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Childhood obesity, dental crowding, and dental arch dimensions

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ABSTRACT

Childhood obesity influences the timing of dental development and eruption, with some researchers suggesting that earlier dental development in children and adolescents with obesity may cause increased dental crowding. The aim of this study is to investigate the association of childhood obesity with dental crowding and arch width. Subjects were recruited from the University of Illinois Chicago's College of Dentistry's Orthodontic Clinic ($n=148$) and categorized into healthy, overweight, or obese body mass index (BMI) as defined by the Center of Disease (CDC) for children and adolescents. Mandibular intercanine distance and crowding (anterior tooth size arch length discrepancy (TSALD) score) was measured. Descriptive statistics, Kruskal-Wallis and Spearman's rank correlation were employed to examine differences in dental crowding and intercanine distance by BMI category and percentile. Our results indicate that although there was no association between BMI and dental crowding, there was a significant, moderate positive correlation with intercanine distance ($p<0.001$, $\rho=0.308$). Contrary to some prior work, we see no evidence of increased crowding in children with high BMI. Notably, wider intercanine distances were observed which may instead contribute to decreased crowding. Although the cause of increased intercanine distance is unclear, this may reflect overall greater mandibular growth.

Background

Timing of human skeletal and dental growth and development can be seen as a plastic process operating within a genetically-constrained range. We know that children exposed to adverse conditions such as malnutrition show delayed skeletal and dental maturation (Alvarez and Navia 1989, Alvarez et al., 1990, Alvarez et al., 1993, but see Elamin and Liversidge, 2013). Similarly, over the course of the 20th century average stature had been trending up (Hauspie et al., 2012) and age at puberty had been trending down (Padez and Rocha, 2003; Hosokawa et al., 2012; Eveleth 2017) as children have better access to nutrition and lower disease burden. On the other end of this spectrum, a growing body of literature has demonstrated that children with obesity show precocious skeletal (e.g., Öhrn et al., 2002; Sadeghianrizi et al., 2005; Gordon et al., 2021; Vora et al., 2022) and dental (e.g., Must et al., 2012; Mack et al., 2013; Nicholas et al., 2018a; Cardona Salazar et al., 2022;) development. While there is strong evidence for a positive correlation

between obesity and accelerated dental development (Park et al., 2023), the potential effects on tooth spacing and arch size/shape are largely unresolved.

Globally, approximately 6.7% of children had overweight or obesity in 2010, up from 4.2% in 1990 (Wang et al., 2006) with a general trend toward continuing increases in rates (De Onis et al., 2010). Prevalence of childhood obesity is highest in high gross domestic product (GDP) nations, though it has also been increasing in lower GDP nations (Gonzales-Alvarez et al., 2020). In high income countries, obesity is linearly associated with decreased household income, whereas the opposite

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is true in lower income countries (Broyles et al., 2015). In Europe, prevalence of overweight and obesity among children increased between 1999 and 2016 though there was evidence of some stabilization in the 2010's (Garrido-Miguel et al., 2019), at least prior to the COVID-19 pandemic. The US has among the highest global prevalence of childhood obesity, with approximately one in three children in the United States has overweight or obesity (Kumar and Kelly, 2017). According to National Health Statistics Reports (2021), the prevalence of obesity was 19.7%, affecting 14.7 million children and adolescents from 2017-2020 (Stierman et al., 2021; CDC, 2023). Obesity is a condition of excess adiposity that has numerous associated systemic comorbidities and health risks (Biro and Wien, 2010; Cuda and Censani, 2019) such as: hypertension (Seravalle and Grassi, 2024), diabetes (Verma and Hussain, 2017), mobility issues (Forhan and Gill, 2013; Agaronnik et al., 2021), dyslipidemia (Vekic et al., 2019), and obstructive sleep apnea (Shah and Roux, 2009). It has been demonstrated that children with obesity are more likely to enter adulthood with the same nutritional status (Romero-Corral et al., 2010; Simmonds et al., 2016).

