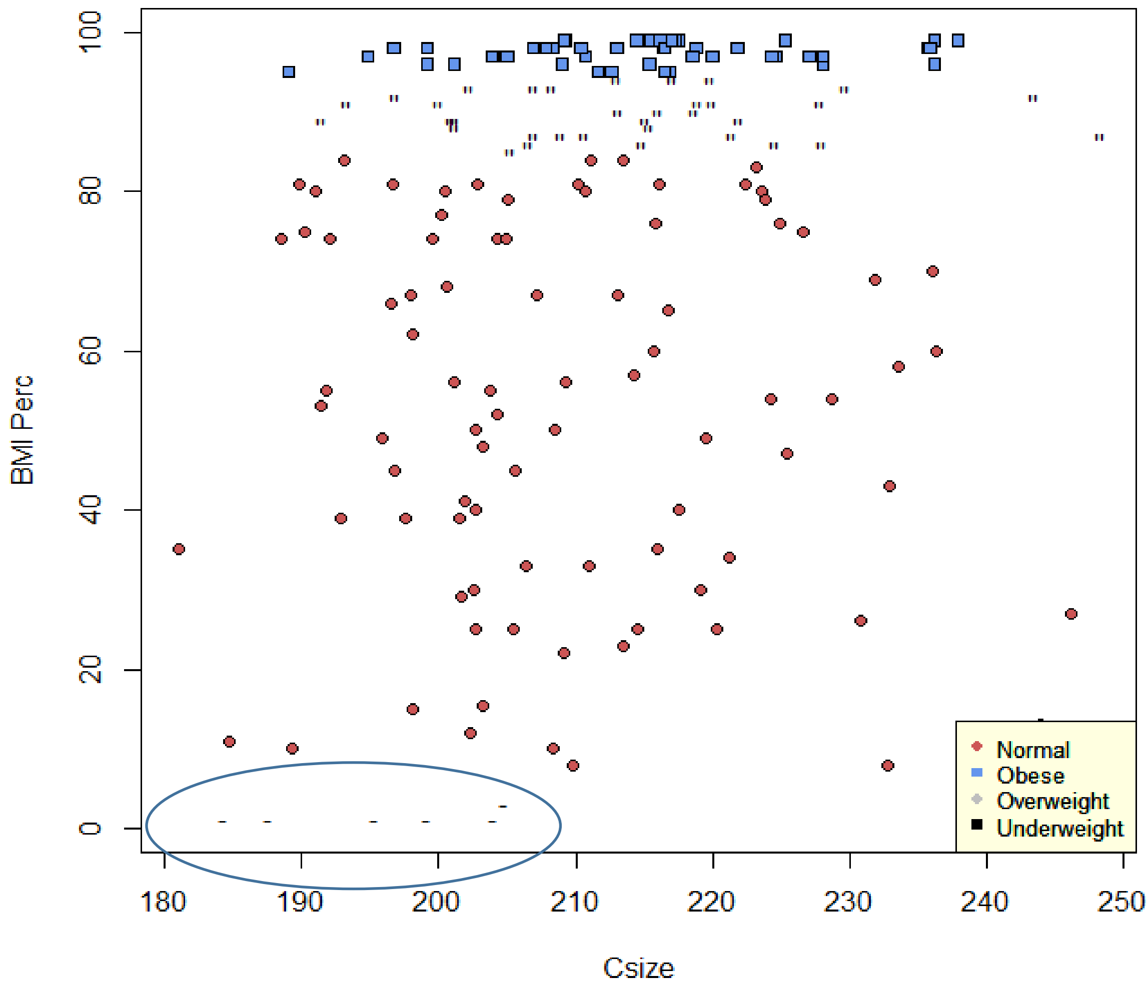

Figure 3. Centroid Size and BMI Percentage

Another PCA was performed following the removal of the underweight subjects from the sample. This again yielded 44 PCs, the first four of which were >5% of the overall facial shape variation (Table VI).

TABLE VI

FIRST SIX PRINCIPLE COMPONENTS YIELDED FROM PRINCIPAL COMPONENT ANALYSIS OF FACIAL SHAPE VARIATION EXCLUDING UNDERWEIGHT SUBJECTS

	PC1	PC2	PC3	PC4	PC5	PC6
Standard Deviation	0.03863	0.03718	0.02524	0.01828	0.01573	0.01480
Proportion of Variance	0.24915	0.23086	0.10635	0.05580	0.04129	0.03659
Cumulative Proportion	0.24915	0.48002	0.58636	0.64217	0.68345	0.72005

The data was normally distributed. Traditional parametric statistics were run. We first tested for allometry by regressing centroid size on overall shape. $p=0.002$ showing that there was evidence of allometry, or shape variation related to size.

A partial correlation analysis was run to investigate the association between centroid size and BMI while holding age constant. This showed that the centroid size was indeed positively correlated with BMI when correcting for variation in age ($p=0.029$, $r=0.168$), though the association is weak.

Due to the evidence of allometry, all subsequent analyses we run on the allometric regression residuals. A new PCA was performed on the regression residuals which yielded 44 PCs, the first 4 of which each represented >5% of the overall facial shape variation (Table VII).

TABLE VII

FIRST SIX PRINCIPLE COMPONENTS YIELDED FROM PRINCIPAL COMPONENT ANALYSIS OF FACIAL SHAPE VARIATION PERFORMED ON THE ALLOMETRIC REGRESSION RESIDUALS

	PC1	PC2	PC3	PC4	PC5	PC6
Standard Deviation	0.03858	0.03477	0.02523	0.01722	0.01561	0.01467
Proportion of Variance	0.25900	0.21042	0.11083	0.05161	0.04241	0.03747
Cumulative Proportion	0.25900	0.46943	0.58025	0.63186	0.67427	0.71174

The data was again normally distributed, so standard parametric statistics were used. We ran separate regression analyses regressing each of the first 4 PCs on BMI percentile. None of the first 4 PCs were correlated with BMI.

Next, a series of ANOVA tests were run on overall facial morphology against each ethnic/racial subgroup in our sample. PC3 was found to be correlated with this variable ($p<0.001$). Figure 4 shows the scatter of facial shape variation representative of PC3 for each subject. As depicted in the thin-plate splines below, PC3 is generally related to retrusion or protrusion of the maxilla (Figure 4). The variation in facial morphology described by PC3 shows that the African-American subgroup has a more protrusive maxilla as compared to the Caucasian and Asian subgroups (Figure 5).

