ASSESSING TEMPOROMANDIBULAR JOINT HYPERMOBILITY IN A YOUNG POPULATION: A PILOT STUDY

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Dedication

I would like to dedicate this to everyone who has kept me going through this looooong, but necessary career change. To my parents, a thousand thank yous. I wouldn't be here without your unconditional love and support. To my brother Luke, I'll miss our reciprocating pep talks at the start of every term, but hopefully now, we're both on to better things. To my friends Alisha and Theresa, this version of dental school wasn't the same without you, but your support from far away meant the world.

Abstract

Introduction: Hypermobile individuals may be more common than once thought. Since these people tend to experience negative sequelae over the course of their lives, it would be beneficial to devise a simple test or set of tests to screen for these patients. The general dentist or orthodontist is in a unique position to assist as they see their patients for frequent recall.

Aim: To evaluate if the maximum mandibular movements can be positively correlated to the Beighton score.

Methods: 30 children aged 9 to 12 years old with no signs or symptoms of TMD were recruited and their maximum mandibular opening and lateral excursives were recorded, along with their Beighton score. They were also examined for the presence or absence of oral frena and the Gorlin sign. Participants completed the Grahame and Hakim questionnaire and were also asked about their tendency to bruise. Descriptive statistics, linear and ordinal regressions, and univariate analyses were used to analyze the collected data. P-values less than 0.05 were considered statistically significant.

Results: Based on the small sample size of this study, there are no statistically significant relationships between the maximum mandibular border movements and the Beighton score in children of this age. Other signs, such as missing frena and presence of Gorlin sign, could not be evaluated due to the small number of affected individuals.

Conclusions: Because a relationship between the Beighton score and the maximum mandibular border movements may exist, a larger cohort should be evaluated in the future. Additionally, while the Grahame and Hakim questionnaire has been found to be

valid in adults, its validity in children is still questionable, but shows promise. Future avenues of improvement include measuring the knees when participants are standing, adding visual aids to the Grahame and Hakim questionnaire, and taking angular measurements of the maximum opening, instead of linear ones.

Table of Contents

List of Tables

List of Figures

Introduction

Ensuring adequate retention after orthodontic treatment can be one of the more frustrating aspects of the profession. Even after finishing a patient's smile with ideal aesthetics and occlusion, a non-compliant retainer patient can experience significant relapse in a relatively short amount of time, thereby frustrating both provider and patient. For patients with connective tissue disorders, such as Ehlers-Danlos syndrome (EDS) and Hypermobility Spectrum disorder (HSD), the risk is especially great. While these patients tend to make rapid progress during treatment, they may also experience significant relapse and require lifetime retention.[1,2]

Historically though, patients with Ehlers-Danlos syndrome and Hypermobility Spectrum disorders were considered relatively rare. Indeed, the most frequently cited statistic in medical literature is 1:5000 for the most common type of Ehlers-Danlos syndrome, hypermobile EDS (hEDS). However, a recent study in Wales suggests that the prevalence for this family of conditions may actually be as high as 1:500.[3]

Considering that these disabling disorders take on average over 18 years and 16 medical providers to be correctly diagnosed from the first onset of symptoms, it would behoove the medical community to take a more proactive approach to diagnosis.[4] Unfortunately, hEDS and HSD, while autosomal dominant conditions, have not been traced to any particular genetic sequence at this time. Therefore, diagnosis is solely clinical and often utilizes a relatively easy-to-perform exam known as the Beighton test, which assesses the flexibility of several major joints in the body. Scoring ranges from 0-9, with a score of 5 or higher signifying greater than normal joint mobility.[5] However, the Beighton test only evaluates a limited number of joints and was originally intended to be utilized only as a screening tool. Consequently, a 2011 study in the Netherlands used the Beighton test to evaluate 551 school-age children for not just the traditional 9 points of flexibility, but 16 others as well to determine if the test is a good indicator for generalized hypermobility. The results of the study found a positive correlation between a higher Beighton score and greater joint mobility at the other tested sites, indicating that the Beighton test is indeed a useful metric for this population.[6] However, the primary joint of interest to the dental community, the temporomandibular joint (TMJ), was not assessed.