A growing body of literature has shown that children with obesity have accelerated skeletal (e.g., Öhrn et al., 2002; Sadeghianrizi et al., 2005; Gordon et al., 2021; Vora et al., 2022) and dental maturation (e.g. Must et al., 2012; Mack et al., 2013; Nicholas et al., 2018a; Cardona Salazar et al., 2022; for a recent review and meta-analysis see Park et al., 2023). Children with obesity erupt their teeth, on average, 6 months to one year earlier than those without (Nicholas et al., 2018b). Furthermore, it has been reported that children with obesity have 1.44 more teeth erupted, on average, than nonobese children after adjusting for gender, age, and race (Must et al., 2012). Accelerated dental eruption has been posited to lead to an earlier need for orthodontic treatment (Nicholas et al., 2018a). Mack and colleagues (2013) have also suggested that early dental eruption in children with obesity may lead to increased incisor crowding. However, these hypotheses have largely not been systematically examined and rely upon an assumption that obesity-accelerated dental development leads to increased decoupling (or modularity) of skeletal and dental development.

During growth, the skeletal relationship between the maxilla and mandible is essential for facial harmony and balance. Dental crowding is a condition where tooth size and jaw size is presumed to be discordant, resulting in "imbrication and rotation

of teeth" (Howe et al., 1983), generating hard to clean areas that may contribute to dental caries, poor periodontal health, and an unaesthetic appearance (El-Mangoury et al., 1987; Hafez et al., 2012; Alsulaiman et al., 2018). While there is unfortunately not one standardized definition, dental crowding is frequently categorized as, or similar to: ideal (0-1mm), mild (1-3 mm), moderate (4-7 mm), and severe (7-10 mm) (Little, 1975; Duncan et al., 2016; Proffit et al., 2018). The diagnosis of the amount of dental crowding plays an important role in treatment.

While it has been suggested that children with obesity may have increased dental crowding (Mack et al., 2013), there has been little published work in this area. Jasim and colleagues (2016) assessed lower incisor crowding as present ($>2\text{mm}$) or absent ($<2\text{mm}$). They found a statistically significant association between BMI (body mass index) and dental crowding, indicating a higher prevalence of crowding in males and females with overweight BMI, 76.56% and 74.55% respectively. Thomaz et al. (2010), who initially considered that malnutrition may contribute to dental crowding, unexpectedly discovered a greater prevalence of dental crowding among high BMI-for-age than among normal BMI-for-age adolescents; however, this association did not hold when they controlled for confounders.

A further consideration in terms of jaw growth is intercanine distance. Intercanine distance is a transverse dental measurement taken from the cusp tip to the contralateral cusp tip (Burke et al., 1998). Studies have shown that maintenance of the intercanine distance is critical to the stability of orthodontic treatment (Tweed, 1945; Burke et al., 1998). In humans, intercanine distance has been shown to be associated with overall facial width (Andria and Dias 1978; Hasanreisoglu et al., 2005) and may thus be seen as representing an aspect of overall timing of transverse skeletal growth. Mandibular intercanine width has been shown to be stable once the four lower incisors erupted by the age of 8 years (Bishara et al., 1997). Thus, having this dental measurement gives insight into the mandibular growth prior to completion of skeletal growth. Previous studies have reported an unclear relationship between mandibular intercanine distance and incisor crowding in children and adolescents. Sayin and Turkkahraman (2004) reported that a significant inverse correlation was found between crowding and deciduous intercanine width in the early mixed dentition, while Indriyanti and colleagues (2018) indicated that there

was no significant association between crowding and deciduous intercanine width. In both studies, permanent canines were not yet erupted. Furthermore, a longitudinal study assessed mandibular arch changes during adolescence and found that as the arch became squarer, the increased intercanine width reduced the risk of crowding (Zigante et al., 2019).

Crowding and intercanine distance reflect important aspects of the development of the dental arch; increased crowding and decreased intercanine distances can result in a less functional anterior dentition. This, together with the social stigma that is sometimes associated with unaesthetic anterior teeth, may lead to increased need for orthodontic treatment. Dental crowding can also negatively impact an individual's ability to effectively clean their teeth and prevent tooth decay. With contemporary high rates of childhood obesity, it is important to explore the potential association between obesity and dental crowding.

The primary aim of this study was to examine the association of body mass index with dental crowding and arch dimensions in children and adolescents. Our null hypothesis was that there is no association between high BMI status and crowding or arch dimensions.

