Childhood obesity, dental crowding, and dental arch dimensions

Kayla Yip[1], Flavio Sanchez[1], Maria Therese Galang-Boquiren[1], Jennifer Caplin[2], Steven F. Miller[3], Crystal Ortiz[4], Christina L. Nicholas[*,1,5]

[1] Department of Orthodontics, University of Illinois Chicago, Chicago, IL 60612-7211, [2]Department of Preventive, Pediatric, and Community Dentistry, University of New England, Portland, ME 04103, [3] Department of Oral Medicine and Diagnostic Sciences, University of Illinois Chicago, Chicago, IL 60612-7211, [4] Community First Medical Center, Chicago, IL 60634, [5] Department of Anthropology, University of Illinois Chicago, Chicago, IL 60612-7211

Keywords: Childhood obesity, dental crowding, intercanine distance

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

*Correspondence to:
Christina L. Nicholas
Department of Orthodontics
801 S. Paulina St. M/C 841
University of Illinois Chicago
Chicago, IL 60612-7211, USA
clnichol@uic.edu

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 (>2mm) or absent (<2mm). 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

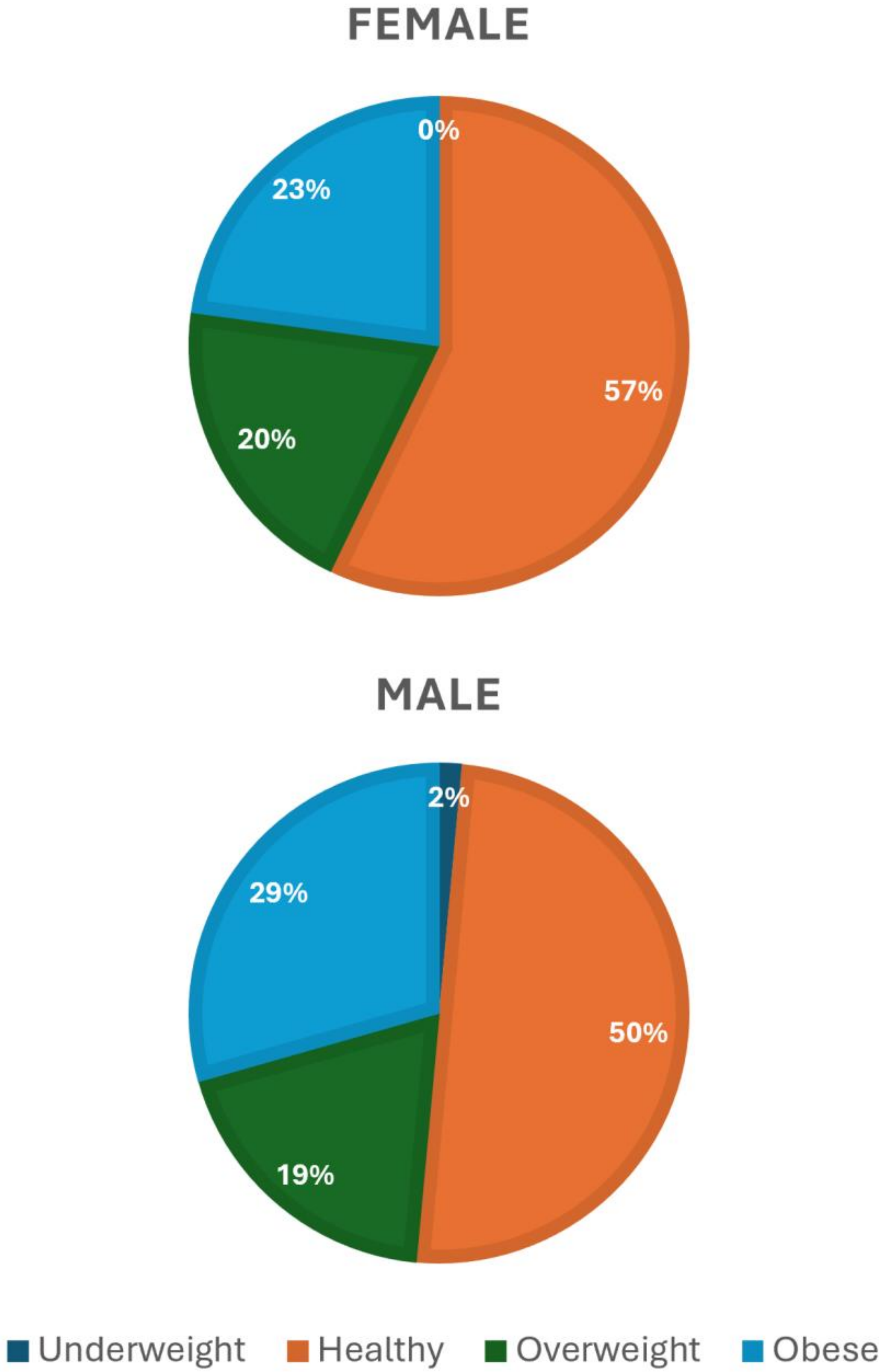

Figure 1. Pie chart of BMI category distribution in the sample by sex. It can be seen that the male sub-sample shows slightly higher rates of overweight and obesity. BMI categories as per CDC BMI cut-offs (CDC, 2022)

Table 2. Descriptive statistics of the sample

		Age (Yrs)		Incisor crowding (mm)		Intercanine distance (mm)	
	n	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