While an expansive range of motion from 35-60 millimeters is generally accepted as normal for maximum opening of the TMJs, research thus far has failed to denote at which point the numbers on the higher end of this scale may indicate excessive mobility.[7] The same issue exists with lateral excursives. Determining where these movements turn from normal to pathologic deserves further investigation and may aid the orthodontist in determining which patients may ultimately need more long-term intervention.

Review of Literature

Systemic Hypermobility

Just as cleft palate can be associated with any number of conditions, so too can joint hypermobility. In and of itself, the term merely describes a joint that exceeds its range of motion, regardless of reason, and is not an official diagnosis. However, it can be used to aid in the diagnosis of many connective tissue conditions. Perhaps one of the most common, according to Demmler's Welsh study[3], is a spectrum of connective tissue disorders up to and including the most severe variant, Ehlers-Danlos syndrome. The nosology of this family of conditions has changed substantially over time, with the most recent update in 2017, spearheaded by the International Consortium on Ehlers-Danlos Syndromes. Indeed, seven new subtypes of Ehlers-Danlos were described, bringing the total to thirteen, along with diagnostic criteria for each. Fortunately, all but one can be definitively diagnosed with genetic testing. Unfortunately, the one that cannot, hypermobile EDS (previously known as EDS-HT or simply EDS III) is by far the most common, comprising 80-90% of all EDS diagnoses[3,8].

The new nomenclature also attempts to clarify the gray area for those who displayed many signs and symptoms of hypermobile EDS (hEDS), but didn't strictly fulfill all of the criteria. In previous iterations of the classification system, these individuals would typically receive a separate diagnosis of Joint Hypermobility Syndrome (JHS). Over time though, it became apparent that little distinction between JHS and hEDS existed[8]. For example, many patients diagnosed with JHS would often eventually be diagnosed with hEDS, and affected families often had a mix of individuals with hEDS and JHS diagnoses[3,8,9]. Therefore, at the 2017 consortium, JHS was replaced with a united Hypermobility Spectrum Disorder. (Figure 1)

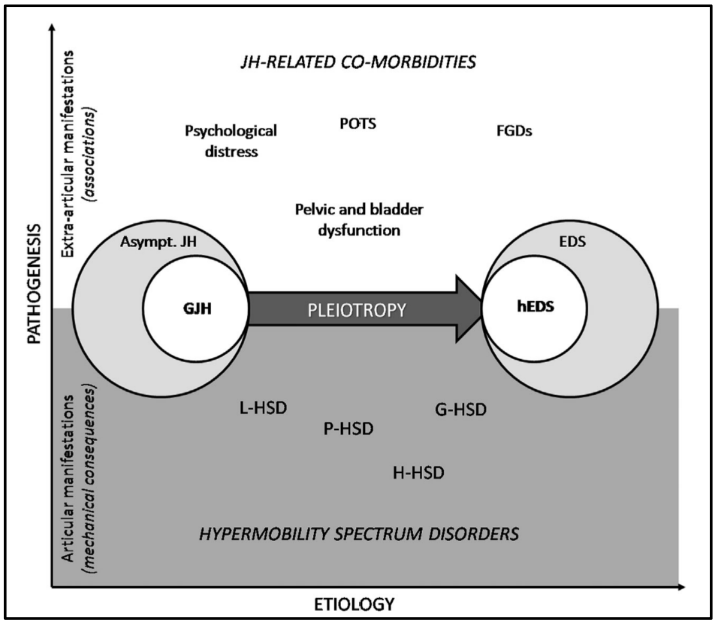

Figure 1: Graphic demonstrating new 2017 spectrum of hypermobility disorders. JH - joint hypermobility; POTS -postural orthostatic tachycardia syndrome; FGDs - functional gastrointestinal disorders; GJH - generalized joint hypermobility; L-HSD - localized hypermobility spectrum disorder; P-HSD - peripheral hypermobility spectrum disorder; H-HSD - historic hypermobility spectrum disorder; G-HSD - generalized hypermobility spectrum disorder. From Castori et al. 2017[10].