Materials and methods

Sample

Cross sectional data was collected at the University of Illinois Chicago's College of Dentistry. Data were comprised of both prospective and retrospective components. The prospective samples were gathered from both the Departments of Orthodontics and Pediatric Dentistry. In total, $n=105$ subjects

were prospectively recruited to participate during their initial records appointments; after screening for inclusion/exclusion criteria (Table 1), $n=79$ subjects were able to be included in this study. The Orthodontic sample was collected as a part of the study, "Linking Malocclusion and Body Mass Via Genetic Variants Within the Hippo Signaling Pathway and Dietary Factors" (IRB 2017-1276). The Pediatric Dentistry sample was collected as a part of the study, "The Influence of Oral Inflammation on Timing of Dental Eruption" (IRB: 2017-0956). The retrospective data ($n=69$) represents patients at the University of Illinois Chicago's Department of Orthodontics who had intraoral scans and height and weight data collected between the dates of 09/01/2003 - 6/1/2018 (IRB: 2017-1341) during the normal course of orthodontic treatment.

Subjects aged 9.0-17.9 years with no prior history of orthodontic treatment were included in this study. The inclusion and exclusion criteria for this study are listed in Table 1. Subjects that had impacted lower canines or unerupted canines, or where lower incisor crowding and/or intercanine distance could not be calculated were removed from the sample analysis.

At subjects' initial appointment, data collection included: demographics (age, race, ethnicity, sex); height; weight; initial panoramic and cephalometric radiographs; and an intraoral scan for 3D model analysis. Using the CDC BMI Calculator for Child and Teen, BMI percentile was computed, accounting for age and sex, and subjects were categorized into Underweight, Healthy, Overweight, and Obese (BMI Calculator for Child and Teen, 2022).

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Children aged 9-18 years	Poor oral health
Healthy (no documented systemic diseases)	Craniofacial anomalies
Permanent lower incisors and canines present	Congenitally missing or supernumerary teeth
No previous orthodontic treatment	Currently taking medications
	Metabolic diseases
	Active carious lesions

Variables measured

Dental crowding was determined by using two measurements: mandibular anterior tooth size arch length discrepancy (TSALD; Bishara et al., 1989) and intercanine distance. Measurements were calculated by using OrthoCAD® Software (Align Technology, San Jose, CA) on the corresponding 3D models of each subject and expressed in millimeters (mm). Lower incisor crowding was calculated using anterior tooth size arch length discrepancy (TSALD), where the sum of the mesio-distal widths of the permanent canines, laterals and centrals were compared to arch length (Bishara et al., 1989). Intercanine distance was measured in millimeters from canine cusp tip to contralateral canine cusp tip.

Malocclusion status was examined as a potential confounding variable. Dolphin Imaging Software (Dolphin Imaging and Management Solutions, Los Angeles, CA) was used to calculate skeletal malocclusion for the prospective sample ($n=79$). Measurements were taken from previously traced cephalograms when available or computed for subjects that did not proceed with treatment. Using Steiner's cephalometric analysis (Steiner, 1953; Steiner, 1959; Steiner, 1960), subjects were categorized into the corresponding skeletal malocclusions: Class I, II or III.

Statistical Analyses

Descriptive statistics were employed to determine mean and standard deviation for age, dental crowding, and intercanine distance. Sample demographics for sex, and ancestry were examined for frequency. BMI parameters were measured as both categorical data (Underweight, Healthy, Overweight, Obese) and continuous data (BMI percentile). Dental crowding and intercanine distances were considered continuous data. Lastly, skeletal malocclusion classification was categorized into Class I, Class II, and Class III. Class I is considered a "normal" skeletal relationship between the maxilla and mandible; Class II has a protrusive maxilla and/or retrusive mandible (maxillary prognathism); and Class III is characterized by a protrusive mandible and/or retrusive maxilla (mandibular prognathism) (Proffit et al., 2018).

Kruskal-Wallis and Spearman's Rank Correlation were used to examine the differences of dental crowding, intercanine distance, and skeletal malocclusion across BMI categories and percentiles for non-parametric data. Partial correlation analyses were conducted to order to control for confounding variables such as sex and age.