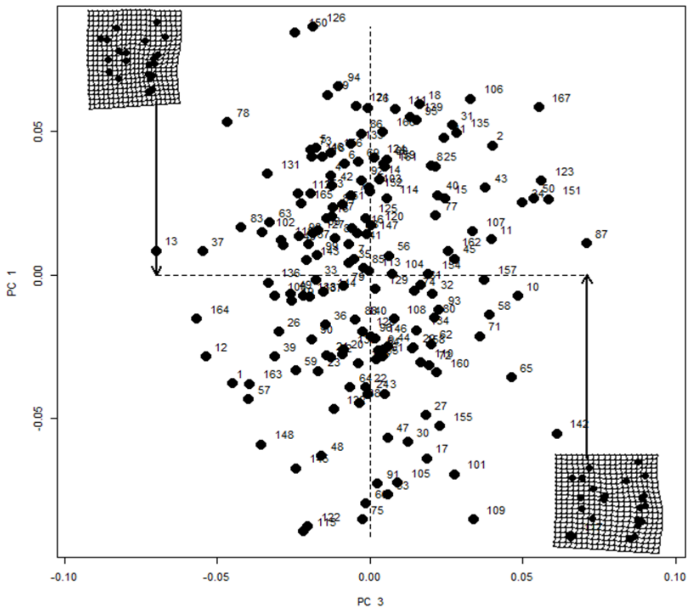

Figure 4. Scatter plot depicting the variation of facial shape representative of PC3

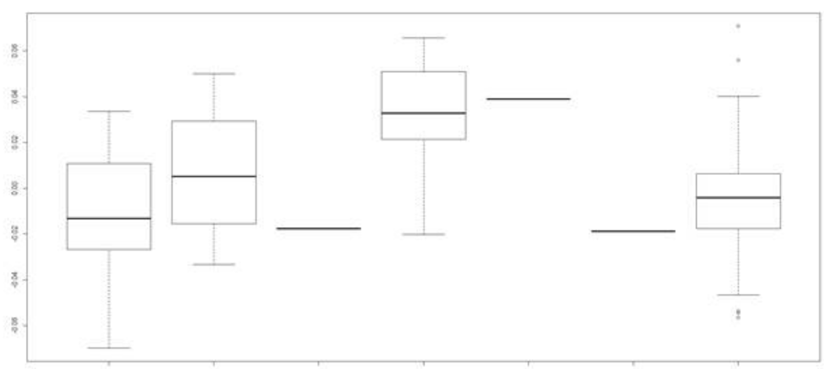

Figure 5. Boxplot depicting the variation in facial morphology of PC3 across each ethnic subgroup

4.3 Statistical Analysis of the Mandible

Next, we decided to look specifically at the mandible because we suspect that growth of this craniofacial structure may be most affected by increased BMI. This PCA yielded 24 PCs, the first 6 of which were >5% of the total shape variation (Table VIII).

TABLE VIII

FIRST SIX PRINCIPLE COMPONENTS YIELDED FROM PRINCIPAL COMPONENT ANALYSIS OF MANDIBULAR SHAPE VARIATION

	PC1	PC2	PC3	PC4	PC5	PC6
Standard Deviation	0.03858	0.03477	0.02523	0.01722	0.01561	0.01467
Proportion of Variance	0.24356	0.18873	0.15091	0.07779	0.06524	0.05178
Cumulative Proportion	0.24356	0.43229	0.58320	0.66099	0.72624	0.77802

The shape of the isolated mandible showed evidence of allometric scaling. Therefore, we ran our PCA on allometric regression residuals. This resulted in 24 PCs. The first 6 were representative of >5% of shape variation (Table IX).

TABLE IX

FIRST SIX PRINCIPLE COMPONENTS YIELDED FROM PRINCIPAL COMPONENT ANALYSIS OF MANDIBULAR SHAPE VARIATION PERFORMED ON ALLOMETRIC REGRESSION RESIDUALS

	PC1	PC2	PC3	PC4	PC5	PC6
Standard Deviation	0.03179	0.02797	0.0248	0.01779	0.01652	0.01466
Proportion of Variance	0.24634	0.19073	0.1499	0.07713	0.06649	0.05241
Cumulative Proportion	0.24634	0.43708	0.5870	0.66412	0.73060	0.78301

A series of ANOVA tests were run on each PC1-6. BMI category was used as our grouping variable. PC6 was the only one found to be approaching a statistical difference across the three BMI categories: normal weight, overweight, obese (p=0.0655) (Figure 6). PC6 describes the height of the mandibular corpus (superiorly-inferiorly). As the BMI percentile increases, the mandibular body becomes taller, corpus height increases (Figure 7). PC6 also describes a less prominent chin and more superior B-point and BMI increases.