Under this new nomenclature, if a patient exhibits joint mobility, but does not fulfill all of the criteria for hEDS, they may receive of a diagnosis of localized HSD (only a few affected joints), peripheral HSD (only the joints of the hands and feet are affected), generalized HSD (many affected joints), or historic HSD (joints were previously affected, but are no longer considered hypermobile). The latter presents an interesting situation as many individuals with hypermobility actually experience a paradoxical reduction in mobility over time, typically as micro and macro traumas accumulate[10–14]. Castori et al proposed that hypermobile joints have a three-stage life cycle, wherein the joints start as "hypermobile" in childhood, then progress to a "pain" stage in young to middle adulthood, and end in a "stiffness" phase[8,15]. Not all stages occur in all patients, nor at the same decades in life, but the sequence holds true[9,11,15]. Furthermore, Castori et al (2011) argue that 33 years old should be the cut-off for attempting to measure mobility, as many individuals with hypermobility begin to experience a decline after this age and would thus have a diagnosis of historic HSD[10,16]. How to test that hypermobility bears discussion next.

Testing of Systemic Hypermobility

Many methods have been developed to test overall joint mobility, with the original standard being the Carter and Wilkinson exam, published in 1964[17]. The joints of interest included both thumbs, knees, elbows, ankles, and all metacarpophalangeal joints. In 1973, Beighton et al established their protocol, modifying several aspects of their predecessors'[18,19]. While the Beighton test maintains the Carter and Wilkinson examination of the thumbs, elbows, and knees, the ankles are swapped out for the lower back and the finger measurements are scaled back to just the fifth digit (Figure 2). Other newer protocols that are seen less frequently in the literature and in practice include the Rotès-Quérol and the Hospital del Mar[20]. The Rotès-Quérol uses the Beighton score as a base, but also adds measurements for the cervical and lumbar spine, shoulders, hips, and metatarsophalangeal joints. The Hospital Del Mar criteria are slightly different and include the thumb, metacarpophalangeal joints, metatarsophalangeal joints, elbows, shoulders, hips, knees, patellae, ankles, and interestingly, a visual assessment for ecchymoses, or bruising. (The additional time investment of these latter two protocols has typically been considered their greatest hindrance to more widespread adoption[11].) The last major exam of note is the 5-Point Questionnaire (5PQ), published by Grahame and Hakim in 2003[21] (Figure 3). Considering the long-held acknowledgement that mobility in hypermobile individuals decreases over time[5,11,18] (hence the new diagnosis of "historic HSD"), the 5-Point Questionnaire is meant to supplement the other tests as these patients age. Ultimately though, the Beighton test has remained the most performed examination of hypermobility, utilized extensively both clinically and in research protocols[5,11,12].

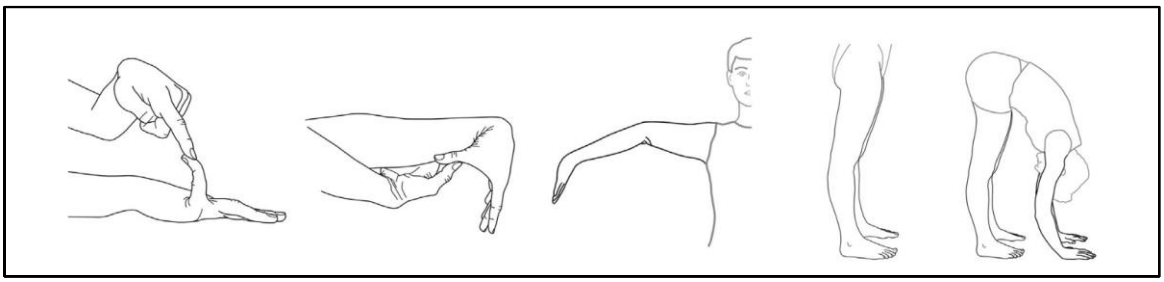

Figure 2: Demonstration of the maneuvers included in the Beighton exam. From Juul-Kristensen *et al*[12].

The Five-Point Questionnaire. Adapted From [Grahame and Hakim, 2003]

1. Can you now (or could you ever) place your hands flat on the floor without bending your knees?
2. Can you now (or could you ever) bend your thumb to touch your forearm?
3. As a child, did you amuse your friends by contorting your body into strange shapes or could you do the splits?
4. As a child or teenager, did your shoulder or kneecap dislocate on more than one occasion?
5. Do you consider yourself "double-jointed"?