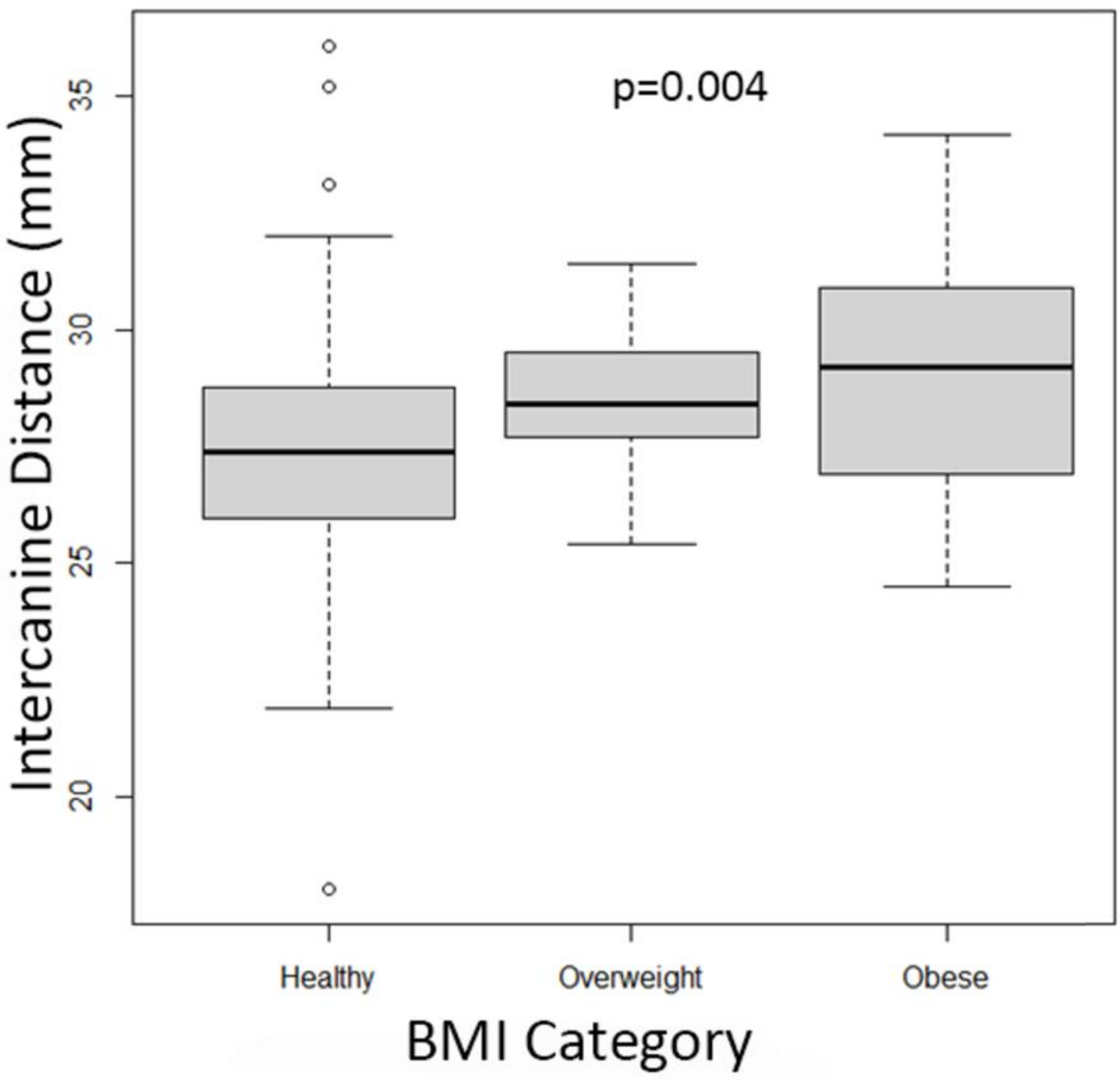

Figure 2. Boxplot depicting intercanine distance by BMI category. There were statistically significant differences between the groups (p=0.004) driven by differences between participants with overweight/obesity and those with a healthy BMI. As BMI percentile increases, so too does intercanine distance.

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 history 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

Funding: American Association of Orthodontists Foundation (AAOF) - Robert E. Gaylord Teaching Fellowship Award (PI: Caplin); American Association of Orthodontists Foundation (AAOF) - Biomedical Research Award (PI: Nicholas)

Authors Contributions: Kayla Yip assisted with project conceptualization, data collection and write up. Flavio Sanchez was involved with project conceptualization, design, and write-up. Steven Miller was involved in project design, data analysis, and write up. Jennifer Caplin assisted with project conceptualization, design, and write up. Maria Therese Galang-Boquiren assisted with project design and write up. Crystal Ortiz assisted with data collection and data analysis. Christina Nicholas led project conceptualization and design, supervised project write up, and was responsible for data analysis.

Acknowledgements: We would like to thank Nish Shivani for his assistance with retrieving data from the electronic health records system. We would also like to thank our reviewers for their helpful feedback which has led to an improved manuscript.

REFERENCES

Agaronnik, N.D., Lagu, T., DeJong, C., Perez-Caraballo, A., Reimold, K., Ressalam, J. and Iezzoni, L.I. 2021. "Accommodating patients with obesity and mobility difficulties: observations from physicians." *Disability and health journal* 14, no. 1: 100951. https://doi.org/10.1016/j.dhjo.2020.100951.

Alsulaiman, A.A., Kaye, E., Jones, J., Cabral, H., Leone, C., Will, L., Garcia, R. 2018. "Incisor malalignment and the risk of periodontal disease progression". *American Journal of Orthodontics and Dentofacial Orthopedics* 153: 512-22. https://doi.org/10.1016/j.ajodo.2017.08.015.

Alvarez, J.O., Navia, J.M. 1989. "Nutritional status, tooth eruption, and dental caries: a review." *The American Journal of Clinical Nutrition* 49, no. 3:417-26. https://doi.org/10.1093/ajcn/49.3.417.