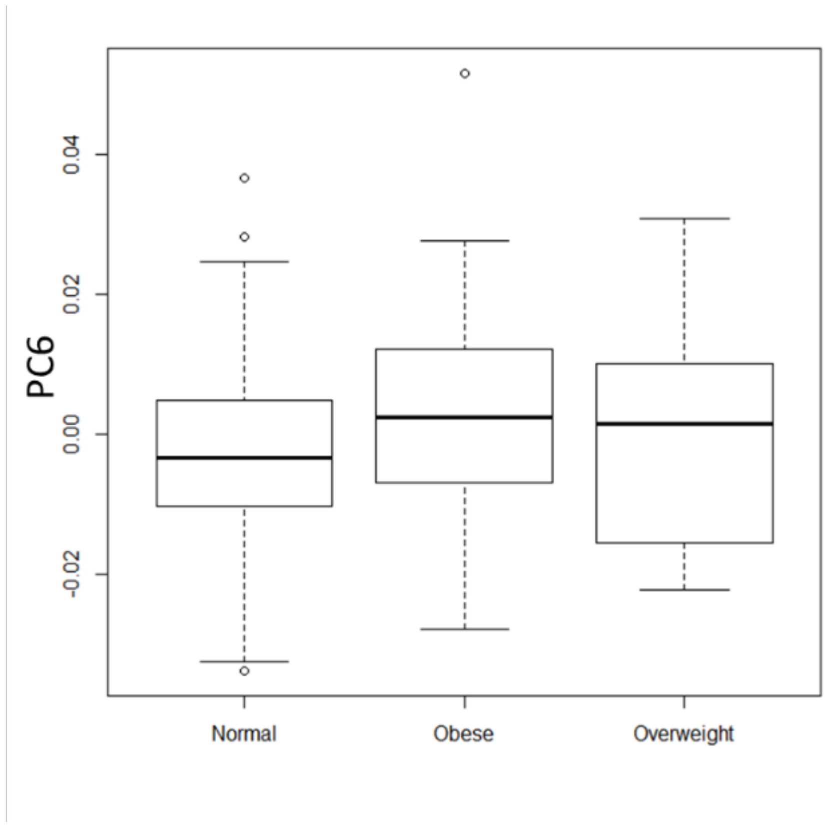

Figure 6. The mandibular shape variation described by PC6 across each BMI category

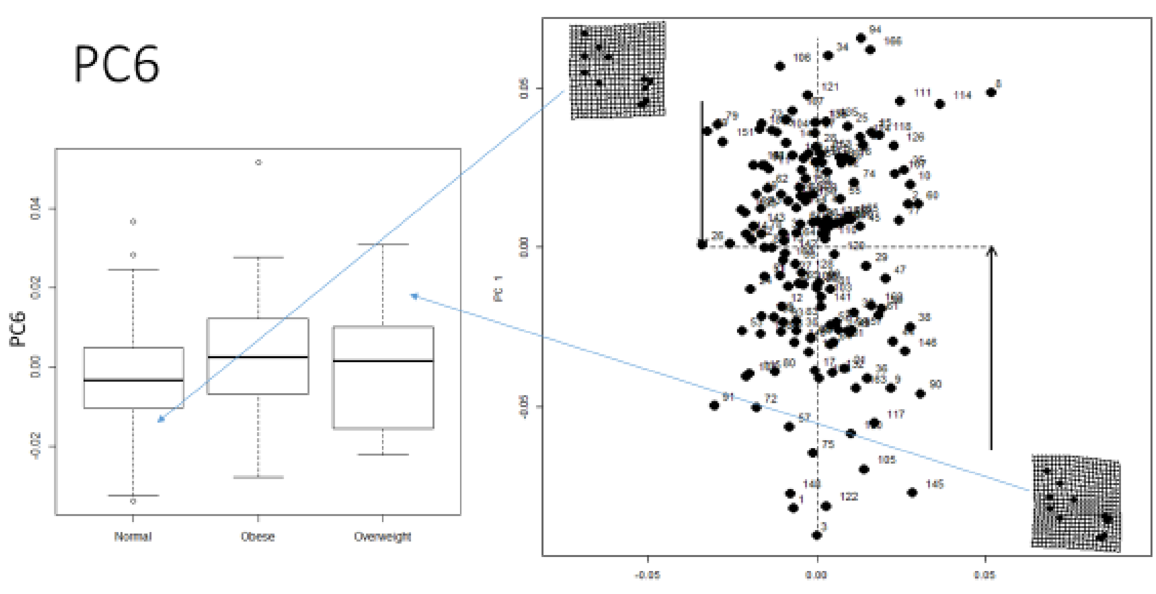

Figure 7. The changes in mandibular shape described by PC6 as BMI increases

A partial correlations analysis was performed on the centroid size of the mandible and BMI, controlling for age. The results yielded a weak (r=0.212) but statistically significant (p=0.005) relationship.

5. DISCUSSION

5.1 Subjects

Childhood obesity is a global health epidemic on the rise. The World Health Organization reported 41 million overweight and obese children under the age of five years old globally in 2016 (WHO, 2017). In the United States of America alone, the obesity rate has climbed to three times what it was thirty years ago. 18.5% of all US children ages 2 to 19 are overweight or obese (Hales et al., 2017).

Chicago ranks amongst the US cities with the highest childhood obesity rates. When surveying Chicago Public Schools, 43.3% of all school aged children were found to be overweight or obese (Healthy Chicago, 2013). This study's subject population was found to be consistent with the Chicago norms finding that 45.5% of our sample was overweight or obese.

5.2 Racial/Ethnic Diversity of Sample

There is an extremely limited amount of existing literature on the relationship between obesity and craniofacial morphology and size. This study is the first of its kind to evaluate this relationship in a racially and ethnically diverse population. Our sample included Non-Hispanic African-American, Asian, Caucasian Non-Hispanic, Caucasian Hispanic, and Multiracial subjects. This is highly representative of the cultural diversity within the City of Chicago.

Facial morphology varies widely based on race and ethnicity (Harris et al., 1977). Guevara and colleagues (2016) studied the relationship between BMI, dental arch form, and malocclusion in an exclusively Puerto Rican population of children and adolescents. Ohrn et al. (2002) reported on their findings of a relationship between obesity and facial growth in a Swedish Caucasian population. The failure of our study's results to strongly support the findings in existing literature may be due to the ethnic diversity of our sample.

There is a possibility that the effects of BMI on facial shape and size expresses differently across racial/ethnic groups. Although this study's subject population is ethnically diverse, there is an over-representation of the Hispanic subgroup. This may have caused our results to be biased or diluted. In future research, a larger sample size including more subjects of each ethnic subgroup could reveal more population specific information about how obesity effects craniofacial morphology.

5.3 **<u>The Mandible in Isolation</u>**

Obesity in children is associated with the early onset of puberty and pubertal growth spurt (He and Karlberg, 2001). Despite obese children having low growth hormone levels, they are reported to grow in stature at a faster rate when compared to normal weight children (Ohrn et al., 2002). On average, the growth spurt of the jaws occurs at the same time as the growth spurt in height. The mandibular growth pattern most closely follows statural, or somatic, growth velocity (Proffit and Fields, 2012) (Figure 8).