A "yes" answer to two or more questions suggests joint hypermobility with 80–85% sensitivity and 80–90% specificity

Figure 3: Grahame and Hakim Questionnaire. From Malfait *et al*[5].

However, the Beighton test and its ilk have received significant criticism for questionable reliability and validity, among other issues. In a 2017 systematic review, the Carter and Wilkinson, Rotès-Quérol, and Hospital del Mar were deemed to have insufficient data to support their reliability and validity[12]. (Although a study of 30 children in 2019 using the Hospital de Mar criteria has since appeared to establish good reliability in that population[22].) While the 5PQ claims to have satisfactory reproducibility, sensitivity, and specificity, its reliability was called into question and its validity has only been examined in adults[21]. The Beighton test was determined to have generally acceptable reliability[23,24], although a 2021 narrative review by Malek et al disagreed, noting that it was only "limited to conflicting"[11]. Its overall validity was also lacking, although it was validated in one study of Dutch children[6]. Furthermore, there was discussion of how the original numerical cut-offs for hypermobility in adults and children were chosen arbitrarily and are not consistent across the literature[6,11,12,24–26], with some authors diagnosing hypermobility with a Beighton score of 4/9, others at 5/9 or 6/9, and even a few at 7/9 or 8/9. Similar discussion has taken place concerning the original angular joint deviation cut-offs[27] and the dichotomous positive or negative scoring, without acknowledgment of the severity of the joint deviation[11,24,25]. On top of that, there is little standardization in how the exam is performed[6,11,12,24]. For example, only some studies utilize goniometers or protractors to measure the angular joint displacement[6,14,23,26,28], some differ in whether certain movements are performed standing[18,29,30] or lying on one's back[6], and the question of active or passive movement has never been decided[6,11]. Other criticisms leveled at the Beighton exam are that it tests primarily upper body joints, with only the knees and lower back representing the lower half[11,28]. The inclusion of the "touch the floor" component has also been called into question as it appears to have abysmally low sensitivity in otherwise hypermobile children (13.8%)[28]. Finally, there is research to suggest that the Beighton score may be influenced by difficult to measure metrics such as "hamstrings length, spinal mobility, hip joint ROM, and anthropometric characteristics"[28], as well as warm-up exercises[5], profession[8] (such as dancer or athlete), or even "climate, temperature, stage of menstrual cycle, and prior physical activity, particularly in those with a borderline presentation"[11]. Even though the Beighton exam receives the brunt of these criticisms, likely due to its prevalence in the literature, it is still the test of choice, and no consensus has established a better or more clinically practical standard at this point. For those interested in the head and neck though, there is currently no measurement of the temporomandibular joint included at present.

Temporomandibular Joint

The temporomandibular joint is a singular piece of biological engineering. During embryonic development, it is the only joint formed by two different mesenchymal tissues, is one of the few to contain a meniscus, and is one of the last to develop. Indeed, by the age of 3, the articular eminence is just barely beginning to form and will not complete development until around age 12. The TMJ has a unique mobility in that it can be thought of as a "sliding ball and socket joint"[1], and is also notable for being the only joint that requires both the left and right to function in harmony to provide functional movement. Unlike other synovial joints, the articular surfaces are not covered by hyaline cartilage, which is composed primarily of type II collagen. Instead, dense fibrous connective tissue, composed mainly of type I collagen, makes up most of the interior lining of the joint, the disc, and the ligaments forming the capsule. (While there is some type II collagen present deep to the articular surfaces, it is believed to have little functional role.)[31–34] As this is the joint that dentists deal with most on a day-to-day basis, understanding its similarities and differences to other joints may provide insight into how it may be affected by hypermobility conditions and several have investigated a potential relationship.

The TMJ, its Border Movements, and the Beighton Score

Even after first being described in 1947 by Shultz, there is still no agreement on when the temporomandibular joint should be characterized as hypermobile[35]. Radiographically, some argue that it's when the head of the condyle moves beyond the articular eminence[36–38], but in her thesis, Johannson-Garnier posits that it should be when the condyle "exceeds the insertion of the anterior TMJ capsule on the temporal bone"[37,39]. These are impractical to assess clinically, so measuring the maximum mandibular movements often substitutes as a way to do so.