Alvarez, J.O., Eguren, J.C., Caceda, J. and Navia, J.M. 1990. "The effect of nutritional status on the age distribution of dental caries in the primary teeth". *Journal of dental research* 69, no. 9: 1564-1566. https://doi.org/10.1177/00220345900690090501.

Alvarez, J.O., Caceda, J., Woolley, T.W., Carley, K.W., Baiocchi, N., Caravedo, L., Navia, J.M. 1993. "A longitudinal study of dental caries in the primary teeth of children who suffered from infant malnutrition." *Journal of Dental Research* 72, no. 12: 1573-6. https://doi.org/10.1177/00220345930720120701.

Andria, L.M., Carlos Días, J.O. 1978. “Relation of maxillary and mandibular intercuspid widths to bizygomatic and bigonial breadths.” *The Angle Orthodontist* 48, no. 2: 154-62. https://doi.org/10.1043/0003-3219(1978)048%3C0154:ROMAMI%3E2.0.CO;2.

Bateson, P., Barker, D., Clutton-Brock, T., Deb, D., D'Udine, B., Foley, R.A., Gluckman, P., Godfrey, K., Kirkwood, T., Lahr, M.M., McNamara, J. 2024. “Developmental plasticity and human health.” *Nature* 430, no. 6998: 419-21. DOI:10.1038/nature02725.

Biro, F.M., Wien, M. 2010. “Childhood obesity and adult morbidities.” *The American Journal of Clinical Nutrition* 91: 1499S-505S. https://doi.org/10.3945/ajcn.2010.28701B.

Bishara, S.E., Jakobsen, J.R., Treder, J.E., Stasl, M.J. 1989. “Changes in the maxillary and mandibular tooth size-arch length relationship from early adolescence to early adulthood: a longitudinal study.” *American Journal of Orthodontics and Dentofacial Orthopedics* 95: 46-59. https://doi.org/10.1016/0889-5406(89)90135-2

Bishara, S.E., Ortho, D., Jakobsen, J.R., Treder, J., Nowak, A.1997. “Arch width changes from 6 weeks to 45 years of age.” *American Journal of Orthodontics and Dentofacial Orthopedics* 111: 401-9. https://doi.org/10.1016/S0889-5406(97)80022-4.

BMI Calculator for Child and Teen. (2022, November 3). Centers for Disease Control and Prevention. https://www.cdc.gov/healthyweight/bmi/calculator.html.

Borzabadi-Farahani, A., Eslamipour, F., Asgari, I. 2011. “Association between orthodontic treatment need and caries experience.” *Acta Odontologica Scandinavica* 69, no. 1: 2-11. https://doi.org/10.3109/00016357.2010.516732.

Burke, S.P., Silveira, A.M., Goldsmith, L.J., Yancey, J.M., Van Stewart, A., Scarfe, W.C. 1998. “A meta-analysis of mandibular intercanine width in treatment and postretention.” *The Angle Orthodontist* 68: 53-60. https://doi.org/10.1043/0003-3219(1998)068%3C0053:AMAOMI%3E2.3.CO;2.

Childhood Obesity Facts | Overweight & Obesity | CDC. (n.d.). https://www.cdc.gov/obesity/data/childhood.html

Cardona Salazar, D.K., Caplin, J., Whyms, P., Alrayyes, S., Nikita, E., Galang-Boquiren, M.T., Truskoski, D., Naqvi, A., Nicholas C.L. 2022. “Nutrition, obesity, and dental development in young adolescents in Chicago.” *American Journal of Human Biology* 34: e23721. https://doi.org/10.1002/ajhb.23721.

Cuda, S.E., Censani, M. 2019. “Pediatric obesity algorithm: a practical approach to obesity diagnosis and management.” *Frontiers in Pediatrics* 6: 431. https://doi.org/10.3389/fped.2018.00431.

Duncan, L.O., Piedade, L., Lekic, M., Cunha, R.S., Wiltshire, W.A. 2016. “Changes in mandibular incisor position and arch form resulting from Invisalign correction of the crowded dentition treated nonextraction.” *The Angle Orthodontist* 86: 577-83. https://doi.org/10.2319/042415-280.1.