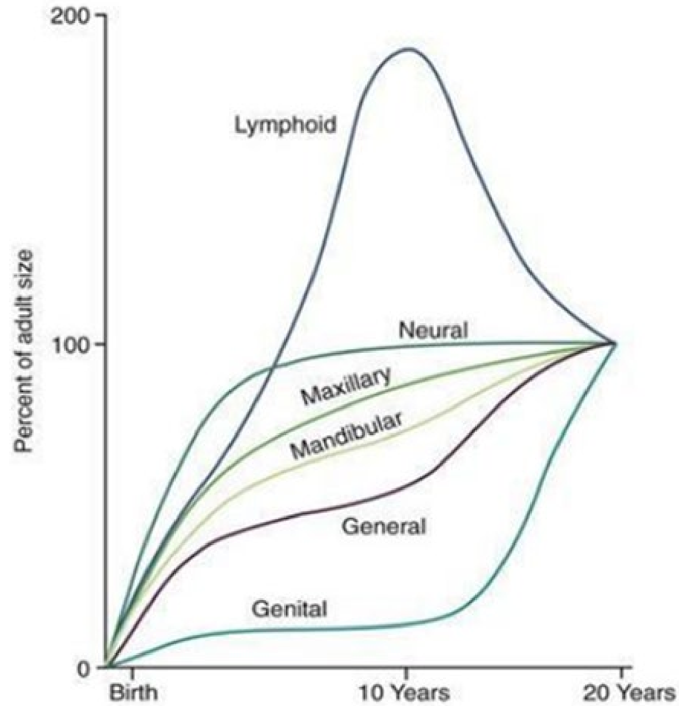

Figure 8. Scammon's growth curve

The decision was made to isolate the mandible and look specifically at this structure's relationship with BMI. This step was made because the mandible continues to grow later and at a larger magnitude than other craniofacial structures (Bjork and Skieller 1983). Also, the prevalence of obesity trends upwards as age increases (Healthy Chicago, 2013). Therefore, we might expect to see the greatest influence of obesity on shape and size in the mandible.

This study found subtle evidence to support the thought that increased BMI is related to shape variation of the mandible. A Principle Component Analysis (PCA) was run on the allometric regression residuals of mandibular shape variation. The PCA yielded six principle components (PCs) that each represented >5% of the mandibular shape variation. The results of ANOVA tests comparing shape variables PC1-6 and the three BMI categories identified that PC6 was approaching statistical significance (p=0.065). PC6 shows a taller mandibular body (superiorly-inferiorly) as BMI percentile increases. PC6 also describes a less prominent chin and more superior B-point as BMI increases.

5.4 **Variation in Shape and Centroid Size**

The relationship between obesity and skeletal craniofacial structures may not be as clear as previously thought and reported on. Ohrn and colleagues found increased mandibular lengths, prognathinc jaws, and reduced upper face height in their obese subjects when compared to the normal weight controls (Ohrn et al., 2002). Guevara was able to identify a correlation between higher BMI and dental arches indicative of a class III malocclusion (Guevara et al., 2016). The current research study failed to produce any evidence in support of those conclusions. We found no significant variation in shape of the mandible or facial complex across BMI categories (normal weight, overweight, obese).

It is important to note that the study conducted by Guevara et al. used geometric morphometric landmarks solely on the dental alveolar arches. Whereas the current study used purely skeletal landmarks. This difference in study design may have attributed to the varied results. The significant relationship reported by Guevara may only be indicative of a dental class III malocclusion, not a facial skeletal pattern or shape.

A partial correlation analysis of centroid size and BMI did revealed a statistically significant positive correlation between BMI and overall facial size when controlling for age (p=0.029, r=0.168). Meaning that as BMI percentile increased, the size of the craniofacial complex also increased. The same was true when analyzing the mandible in isolation. Mandibular centroid size increased as BMI increased when controlling for age (p=0.05, r=0.212).

6. CONCLUSION

In conclusion, our results are too ambiguous for any clear clinical recommendations. Evidence was found of an association between high BMI and increased centroid size of the mandible and facial complex when controlling for age. BMI could be affecting the time of growth causing overweight/obese children to grow larger faces (and mandibles) at an earlier age when compared to normal weight children. Alternatively, BMI could be affecting the total magnitude of craniofacial growth. We are unable to make that distinction with this cross-sectional data set.

We failed to reject the following null hypotheses:

- There is no relationship between BMI and the shape of the mandible in children and adolescents.
- There is no relationship between BMI and craniofacial shape in children and adolescents.

We reject the following null hypotheses:

- There is no relationship between BMI and mandible size in children and adolescents.
- There is no relationship between BMI and craniofacial size in children and adolescents.

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APPENDICES

APPENDIX A

Exemption Determination
Amendment to Research Protocol – Exempt Review
UIC Amendment #1

November 20, 2018

Lauren A. Gordon, DDS
Orthodontics

RE: Protocol # 2018-0716
"The Relationship Between Obesity and Mandible Size in Children and Adolescents"

Please note that the end date for data collection cannot be extended beyond October 16, 2018 unless you withdraw this Claim of Exemption and instead submit an Initial Review Health and Biological Sciences Application and obtain IRB approval for the analysis of prospectively collected medical records. As per federal regulation, "existing" data is data that existed at the time the research was initially proposed.

Dear Dr. Gordon:

The OPRS staff/members of Institutional Review Board (IRB) #7 have reviewed this amendment to your research and have determined that your amended research continues to meet the criteria for exemption as defined in the U. S. Department of Health and Human Services Regulations for the Protection of Human Subjects [(45 CFR 46.101(b)].

The specific exemption category under 45 CFR 46.101(b) is: 4

You may now implement the amendment in your research.

Please note the following information about your approved amendment:

<u>Exemption Period:</u>	**November 20, 2018 – November 19, 2021**
Performance Site:	UIC
Subject Population:	De-identified medical records initially collected for clinical purposes from January 1, 2000 through October 16, 2018.
Number of Subjects:	200

<u>Amendment Approval Date:</u> November 20, 2018

<u>Amendment:</u>

Summary: UIC Amendment #1: Data collection of this study has not yet begun. This is a proposed Amendment to alter the subject enrollment date cut off from December 1, 2017 to October 16, 2018. The subject population would include de-identified medical records initially collected for clinical purposes from January 1, 2000 to October 16, 2018.