While it may seem obvious today that knowing the boundary movements of the temporomandibular joint can be instrumental in assessing potential dysfunction, it wasn't until the 1960s and 1970s that significant research was undertaken to establish these values in both adults and children. Indeed, a nearly bewildering number of studies from this period, mostly from Northern Europe, set out to determine both normal and pathologically low values for these populations.

In 1960, while investigating a TMJ condition he termed “elapsio praearticularis”, Nevakari reported that in children aged 6-12, non-pathologic maximum opening varied between 35-60 mm and averaged 46 mm.[38] Unfortunately, his method of passively inserting wooden blocks of progressing 5 mm incremental sizes into his subjects’ mouths left something to be desired for accuracy’s sake. Additionally, while he recorded his participants’ overbites, it does not appear that he took them into consideration when calculating his results, a common source of contention to be discussed shortly. However, the study did establish the finding that boys and girls in this age cohort have no statistical difference in terms of their maximum opening, further born out in follow-up studies as well.[7,40–43]

Ingervall advanced the study of joint mobility in children in 1970 by examining not just maximum opening, but also maximum lateral excursions and protrusion in a population of Swedish 7-year-olds, 10-year-olds, and 20-year-old women. He confirmed Nevakari’s earlier finding that there was no difference in mean maximum opening for boys and girls in the younger cohorts (46 mm for the 7-year-olds and 51 mm for the 10-year-olds), although he did describe that boys had slightly greater lateral movements than girls (10.5 mm vs. 10mm) and that the younger kids had overall smaller measurements than the older kids, as would be expected. Interestingly though, the 10-year-old girls had the same jaw mobility as the 20-year-old women, suggesting that little functional change occurs in the 2nd decade of life for females. Finally, he proposed a straightforward definition of restricted mandibular movement: two standard deviations below the mean. Therefore, he posited that 7 year olds with a maximum opening of 37-38 mm and 10 year olds with a maximum opening of 41-42 mm and lateral excursives of 7-8 mm should be evaluated for TMD.[40]

In reviewing the substantial amount of literature beyond the two afore-mentioned studies though, it becomes abundantly clear that the question of TMJ mobility in children is hardly a settled subject. (Unfortunately, as far as can be ascertained, no systematic reviews or meta-analyses have been conducted on the extensive research up to this point.) Part of this is due to study design. As previously mentioned, while many studies incorporate the patient's overbite, or open bite as the case may be, into the linear measurement from upper to lower incisal edge during maximum opening[40–42,44–47], not all do[7,38,48–50]. Additionally, only one study explicitly mentioned excluding participants who had received orthodontic care[49], while the status of participants in all other studies was deemed unknown. While many studies did explicitly exclude participants with signs and symptoms of TMD[41,44,46,49], one allowed participants with non-painful TMD to qualify[51], and another retrospective study made no mention of TMD history[7].

However, the study protocols also shared many similarities. For example, it was nearly universal that participants were asked to perform the jaw mobility exercises multiple times, with only Müller et al performing the maneuvers once, but noting that they were performed at the end of an extensive dental exam during which the patients opened and closed many times[7]. Additionally, patients were again nearly universally allowed to perform the movements on their own and were not assisted by the researcher, except in the case of Bonjardim et al, where the authors state only “slight bidigital pressure” was applied during maximum opening[42]. Finally, the mandibular movements were almost always measured linearly, either using Therabite or straight rulers, with the notable exceptions of Dijkstra et al and Wright et al, advocates of angular measurement techniques, to be discussed later.[44,52–54]

When it comes to evaluating TMJ hypermobility against the Beighton score, most research has focused on TMD as the outcome, not mandibular border movements[11,55,56]. Consequently, most of these studies involve older patients and/or those who already present with TMD signs and symptoms[37,57]. These studies tend to show inconclusive results in terms of a correlation between high Beighton score and hypermobility of the TMJ[36,58], although Hirsch et al showed a positive correlation, but not one that is likely clinically significant[14]. Studies that have looked at younger populations though have seen better correlation between the two, perhaps because the sequelae of having joint hypermobility may take decades to become apparent[30,59]. No research thus far has looked specifically at the study population used in Smits-Engelsman *et al* study (6–12-year-olds), for whom it was determined that the Beighton score was a valid measure of generalized joint mobility.