Results

Our sample subjects who met the inclusion criteria ($n=148$) had a mean age of 13.72 years (SD 2.01yrs). Of the included sample, the BMI categorization revealed: $n=46$ Obese (31%), $n=27$ Overweight (18%), $n=74$ Healthy (50%), and $n=1$ Underweight (1%). Rates of obesity and overweight were slightly higher in males than in females (Fig. 1).

Among the total sample, mean crowding measured 2.08mm (SD 2.71mm) and mean intercanine distance measured 28.1mm, (SD 2.69mm; Table 2). A greater frequency of skeletal Class II malocclusion (maxillary prognathism; $n=36$) was observed, representing 46% of the sample, followed by Class I ($n=24$) and Class III (mandibular prognathism; $n=18$). Due to the small number of underweight subjects ($n=1$), this subsample was removed from further analyses.

There was no association between BMI percentile and crowding ($p=0.315$). There was a statistically significant positive correlation between BMI percentile and intercanine distance ($p<0.001$, $\rho=0.308$) whereby higher BMI scores corresponded with wider intercanine distances (Fig. 2). This relationship holds true when correcting for the effects of age, sex, or Angle (skeletal malocclusion) classification ($p<0.001$, partial correlation= 0.32).

Given the paucity of previously published data, we retrospectively analyzed effect size in our sample to estimate power. We found very small effect sizes when conducting pairwise comparisons of the BMI groups by anterior TSALD score (healthy - obese: Cohen's Kappa $d=-0.014$; healthy - overweight: Cohen's Kappa $d=0.027$; overweight - obese: Cohen's Kappa $d=0.037$). Using this effect size data to then calculate sample size yields extremely large sample size requirements (11,468 - 80,092).

Discussion

Despite some prior work postulating that earlier tooth eruption found in children with obesity may lead to crowding (Mack et al., 2013; but see Soares Bonato et al. (2022)), our study reveals that in our sample, we see adequate space for tooth eruption in the mandibles of children with obesity and that no differences are seen in amount of dental crowding across children with and without obesity. This is in line with the finding of Soares Bonato and colleagues (2022), who report similar levels of crowding in adolescents with and without obesity at their baseline timepoint. We suggest that this may indicate that skeletal maturation follows similar patterns of acceleration as dental maturation (Gordon