APPENIX A (continued)

You are reminded that investigators whose research involving human subjects is determined to be exempt from the federal regulations for the protection of human subjects still have responsibilities for the ethical conduct of the research under state law and UIC policy. Please be aware of the following UIC policies and responsibilities for investigators:

1. Amendments You are responsible for reporting any amendments to your research protocol that may affect the determination of the exemption and may result in your research no longer being eligible for the exemption that has been granted.

2. Record Keeping You are responsible for maintaining a copy all research related records in a secure location in the event future verification is necessary, at a minimum these documents include: the research protocol, the claim of exemption application, all questionnaires, survey instruments, interview questions and/or data collection instruments associated with this research protocol, recruiting or advertising materials, any consent forms or information sheets given to subjects, or any other pertinent documents.

3. Final Report When you have completed work on your research protocol, you should submit a final report to the Office for Protection of Research Subjects (OPRS).

Please be sure to use your research protocol number (2018-0716) on any documents or correspondence with the IRB concerning your research protocol.

We wish you the best as you conduct your research. If you have any questions or need further help, please contact me at (312) 355-2908 or the OPRS office at (312) 996-1711.

Sincerely,
Charles W. Hoehne, B.S., C.I.P.
Assistant Director, IRB #7
Office for the Protection of Research Subjects