Other Oral Signs of EDS

Beyond the TMJ, several other oral signs have been noted in the literature for those with EDS. Gorlin et al reported that the Gorlin sign, i.e. being able to touch the tip of one's tongue to his or her nose, is present in about 50% of people with EDS, vs about 10% of unaffected people.[60] Whether this phenomenon can be seen in a hypermobile non-EDS population remains to be seen.

Additionally, De Felice et al reported that in 12 individuals diagnosed with classic and hypermobile EDS, 100% were missing their lower labial frenum and 75% were missing their lingual frenum (Figure 4). These patients were contrasted against 154 non-hypermobile controls, with 0% missing their lingual frenum and only 1 individual missing their lower labial frenum[61]. While Machet et al didn't find the same high sensitivity in a mixed population of 43 classic, hypermobile, and vascular EDS patients (42% sensitivity for missing lower labial and 53.5% for missing lingual), their specificities were essentially the same (98% and 99%, respectively) against 86 case controls[62]. Again, this relationship has not yet been reported for a hypermobile non-EDS population. While not investigated in this study, other dental signs of EDS are listed in Table 1 for completeness.

Figure 4 : Comparison of missing and present frena. Left side demonstrating missing labial and lingual frena. Right side demonstrating present frena. From De Felice et al[61]

Table 1: Other common dental manifestations of EDS. From Mitakides et al[1].

TABLE I. Dental Manifestations of EDS

Soft tissue
- Fragile oral mucosa
- Early onset of periodontal defects

Dentition
- High cusps and deep fissures on the crowns of teeth
- Higher incidence of enamel and dental fractures
- Stunted roots or dilacerations
- Coronal pulp stones
- Aberrant dentinal tubules
- Pulpal vascular lesions and denticles
- Ready movement of teeth in response to orthodontic forces
- Easier accomplishment of orthodontic retention

Temporomandibular joint
- Hypermobile TMJ with high incidence of subluxation/dislocation
- TMD

Specific Aims

The general purpose of this study is to determine if there is a statistically and if so, clinically significant value at which TMJ hypermobility may be diagnosed in a young population. The specific aims of this study were:

1. Determine if a patient's Beighton score correlates to his or her maximum mandibular opening in a healthy population, aged 9-12.
2. Determine if a patient's Beighton score correlates to his or her lateral range of motion in a healthy population, aged 9-12.
3. Determine if a patient's Beighton score correlates with other frequently cited indicators of hypermobility disorders, including absence of frena, presence of Gorlin sign, and tendency to bruise.

Hypotheses

1. H_0: There is no relationship between Beighton score and maximum mandibular opening.
2. H_0: There is no relationship between Beighton score and maximum left and right lateral excursive movements.
3. H_0: There is no relationship between other signs of hypermobility and the Beighton score.

Materials and Methods

This was a prospective cross-sectional study, during which data was collected from participants and no variables were tested. A power analysis was completed prior to beginning the study. With 35 subjects enrolled, there would be 80% power to detect a correlation coefficient of 0.5 between Beighton score and the primary outcomes of maximum mouth opening and lateral excursive movements at the 0.025 significance level.

The sole data collector (EB) was trained by a Doctor of Physical Therapy in the TMD department at the University of Minnesota in proper use of goniometers using the anatomical landmarks identified by Smits-Engelsman et al in their appendix[6].

A healthy study population of 30 children, aged 9y0m to 12y11m old, was identified through initial screening of patients presenting either to the University of Minnesota's orthodontic clinic for an initial orthodontic exam or to the pre-doctoral pediatric clinic for a recall exam. To reduce bias, the participants were drawn consecutively from the available patient pools in these clinics. Once identified by age, parents of potential participants were given a flyer informing them of the study. To eliminate potential confounding factors, participants were excluded if their parents reported a history of trauma to their child's head, neck, and joints of interest, craniofacial deformities, previous history of orthodontic treatment, or temporomandibular disorder in their child's medical history.