Elamin, F., Liversidge, H.M. 2013. “Malnutrition has no effect on the timing of human tooth formation.” *PloS one*. 2013 8, no. 8: e72274. https://doi.org/10.1371/journal.pone.0072274

El-Mangoury, N.H., Gaafar, S.M., Mostafa, Y.A. 1987. “Mandibular anterior crowding and periodontal disease.” *The Angle Orthodontist* 57: 33-8. https://doi.org/10.1043/0003-3219(1987)057%3C0033:MACAPD%3E2.0.CO;2.

Eveleth, P.B. 2017. “Timing of menarche: Secular trend and population differences.” In: School-age pregnancy and parenthood. pp. 39-52. Routledge.

Forhan, M., Gill, S.V. 2013. “Obesity, functional mobility and quality of life.” *Best Practice & Research Clinical Endocrinology & Metabolism*. 27: 129-37. https://doi.org/10.1016/j.beem.2013.01.003.

Gordon, L.A., Miller, S.F., Caplin, J., Galang-Boquiren, M.T., Alrayyes, S., Nicholas, C.L. 2021. “Childhood obesity may accelerate timing of human facial growth.” *Archives of Oral Biology* 121: 104964. https://doi.org/10.1016/j.archoralbio.2020.104964.

Hafez, H.S., Shaarawy, S.M., Al-Sakiti, A.A., Mostafa, Y.A. 2012. “Dental crowding as a caries risk factor: a systematic review.” *American Journal of Orthodontics and Dentofacial Orthopedics* 142: 443-50. https://doi.org/10.1016/j.ajodo.2012.04.018.

Hasanreisoglu, U., Berksun, S., Aras, K., Arslan, I. 2005. “An analysis of maxillary anterior teeth: facial and dental proportions.” *The Journal of Prosthetic Dentistry* 94, no. 6: 530-8. https://doi.org/10.1016/j.prosdent.2005.10.007.

Hauspie, R.C., Vercauteren, M., Susanne, C. 1997. “Secular changes in growth and maturation: an update.” *Acta Paediatrica* 86, no. S423: 20-7. doi: 10.1111/j.1651-2227.1997.tb18364.x.

Hochberg, Z.E. 2011. “Developmental plasticity in child growth and maturation." *Frontiers in Endocrinology* 29, no. 2: 41. https://doi.org/10.3389/fendo.2011.00041.

Hosokawa, M., Imazeki, S., Mizunuma, H., Kubota, T., Hayashi, K. 2012. "Secular trends in age at menarche and time to establish regular menstrual cycling in Japanese women born between 1930 and 1985." *BMC Women's Health* 12: 1-6.

Howe, R.P., McNamara, Jr. J.A., O'Connor, K.A. 1983. "An examination of dental crowding and its relationship to tooth size and arch dimension." *American Journal of Orthodontics* 83: 363-73. https://doi.org/10.1016/0002-9416(83)90320-2.

Indriyanti, R., Efendi, S.H., Maskoen, A.M., Riyanti, E. 2018. "Predisposing factors analysis of mandibular anterior tooth crowding in the mixed dentition period by the tooth size and dental arch width." *Padjadjaran Journal of Dentistry* 30: 208-14.

Jasim, E.S., Garma, N.M., Nahidh, M. 2016. "The association between malocclusion and nutritional status among 9-11 years old children." *Iraqi Orthodontic Journal* 12:13-4.

Kumar, S., Kelly, A.S. 2017. "Review of childhood obesity: from epidemiology, etiology, and comorbidities to clinical assessment and treatment." In: Mayo Clinic Proceedings Vol. 92, No. 2: 251-265. Elsevier.