cc: Budi Kusnoto
Christina Nicholas

APPENDIX B

Unique ID	Ceph Date	Age at time of Ceph(Years)	Age at time of Ceph(Months)	Sex	Race	Ethnicity	Date of H/W/BMI	Height (inches)	Weight (lbs)	BMI	BMI (CDC Calculated)	Percentile (CDC)
001	05/29/2018	15.2	182	Female	WHITE	HISP	5/29/2018	67	244	38.2	38.2	99
002	03/20/2017	16.21	194.5	Male	WHITE	HISP	3/22/2017	69	220	32.5	32.5	99
003	09/20/2018	16.8	200	Male	WHITE	HISP	9/20/2018	66	182.6	29.5	29.5	97
004	09/17/2018	11.3	135	Male			9/17/2018	61	148	28	28	98
005	12/18/2017	12.8	152	Male	WHITE	HISP	2/15/2018	61	130	24.6	24.6	95
006	07/26/2017	12.68	152.18	Male			10/18/2017	65	125.4	20.9	20.9	80
007	08/06/2018	14.2	170	Male	WHITE	HISP	8/6/2018	67	139.6	21.9	21.9	79
008	09/11/2017	12.68	152.21	Female	ASIAN ,WHITE	OTHER	9/11/2017	57	118.2	25.6	25.6	94
009	09/20/2017	11.59	139.14	Male	WHITE	HISP	9/20/2017	49	68.6	20.1	20.1	81
010	09/25/2017	12.84	154.12	Female	WHITE	OTHER	9/25/2017	63	132	23.4	23.4	89
011	09/25/2017	12.79	153.46	Female	WHITE	HISP	9/25/2017	60	92.6	18.1	18.1	43
012	09/26/2017	13.48	161.71	Female	WHITE	HISP	9/26/2017	58	85.6	17.9	17.9	34
013	09/26/2017	17.22	206.62	Male	WHITE	OTHER	9/26/2017	69	254	37.5	37.5	99
014	09/26/2017	14.98	179.78	Female	WHITE	HISP	9/26/2017	61	230	43.5	43.5	99
015	09/28/2017	13.93	167.13	Male	WHITE	HISP	9/28/2017	67	185	29	29	98
016	09/28/2017	11.68	140.16	Female	BLACK	OTHER	9/28/2017	57	129.8	28.1	28.1	98
017	09/29/2017	11.56	138.68	Male	BLACK	OTHER	9/29/2017	63	94.6	16.8	16.8	33
018	09/29/2017	14.74	176.89	Male	WHITE	HISP	9/29/2017	63	123.2	21.8	21.8	76
019	09/29/2017	17.27	207.21	Male			9/29/2017	72	160.6	21.8	21.8	54
020	09/29/2017	14.18	170.12	Male	WHITE	HISP	9/29/2017	60	126	24.6	24.6	98
021	09/29/2017	11.1	133.26	Male	WHITE	OTHER	9/29/2017	57	88.6	19.2	19.2	77
023	10/03/2017	10.52	126.19	Female	WHITE	OTHER	10/3/2017	58	124	25.9	25.9	97
024	10/03/2017	10.77	129.25	Female	WHITE	OTHER	10/3/2017	53	69.4	17.4	17.4	49
025	10/03/2017	16.67	199.98	Male	WHITE	OTHER	10/3/2017	69	170	25.4	25.4	87
026	10/04/2017	11.07	132.8	Male	WHITE	HISP	10/4/2017	57	90	19.5	19.5	80
027	10/09/2017	15.33	183.95	Male	WHITE	HISP	10/9/2017	61	96.4	18.2	18.2	22
028	10/09/2017	10.2	122.45	Male	ASIAN	OTHER	10/9/2017	54	64.2	15.5	15.5	15.4
029	10/09/2017	9.83	117.91	Female			10/9/2017	53	49.5	12.4	12.4	1
030	10/09/2017	12.24	146.86	Female	WHITE	HISP	10/9/2017	56	78	17.5	17.5	39
031	10/09/2017	14.84	178.04	Female	ASIAN	OTHER	10/9/2017	48	92.6	28.3	28.3	95
032	10/09/2017	14.67	176.03	Female	WHITE	HISP	10/9/2017	71	181	25.2	25.2	90
033	10/09/2017	13.79	165.45	Male	WHITE	HISP	10/9/2017	68	187	28.4	28.4	98
034	10/11/2017	16.62	199.49	Male	WHITE	HISP	10/11/2017	71	147	20.5	20.5	43
035	10/11/2017	11.65	139.76	Male	WHITE	HISP	10/11/2017	52	85.2	22.2	22.2	91
036	10/12/2017	12.76	153.17	Female	WHITE	HISP	10/12/2017	62	104	19	19	56
037	10/13/2017	12.05	144.59	Female	WHITE	HISP	10/13/2017	61	108	20.4	20.4	76
038	10/13/2017	12.81	153.72	Female	ASIAN	OTHER	10/13/2017	61	91	17.2	17.2	29
039	10/13/2017	14.52	174.26	Female	WHITE	OTHER	10/13/2017	61	104	19.6	19.6	50
040	10/13/2017	12.68	152.18	Female	WHITE	HISP	10/13/2017	57	119.8	25.9	25.9	95
041	10/16/2017	12.2	146.43	Male	ASIAN	OTHER	10/16/2017	55	60.4	14	14	1
042	10/16/2017	16.44	197.32	Female	WHITE	HISP	10/16/2017	62	103	18.8	18.8	25
043	10/16/2017	17.93	215.13	Female	ASIAN	OTHER	10/16/2017	64	135.2	23.2	23.2	81
044	10/17/2017	15.02	180.21	Female	WHITE	OTHER	10/17/2017	66	156	25.2	25.2	89
046	10/18/2017	16.92	203.04	Male	WHITE	HISP	10/18/2017	68	166	25.2	25.2	87
047	10/18/2017	14.15	169.79	Male	WHITE	OTHER	10/18/2017	67	193	30.2	30.2	98
048	11/02/2017	12.94	155.33	Male	WHITE	HISP	11/2/2017	60	132.6	25.9	25.9	96
049	11/02/2017	13.48	161.81	Female	WHITE	HISP	11/2/2017	58	97	20.3	20.3	66
050	11/07/2017	12.21	146.46	Female	WHITE	HISP	11/7/2017	60	168	32.8	32.8	99
053	10/20/2017	13.95	167	Male	BLACK	OTHER	10/20/2017	71	164	22.9	22.9	86
054	11/10/2017	12	144.03	Male			11/10/2017	61	129	24.4	24.4	95
055	11/13/2017	14.52	174.26	Male	WHITE	HISP	11/13/2017	68	127	19.3	19.3	47
056	11/14/2017	15.73	188.71	Female	WHITE	OTHER	11/14/2017	58	121	25.3	25.3	88
057	11/14/2017	12.42	149.09	Female	WHITE	HISP	11/14/2017	65	180	30	30	98