Upon provisional acceptance into the study, a clinical examination of the TMJs was performed to evaluate for signs of TMD that may not have been reported, such as TMJ clicking or crepitus. If signs of joint dysfunction were identified in the participant, then he or she was excluded from the study. Those with no joint sounds or reported pain were considered to be fully enrolled in the study once consent and assent were obtained according to the parameters set by the University of Minnesota's Institutional Review Board (Study ID 00015209).

Participants then had their height (to the nearest centimeter) and weight (to the nearest 0.1 pound) recorded using a wall-mounted tape measure and an Angel USA 400 pound capacity digital scale, respectively. In the treatment chair, with the participants slightly reclined and their head supported, an oral examination quantified overbite and overjet using a Goldman-Fox style perio probe. Overbite was measured as an average of both central incisors and overjet was similarly averaged between the two central incisors. These measurements were recorded to the nearest half millimeter. To investigate specific aim 3, the lips and cheeks were stretched to determine if any of the 7 primary oral frena were missing. The investigator noted if any of the three in the buccal vestibule of the maxilla, three in the buccal vestibula of the mandible, or the lingual frenum were missing. A score from 0-7 was assigned based on how many frena were still present and those that were missing were noted by position, such as a missing right mandibular buccal frenum for example. Participants were also asked to touch the tip of their tongue to their nose, also known as the Gorlin test. This was recorded either as positive or negative. The last measurement taken used the linear arm of a HiRes goniometer (Baseline) to measure from subnasale to menton to the nearest half millimeter while the patient was in their vertical dimension of occlusion (VDO), which was instructed as "most comfortable bite".

After the oral clinical examination, the Grahame and Hakim five-point questionnaire was administered. Participants could answer either yes or no to each question. If patients had successfully performed one of the maneuvers on the questionnaire, the answer was recorded as an automatic yes. Finally, patients were asked if they bruised easily, which was also recorded as a yes or no response.

To investigate specific aim 1, the participants were instructed to perform an oral warm-up exercise. As Muller *et al* and other previous studies have advised in order to produce a more accurate reading, participants were asked to open as widely as they could unassisted three times in a row[7,63]. The third opening was then measured using a Therabite ruler (Atos Medical AB). The reading was recorded to the nearest half millimeter. During data evaluation, the averaged OB was added to this maximum opening value. To investigate primary aim 2, participants were next instructed to perform similar oral warm-ups by laterally opening the mouth unassisted as far as possible from side-to-side 3 times. The third reading was then recorded to the nearest ½ mm on the same Therabite ruler used for maximum mandibular opening, since the ruler also has millimeter measurements for this purpose. The location of the participant's lower midline was marked on the Therabite to the nearest half millimeter to account for any deviation from the upper midline. During data evaluation, if a participant had a lower midline deviation of 2 mm to the left for example, 2 mm was subtracted from the left lateral excursive value.

Finally, the Beighton score was assessed. Before performing the test, participants were asked to remove their shoes and a demonstration was presented as to how the movements were to be performed. A large goniometer (01135, Lafayette Instrument Company) was used to record angular measurements to the nearest degree of both elbows and both knees, with the patient lying on a flat table for the latter.[6] A value of 190 degrees or greater was recorded as positive for each joint. The flexibility of the little fingers was assessed visually. If the participant was able to pull their pinky back to 90 degrees relative to the dorsum of the hand, the joint was listed as positive. Thumb flexibility was also assessed visually as either positive or negative for each side. Participants were instructed to fold their thumb back to get it to lay completely parallel to the length of the forearm. If they were able to, this was recorded as positive. Lastly, participants were asked to touch the ground without bending their knees. This result was recorded as either positive or negative. The final Beighton score was recorded as a discrete number from 0-9.

Statistical Methods

Participant characteristics and responses were summarized using counts and rates or means and standard deviations. The relationships between Beighton score and other outcome measures, participant characteristics, and question responses were examined using both linear (Table 7) and ordinal (Table 10) regression models and correlation coefficients. Analyses were conducted using R version 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria).

Results

<u>Descriptive Statistics</u>

Patient characteristics and results for all 30 participants are summarized in the following tables. (Table 2-6). See appendix for graphical interpretation of data for each Grahame and Hakim Questionnaire response (Figure 14), distribution of the total Beighton score in the population (Figure 15), and results of each individual component of the Beighton score (Figure 16).