Kuzawa, C.W. 2007. "Developmental origins of life history: growth, productivity, and reproduction." *American Journal of Human Biology* 19, no. 5: 654-61. https://doi.org/10.1002/ajhb.20659.

Little, R.M. 1975. "The irregularity index: a quantitative score of mandibular anterior alignment." *American Journal of Orthodontics* 68: 554-63. https://doi.org/10.1016/0002-9416(75)90086-X.

Mack, K.B., Phillips, C., Jain, N., Koroluk, L.D. 2013. "Relationship between body mass index percentile and skeletal maturation and dental development in orthodontic patients." *American Journal of Orthodontics and Dentofacial Orthopedics* 143: 228-34. https://doi.org/10.1016/j.ajodo.2012.09.015.

Maeda, K., Tsuiki, S., Isono, S., Namba, K., Kobayashi, M., Inoue, Y. 2012. "Difference in dental arch size between obese and non-obese patients with obstructive sleep apnoea." *Journal of Oral Rehabilitation* 39: 111-7. https://doi.org/10.1111/j.1365-2842.2011.02243.x.

Must, A., Phillips, S.M., Tybor, D.J., Lividini, K., Hayes, C. 2012. "The association between childhood obesity and tooth eruption." *Obesity* 20: 2070-4. https://doi.org/10.1038/oby.2012.23

Nicholas, C.L., Kadavy, K., Holton, N.E., Marshall, T., Richter, A., Southard, T. 2018a. "Childhood body mass index is associated with early dental development and eruption in a longitudinal sample from the Iowa Facial Growth Study." *American Journal of Orthodontics and Dentofacial Orthopedics* 154: 72-81. https://doi.org/10.1016/j.ajodo.2017.10.033.

Nicholas, C.L., Thalji, G., Richter, A. 2018b. "Childhood obesity and accelerated timing of dental development: A critical review." *Forensic Anthropology* 1, no 3: 170-9. https://doi.org/10.5744/fa.2018.0018.

Öhrn, K., Al-Kahlili, B., Huggare, J., Forsberg, C.M., Marcus, C., Dahllöf, G. 2002. "Craniofacial morphology in obese adolescents." *Acta Odontologica Scandinavica* 60: 193-7. https://doi.org/10.1080/000163502760147936.

Padez, C., Rocha, M.A. 2003. "Age at menarche in Coimbra (Portugal) school girls: a note on the secular changes." *Annals of Human Biology* 30, no. 5: 622-32. https://doi.org/10.1080/03014460310001592650.

Park, T.H., Lin, J.H., Chung, C.H., Zheng, Z. and Li, C., 2023. "The skeletal and dental age advancements of children and adolescents with overweight and obesity: A systematic review and meta-analysis." *American Journal of Orthodontics and Dentofacial Orthopedics* 164, no. 3: 325-339. https://doi.org/10.1016/j.ajodo.2023.05.022.

Portelli, M., Matarese, G., Militi, A., Cordasco, G., Lucchese, A. 2012. "A proportional correlation index for space analysis in mixed dentition derived from an Italian population sample." *European Journal of Paediatric Dentistry* 13, no. 2: 113-7.

Proffit, W.R., Fields, Jr. H.W., Larson, B. 2018. Contemporary Orthodontics. Mosby.

Romero-Corral, A., Caples, S.M., Lopez-Jimenez, F., Somers, V.K. 2010. "Interactions between obesity and obstructive sleep apnea: implications for treatment." *Chest* 137: 711-9. https://doi.org/10.1378/chest.09-0360.

Sadeghianrizi, A., Forsberg, C.M., Marcus, C., Dahllöf, G. 2005. "Craniofacial development in obese adolescents." *The European Journal of Orthodontics* 27: 550-5. https://doi.org/10.1093/ejo/cji048.

Sayin, M., Türkkahraman, H. 2004. "Factors contributing to mandibular anterior crowding in the early mixed dentition." *The Angle Orthodontist* 74: 754-8. https://doi.org/10.1043/0003-3219(2004)074%3C0754:FCTMAC%3E2.0.CO;2.