058	11/14/2017	14.88	178.6	Female	WHITE	HISP	11/14/2017	64	124	21.3	21.3	67
059	11/14/2017	12.24	146.92	Female	WHITE	HISP	11/14/2017	58	73.4	15.3	15.3	8
060	11/15/2017	13.13	157.54	Male	WHITE	HISP	11/15/2017	64	112	19.2	19.2	60
061	11/17/2017	14.28	171.33	Male	WHITE	HISP	11/17/2017	64	114.6	19.7	19.7	54
062	11/17/2017	17.85	214.24	Female	WHITE	HISP	11/17/2017	62	146	26.7	26.7	89
063	11/17/2017	11.33	135.92	Female	BLACK	OTHER	11/17/2017	63	174	30.8	30.8	99
064	11/21/2017	11.19	134.24	Male	WHITE	HISP	11/21/2017	59	110	22.2	22.2	93
065	11/21/2017	11.16	133.95	Female	BLACK	OTHER	11/21/2017	62	65.2	11.9	11.9	1
066	11/22/2017	13.15	157.8	Female	WHITE	HISP	11/22/2017	62	123	22.5	22.5	84
067	11/22/2017	16.54	198.44	Male	WHITE	OTHER	11/22/2017	65	145	24.1	24.1	82
068	11/27/2017	10.26	123.14	Male	WHITE	HISP	11/27/2017	51	75	20.3	20.3	89
069	11/27/2017	11.94	143.28	Female	BLACK	OTHER	11/27/2017	56	79	17.7	17.7	45
070	11/27/2017	11.34	136.08	Female	WHITE	HISP	11/27/2017	59	97	19.6	19.6	74
071	11/29/2017	13.51	162.17	Female	WHITE	HISP	11/29/2017	63	163.6	29	29	97
072	11/30/2017	14.35	172.25	Male	WHITE	HISP	11/30/2017	70	155.4	22.3	22.3	81
073	12/01/2017	14.32	171.79	Female	BLACK ,WHITE	OTHER	12/1/2017	67	148	23.2	23.2	87
075	12/04/2017	11.03	132.34	Male	WHITE	HISP	12/4/2017	56	118	26.5	26.5	98
076	12/04/2017	12.57	150.83	Male	ASIAN	OTHER	12/4/2017	59	106	21.4	21.4	85
077	12/04/2017	11.83	141.96	Male	WHITE	HISP	12/4/2017	61	107	20.2	20.2	81
078	12/04/2017	16.19	194.33	Female	WHITE	HISP	12/4/2017	48	101	30.8	30.8	97
079	12/04/2017	14.31	171.7	Female	WHITE	OTHER	12/4/2017	63	127.6	22.6	22.6	79
080	12/05/2017	14.23	170.78	Male		OTHER	12/5/2017	60	80.2	15.7	15.7	3
081	12/07/2017	10.12	121.49	Female	WHITE	HISP	12/7/2017	53	82	20.5	20.5	87
082	12/08/2017	11.51	138.09	Female	ASIAN	OTHER	12/8/2017	54	63	15.2	15.2	10
083	12/08/2017	13.17	158.03	Female	WHITE	OTHER	12/8/2017	61	96.6	18.3	18.3	41
084	12/12/2017	12.46	149.49	Male	WHITE	OTHER	12/12/2017	63	151	26.7	26.7	97
085	12/12/2017	12.99	155.86	Female	WHITE	HISP	12/12/2017	58	112	23.4	23.4	89
086	12/12/2017	12.22	146.6	Male	WHITE	HISP	12/12/2017	56	91.6	20.5	20.5	81
087	12/14/2017	12.25	147.06	Female	WHITE	OTHER	12/14/2017	61	115.4	21.8	21.8	84
088	12/21/2017	17.12	205.47	Male	BLACK	OTHER	12/21/2017	68	130	19.8	19.8	27
089	01/02/2018	14.11	169.3	Female	WHITE	HISP	1/2/2018	64	163.8	28.1	28.1	96
090	01/03/2018	13.89	166.74	Female	WHITE	OTHER	1/3/2018	64	110	18.9	18.9	45
091	01/03/2018	11.7	140.45	Female	WHITE	OTHER	1/3/2018	56	70	15.7	15.7	15
092	01/03/2018	12.47	149.62	Male	WHITE	OTHER	1/3/2018	64	105	18	18	49
093	01/08/2018	14.16	169.95	Female	WHITE	HISP	1/8/2018	64	141	24.2	24.2	88
094	01/08/2018	14.72	176.59	Female	WHITE	HISP	1/8/2018	63	202	35.8	35.8	99
095	01/08/2018	13.87	166.41	Male	WHITE	HISP	1/8/2018	66	108	17.4	17.4	23
096	01/16/2018	11.27	135.2	Female	WHITE	HISP	1/16/2018	56	78	17.5	17.5	48
097	01/16/2018	15.38	184.51	Male	BLACK	OTHER	1/16/2018	71	183	25.5	25.5	92
098	01/16/2018	12.15	145.81	Male		HISP	1/16/2018	60	129	25.2	25.2	96
099	01/17/2018	15.43	185.1	Female	WHITE	HISP	1/17/2018	62	98.7	18.1	18.1	20
103	01/17/2018	13.59	163.12	Female	WHITE	OTHER	1/17/2018	62	95	17.4	17.4	25
104	01/18/2018	15.82	189.83	Male	WHITE	HISP	1/18/2018	67	133.6	20.9	20.9	58
105	01/19/2018	14.09	169.07	Male	WHITE	OTHER	1/19/2018	61	98	18.5	18.5	39
106	01/19/2018	14.81	177.71	Female	WHITE	HISP	1/19/2018	59	110	22.2	22.2	75
107	03/20/2018	12.87	154.45	Male	WHITE	HISP	1/29/2018	59	118.6	24	24	93
108	03/20/2018	14.14	169.72	Female	WHITE	OTHER	3/12/2018	62	115.4	21.1	21.1	69
109	03/20/2018	11.39	136.64	Female		HISP	1/24/2018	53	55.8	14	14	1
110	03/20/2018	11.55	138.55	Female	WHITE	HISP	2/19/2018	61	145.6	27.5	27.5	98
111	03/20/2018	13.06	156.71	Male		HISP	3/7/2018	65	106.2	17.7	17.7	34
112	03/21/2018	15.92	190.98	Female	WHITE	HISP	2/21/2018	61	139.6	26.4	26.4	91
113	03/22/2018	12.81	153.72	Female			3/5/2018	64	111.2	19.1	19.1	56
114	03/26/2018	10.72	128.62	Female	WHITE	HISP	1/23/2018	57	114	24.7	24.7	96
115	03/28/2018	15.96	191.47	Male	BLACK	OTHER	3/28/2018	74	140	18	18	13
116	03/28/2018	13.27	159.21	Female	WHITE	OTHER	3/28/2018	62	104	19	19	52