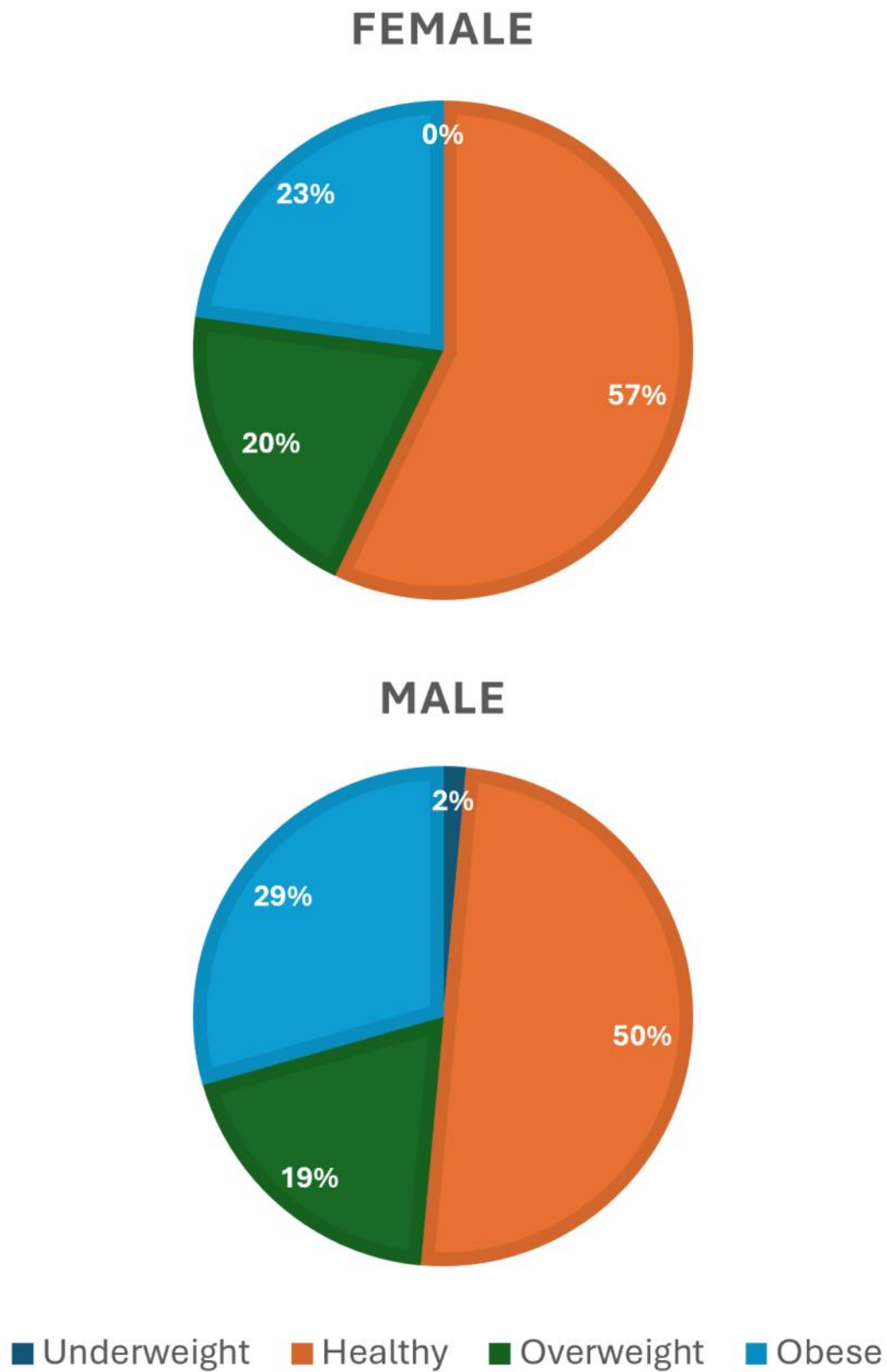


Figure 1. Pie chart of BMI category distribution in the sample by sex. It can be seen that the male sub-sample shows slightly higher rates of overweight and obesity. BMI categories as per CDC BMI cut-offs (CDC, 2022)

Table 2. Descriptive statistics of the sample

	<i>n</i>	Age (Yrs)		Incisor crowding (mm)		Inter canine distance (mm)	
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Males	68	13.50	1.93	1.84	2.67	28.85	2.54
Females	80	13.29	1.95	2.30	2.75	27.48	2.66
Total	148	13.39	1.94	2.08	2.71	28.10	2.69