Seravalle, G. and Grassi, G., 2024. "Obesity and hypertension." *Obesity: Clinical, Surgical and Practical Guid*e. 65-79.

Shah, N., Roux, F. 2009. "The relationship of obesity and obstructive sleep apnea." *Clinics in Chest Medicine* 30: 455-65. https://doi.org/10.1016/j.ccm.2009.05.012.

Simmonds, M., Llewellyn, A., Owen, C.G., Woolacott, N. 2016. "Predicting adult obesity from childhood obesity: a systematic review and meta-analysis." *Obesity Reviews* 17: 95-107. https://doi.org/10.1111/obr.12334.

Soares Bonato, R.C., Abel Mapengo, M.A., de Azevedo-Silva, L.J., Janson, G., de Carvalho Sales-Peres, S.H. 2022. "Tooth movement, orofacial pain, and leptin, interleukin-1β, and tumor necrosis factor–α levels in obese adolescents." *The Angle Orthodontist* 92: 95-100. https://doi.org/10.2319/011321-44.1.

Steiner, C.C. 1953. "Cephalometrics for you and me." *American Journal of Orthodontics* 39: 729-55. https://doi.org/10.1016/0002-9416(53)90082-7.

Steiner, C.C. 1959. "Cephalometrics in clinical practice." *The Angle Orthodontist* 29: 8-29. https://doi.org/10.1043/0003-3219(1959)029%3C0008:CICP%3E2.0.CO;2.

Steiner, C.C. 1960. "The use of cephalometrics as an aid to planning and assessing orthodontic treatment: report of a case." *American Journal of Orthodontics* 46: 721-35. https://doi.org/10.1016/0002-9416(60)90145-7.

Stierman, B., Afful, J.B.A., Carroll, M.D., Chen, T., Davy, O., Fink, S., Fryar, C.D., Gu, Q., Hales, C.M., Hughes, J., Ostchega, Y., Storandt, R.J., Akinbami, L.J. 2021. "NHSR 158. National Health and Nutrition Examination Survey 2017–March 2020 Pre-pandemic Data Files." *National Health Statistics Reports*.

Thomaz, E.B., Cangussu, M.C., da Silva, A.A., Assis, A.M. 2010. "Is malnutrition associated with crowding in permanent dentition?" *International Journal of Environmental Research and Public Health* 7: 3531-44. https://doi.org/10.3390/ijerph7093531.

Tweed, C.H. 1945. "A philosophy of orthodontic treatment." *American Journal of Orthodontics and Oral Surgery* 31:74-103. https://doi.org/10.1016/S0096-6347(45)90163-3.

Vekic, J., Zeljkovic, A., Stefanovic, A., Jelic-Ivanovic, Z., Spasojevic-Kalimanovska, V. 2019. "Obesity and dyslipidemia." *Metabolism* 92:71-81. https://doi.org/10.1016/j.metabol.2018.11.005.

Verma, S., Hussain, M.E. 2017. "Obesity and diabetes: an update." *Diabetes & Metabolic Syndrome: Clinical Research & Reviews* 11:73-9. https://doi.org/10.1016/j.dsx.2016.06.017.

Vora, S.R., Tam, S., Katsube, M., Pliska, B., Heda, K. 2022. "Craniofacial form differences between obese and nonobese children." *American Journal of Orthodontics and Dentofacial Orthopedics* 162: 744-52. https://doi.org/10.1016/j.ajodo.2021.07.018.

Zigante, M., Pavlic, A., Mathewson, A., Spalj, S. 2019. "Changes of mandibular dental arch shape during adolescence and its influence on late mandibular incisor crowding." *Homo: Internationale Zeitschrift fur die Vergleichende Forschung am Menschen* 70: 185-92. https://doi.org/10.1127/homo/2019/1070.