APPENDIX B (continued)

117	03/29/2018	12.66	151.92	Female	BLACK	OTHER	2/14/2018	65	168	28	28	97
118	03/30/2018	15.12	181.49	Female	WHITE	HISP	3/30/2018	63	147	26	26	91
120	03/30/2018	14.48	173.8	Male	WHITE	OTHER	3/30/2018	63	161	28.5	28.5	97
121	03/30/2018	14.95	179.45	Male	WHITE	HISP	3/30/2018	68	155	23.6	23.6	86
122	04/02/2018	9.36	112.3	Female	WHITE	HISP	4/2/2018	55	74	17.2	17.2	62
123	04/02/2018	12.12	145.41	Male	WHITE	HISP	4/2/2018	55	113	26.3	26.3	97
125	04/03/2018	12.71	152.48	Male			4/3/2018	55	80	18.6	18.6	55
126	04/04/2018	12.61	151.36	Male	WHITE	HISP	4/4/2018	61	93	17.6	17.6	39
127	04/04/2018	16.67	200.05	Male	WHITE	HISP	4/4/2018	68	248	37.7	37.7	99
128	04/06/2018	9.99	119.89	Female	WHITE	HISP	1/22/2018	53	64	16	16	35
130	04/11/2018	12.38	148.6	Male	WHITE	HISP	4/11/2018	62	180	32.9	32.9	99
131	04/11/2018	14.77	177.25	Female	BLACK	OTHER	4/11/2018	65	199.4	33.2	33.2	98
132	04/11/2018	13.45	161.45	Female			4/11/2018	62	104	19	19	50
133	04/11/2018	14.31	171.73	Female	WHITE	HISP	4/11/2018	62	124	22.7	22.7	81
134	04/12/2018	15.97	191.64	Female	WHITE	OTHER	4/12/2018	57	105.4	22.8	22.8	74
135	04/13/2018	12.83	153.99	Female	WHITE	HISP	4/13/2018	57	118	25.5	25.5	94
136	04/13/2018	17.46	209.48	Female	WHITE	HISP	4/13/2018	61	95	17.9	17.9	10
137	04/13/2018	11.82	141.8	Female	WHITE	HISP	4/13/2018	62	156	28.5	28.5	98
138	04/16/2018	13.87	166.41	Female	WHITE	OTHER	4/16/2018	63	102	18.1	18.1	33
139	04/16/2018	17.58	210.96	Female	WHITE	HISP	4/16/2018	66	139	22.4	22.4	65
140	04/16/2018	13	155.96	Female	WHITE	HISP	4/16/2018	63	118.2	20.9	20.9	75
141	04/16/2018	12.86	154.28	Female	WHITE	HISP	4/16/2018	60	100.2	19.6	19.6	67
142	04/17/2018	11.66	139.86	Male	BLACK	OTHER	4/17/2018	60	86	16.8	16.8	96
143	04/18/2018	16.65	199.75	Female	WHITE	HISP	2/14/2018	65	154	25.6	25.6	87
144	04/18/2018	16.26	195.15	Male			4/18/2018	69	120	17.7	17.7	8
145	04/19/2018	15.14	181.72	Female	WHITE	HISP	4/19/2018	61	91	17.2	17.2	12
147	04/23/2018	19.98	239.77	Male	WHITE	OTHER	4/11/2018	69	130	19.2	19.2	6
148	04/24/2018	16.04	192.46	Male	WHITE	HISP	4/24/2018	68	168	25.5	25.5	90
149	04/24/2018	11.8	141.57	Male	WHITE	HISP	4/24/2018	62	126.8	23.2	23.2	93
150	04/25/2018	12.96	155.47	Male	BLACK	OTHER	4/24/2018	63	147	26	26	96
151	05/01/2018	12.21	146.5	Male	WHITE	HISP	5/1/2018	64	128.4	22	22	89
152	05/01/2018	12.27	147.22	Female	WHITE	HISP	5/1/2018	64	223	38.3	38.3	99
153	05/01/2018	15.48	185.79	Female	WHITE	HISP	5/1/2018	65	170	28.3	28.3	95
154	05/02/2018	15.74	188.88	Male	WHITE	HISP	5/2/2018	70	137	19.7	19.7	40
155	05/03/2018	11.22	134.64	Male	NATIVE,WHITE	HISP	5/3/2018	70	178	25.5	25.5	97
156	05/03/2018	14.02	168.18	Male	WHITE	OTHER	5/3/2018	71	127.6	17.8	17.8	26
157	05/07/2018	14.09	169.03	Female	WHITE	HISP	5/7/2018	63	147	26	26	93
158	05/08/2018	17.76	213.13	Male	WHITE	HISP	5/8/2018	68	169	25.7	25.7	86
159	05/08/2018	14.01	168.08	Female	WHITE	HISP	5/8/2018	63	125	22.1	22.1	60
160	05/29/2018	15.17	182.08	Female	WHITE	HISP	5/29/2018	67	244	38.2	38.2	99
161	05/29/2018	9.63	115.52	Female	WHITE	HISP	5/29/2018	53	73	18.3	18.3	74
163	06/05/2018	11.54	138.48	Female	WHITE	HISP	6/5/2018	59	85	17.2	17.2	40
165	06/13/2018	14.96	179.55	Female	WHITE	HISP	6/13/2018	63	150	26.6	26.6	93
166	06/21/2018	14.09	169.1	Male	ASIAN	OTHER	6/21/2018	66	136	21.9	21.9	80
167	06/29/2018	15.11	181.29	Female	WHITE	HISP	6/29/2018	63	193	34.2	34.2	98
168	07/03/2018	13.65	163.75	Male	WHITE	HISP	7/3/2018	64	103	17.7	17.7	30
169	07/17/2018	14.61	175.31	Female	WHITE	HISP	7/17/2018	59	135	27.3	27.3	94
170	07/18/2018	13.57	162.86	Female	WHITE	HISP	7/18/2018	61	92	17.4	17.4	25
171	07/23/2018	11.91	142.92	Female	WHITE	HISP	7/23/2018	60	150	29.3	29.3	98
172	07/25/2018	9.51	114.1	Female	BLACK	OTHER	7/25/2018	55	76	17.7	17.7	67
173	07/30/2018	10.97	131.65	Male	WHITE	HISP	7/30/2018	60	90	17.6	17.6	57
174	08/01/2018	9.62	115.38	Female	WHITE	OTHER	8/1/2018	52	65	16.9	16.9	55
175	08/06/2018	15.33	183.98	Male	WHITE	HISP	7/19/2018	65	130	21.6	21.6	70
176	08/09/2018	14.37	172.39	Female	WHITE	HISP	8/9/2018	60	130	25.4	25.4	91
177	08/09/2018	12.45	149.42	Female	WHITE	HISP	8/9/2018	60	87.4	17.1	17.1	30
178	08/09/2018	14.34	172.12	Male	WHITE	HISP	8/9/2018	68	160	24.3	24.3	91
179	08/21/2018	10.84	130.07	Female	WHITE	HISP	8/21/2018	57	69	17.9	14.9	11
180	08/30/2018	13.51	162.14	Female		HISP	8/30/2018	64	120.6	20.7	20.7	68
181	09/05/2018	15.91	190.92	Female	BLACK	OTHER	9/5/2018	65	249	41.4	41.4	99
183	09/07/2018	12.2	146.4	Male	WHITE	HISP	9/7/2018	62	108.2	19.8	19.8	74
184	09/17/2018	11.24	134.87	Male			9/17/2018	61	148	28	28	98
185	09/20/2018	11.69	140.25	Male	WHITE	HISP	9/20/2018	53	71	17.8	17.8	53
186	09/20/2018	10.52	126.19	Female	WHITE	HISP	9/20/2018	48	73.8	22.5	22.5	92
187	09/20/2018	16.66	199.95	Male	WHITE	HISP	9/20/2018	66	182.6	29.5	29.5	97
188	09/20/2018	15	180.01	Male	BLACK	OTHER	9/20/2018	66	180	29	29	97
189	09/21/2018	13.84	166.05	Male	ASIAN	OTHER	9/21/2018	64	145.2	24.9	24.9	93
190	09/21/2018	11.99	143.84	Male	WHITE	HISP	9/21/2018	62	121	22.1	22.1	90
191	09/21/2018	12.38	148.6	Female	WHITE	HISP	9/21/2018	56	90.6	20.3	20.3	84
192	09/21/2018	13.33	159.9	Male	BLACK	OTHER	9/21/2018	62	97	17.7	17.7	35
193	09/28/2018	12.51	150.08	Male	ASIAN	OTHER	9/28/2018	63	119	21.1	21.1	83
195	10/03/2018	15.54	186.51	Female	BLACK	OTHER	10/3/2018	63	139	24.6	24.6	86
196	10/04/2018	13.31	159.67	Female			10/4/2018	59	141	28.5	28.5	97
197	10/04/2018	11.55	138.61	Female	WHITE	HISP	10/4/2018	56	88.5	19.8	19.8	74
198	10/04/2018	16.5	197.95	Male	WHITE	HISP	9/19/2018	64	110	18.9	18.9	25
199	10/05/2018	13.23	158.72	Female	BLACK	OTHER	10/5/2018	61	115	21.8	21.8	80
200	10/05/2018	14.63	175.61	Female	BLACK	OTHER	10/5/2018	67	224	35.1	35.1	99
201	10/08/2018	10.51	126.16	Male	WHITE	HISP	10/8/2018	51	50	13.5	13.5	1
202	10/10/2018	11.49	137.82	Female	WHITE	HISP	10/10/2018	63	140.6	24.9	24.9	95

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