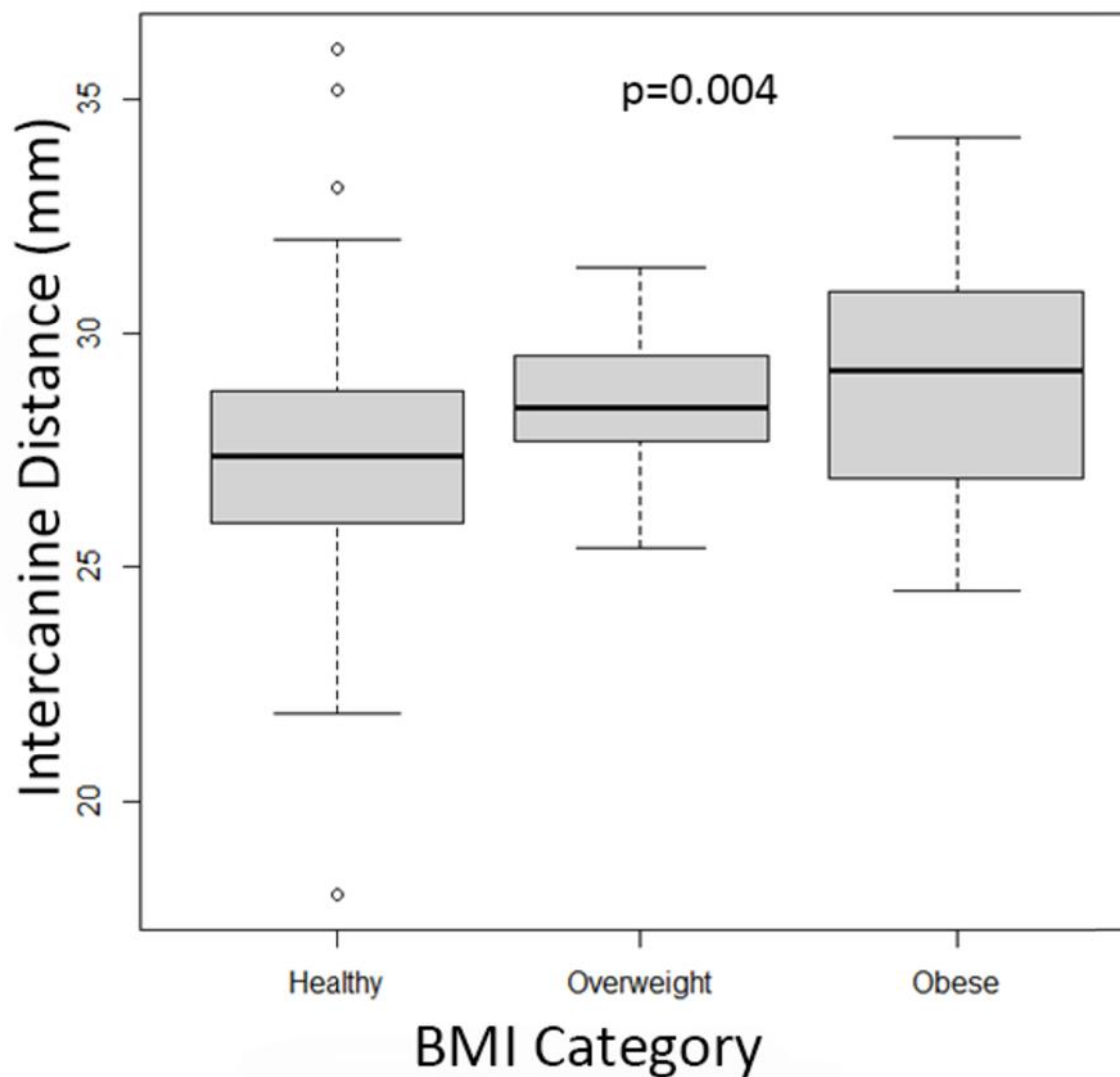


Figure 2. Boxplot depicting intercanine distance by BMI category. There were statistically significant differences between the groups ($p=0.004$) driven by differences between participants with overweight/obesity and those with a healthy BMI. As BMI percentile increases, so too does intercanine distance.

et al., 2021), allowing for adequate space for the permanent teeth. Although the wide age range of 9-18 years in our sample means that not all subjects are skeletally mature, arch length stabilizes once the lower incisors and canines have erupted (Bishara et al., 1997).

It should be noted that our results are contrary to those seen by Jasim and colleagues (2016), who found a greater presence of dental crowding in children with obesity. This may be explained by differences in the population composition of our samples, the wider age range in the present study, or the differences in how dental crowding was measured. This previous study (Jasim et al., 2016), scored the condition as present/absent, whereas in the current study TSALD was used to produce a continuous measurement of crowding. However, switching to a presence/absence approach does not yield a statistically significant difference in our sample. Furthermore, and Thomaz and colleagues (2010) found evidence of more frequent dental crowding (scored again as present/absent) in children with high BMI, but this association disappeared when adjusted for confounding variables. Given that our power calculations yielded very small effect sizes, it seems possible that with large enough sample sizes, there may be differences in amount of crowding by BMI group, but that these differences may be so subtle as to potentially not be clinically or biologically meaningful.

In our sample, we saw a significant association between BMI and intercanine distance ($p < 0.001$, $\rho = 0.0308$) indicating an increase in intercanine distance with higher BMI percentiles (that is to say, a wider anterior mandibular dental arch). This finding supports the study by Maeda et al. (2011), that found dental arch widths were significantly larger in obese than non-obese obstructive sleep apnea (OSA) patients.

Furthermore, there may be influence from soft tissue contributing to the findings in our study that showed increased intercanine distance in individuals with higher BMI percentiles. The increase in lower canine distance could be related to a larger tongue size. Previous studies examining tongue size in adult patients with both obesity and OSA, found larger tongue sizes in obese subjects (Maeda et al., 2011). Increased intercanine distance may also reflect accelerated facial skeletal growth. Prior work on skeletal size, shape, and timing of growth in children with obesity has focused on lateral cephalograms (Ohrn et al., 2002; Sadeghianrizi et al., 2015; Gordon et al., 2021; Vora et al., 2022) which lack a transverse (width) component. It may

be that both mandibular width and mandibular length are either absolutely larger or are growing at an accelerated rate in children with obesity. Future studies utilizing CBCT (cone beam computed tomography) data may be required to clarify this relationship.

In our study, we see no association between BMI and skeletal malocclusion as assessed by Angle Classification. In a study by Vora et al., (2022), obese patients exhibited relatively prognathic mandibles, which may be indicative of Class III skeletal relationship. Other work has shown a greater mandibular length (condylion to pogonion) in children with obesity (Ohrn et al., 2002; Gordon et al., 2021). Our broad age range and relatively small sample size may be preventing us from detecting subtle differences in skeletal malocclusion across BMI categories, particularly if this malocclusion arises later in adolescent craniofacial growth.

Some limitations of our current study include the relatively small sample size and uneven distribution by age, sex, and ancestry. It is possible that patterns of difference in dental crowding may be subtle and only apparent with larger samples. Due to the lack of prior published data on mean and standard deviation for TSALD scores in children with and without obesity, we were unable to conduct a power analysis prior to undertaking the current study. Our retrospective power analysis yielded small estimated effect sizes, however. It should also be noted that the relatively wider intercanine distances seen in children with obesity would seem to imply that larger samples may be unlikely to detect greater crowding in this group. Prior research has also indicated an association between orthodontic treatment need (i.e., factors such as crowding and other forms of malocclusion) and low socioeconomic status (Borzabadi-Farahani et al., 2011). Unfortunately, we were unable to obtain socioeconomic status data for our sample, but this is an area ripe for future investigation. Finally, while our sample had some diversity in ancestry group, we likely did not have large enough sample sizes to detect potential differences across groups. There is prior research suggesting population-level variation in dental spacing/crowding (Portelli et al., 2012), thus more work in large, diverse samples may be warranted.

It is important to note that, although this study did not yield an association between obesity and lower incisor crowding, we did observe differences in arch width (intercanine distance) and obesity has been previously shown to have a role in dental and skeletal maturation (Park et al., 2023). Life his-

tory theory emphasizes the potential role of nutrition (and/or other endocrine-related factors) in growth and development, particularly at transitions between stages (Bateson et al., 2004; Kuzawa, 2007). Developmental plasticity in the timing of transitions between life history stages can, for example, help to explain secular changes in stature and puberty (Bateson et al., 2004; Hochberg, 2011).

Our sample overlaps a key transition from the juvenile to adolescent stages. The lack of greater dental crowding, together with increased intercanine distances, would support the hypothesis that both skeletal and dental developmental timing is shifted in children with obesity. Our data do not support a decoupling (increased modularity) across skeletal and dental development in children with obesity. From a functional standpoint, it would seem optimal for dental and skeletal maturation to remain well-aligned even in individuals experiencing either higher or lower than typical levels of nutritional intake. Additional research, particularly with longitudinal data, will be needed to fully parse the relationship between rate/timing of dental and skeletal craniofacial growth in children with obesity.

Conclusions

Our results indicate a complex picture with regards to dental crowding and arch size among a population of children and adolescents with health, overweight, and obese BMIs recruited from an urban US healthcare setting (University of Illinois Chicago College of Dentistry). We confirm prior research that showed increased intercanine distances in children with obesity. We do not find evidence that there is an association between high BMI and crowding, and our data suggest that even if such a pattern were to exist it is likely subtle. However, patterns of crowding in high BMI children may vary by population and thus ideally further studies, employing diverse samples, are needed to more fully examine this question.

Ethics approval: University of Illinois Chicago IRB approval: IRB 2017-1276, IRB: 2017-0956

Availability of Data and Material: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request

Conflict of Interest: The authors declare that they have no competing interests

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3

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14

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