Table 2: Population characteristics

Height [cm]	
Mean (SD)	**151.1 (9.7)**
Weight [lbs]	
Mean (SD)	**101.9 (25.8)**
Age [months]	
Mean (SD)	**135.7 (12.7)**
Age [years]	
Mean (SD)	**11.3 (1.1)**
Sex	
Male	**13 (43.3%)**
Female	**17 (56.7%)**

Table 3: Mandibular border movement measurements, including range, mean, and standard deviation

Max opening without OB [mm]	
Mean (SD)	51.4 (6.1)
Range	39-62
Max opening with OB [mm]	
Mean (SD)	55 (6.6)
Range	43-67.5
Max left lateral [mm]	
Mean (SD)	9.7 (2)
Range	6.5-14.5
Max right lateral [mm]	
Mean (SD)	10.3 (2)
Range	6.5-14

Table 4: Responses to Graham & Hakim Questionnaire and bruising question, with means and standard deviations for first five questions and then all six questions

Q1 Response	
No	21 (70%)
Yes	9 (30%)
Q2 Response	
No	23 (76.7%)
Yes	7 (23.3%)
Q3 Response	
No	16 (53.3%)
Yes	14 (46.7%)
Q4 Response	
No	29 (96.7%)
Yes	1 (3.3%)
Q5 Response	
No	22 (73.3%)
Yes	8 (26.7%)
Q6 Response	
No	17 (56.7%)
Yes	13 (43.3%)
Q1-5 Total	
Mean (SD)	1.3 (1.1)
Q1-6 Total	
Mean (SD)	1.7 (1.3)

Table 5: Summary statistics for each participant's Beighton score and each individual joint. For the pinky, thumb, elbow, and knee components, a score of 0 indicates that the joint was not hypermobile bilaterally. A score of 1 indicates that either the left or right joint tested positive for hypermobility. A score of 2 indicates bilateral hypermobility. The "touch floor" component is scored as either 0 for an inability to touch the floor or 1 for being able to.

Total Beighton Score	
0	1 (3.3%)
1	1 (3.3%)
2	12 (40%)
3	4 (13.3%)
4	5 (16.7%)
5	2 (6.7%)
6	4 (13.3%
7	1 (3.3%)
8	0 (0%)
9	0 (0%)
Total Beighton Score	
Mean (SD)	3.3 (1.7)
Pinky Score	
0	15 (50%)
1	2 (6.7%)
2	13 (43.3%)
Thumb Score	
0	24 (80%)
1	3 (10%)
2	3 (10%)
Elbow Score	
0	2 (6.7%)
1	3 (10%)
2	25 (83.3%)
Knee Score	
0	24 (80%)
1	5 (16.7%)
2	1 (3.3%)
Touch floor score	
0	29 (96.7%)
1	1 (3.3%)

Table 6: Other oral manifestations

Total number of frena present (of 7)	
5	1 (3.3%)
6	5 (16.7%)
7	24 (80%)
Lingual frenum present	
No	3 (10%)
Yes	27 (90%)
Gorlin sign	
Negative	28 (93.3%)
Positive	2 (6.7%

Maximum opening to Beighton Score

There was no statistically significant relationship between maximum opening measured with (p=0.395) or without overbite (p=0.3) against the Beighton score. However, positive correlation coefficients were noted: 0.161 and 0.196, respectively (Table 7 and Figures 5 and 6).

To account for potential differences in facial morphology, univariate regressions were also run for the ratio of maximum opening with (p=0.376) and without overbite (p=0.287) to subnasale-menton against the Beighton score. Neither was determined to be statistically related (Table 9).

Table 7: Pearson Correlations for Beighton score against maximum mandibular border movements

Pearson Correlations with Total Beighton Score

	Correlation Coef. (r)	95% CI	p-value
Total Beighton Score **Max Opening [mm]**	0.196	(-0.177, 0.519)	0.3
Total Beighton Score **Max Opening with OB [mm]**	0.161	(-0.211, 0.493)	0.395
Total Beighton Score **Max Left Lat [mm]**	0.253	(-0.118, 0.562)	0.177
Total Beighton Score **Max Right Lat [mm]**	-0.007	(-0.366, 0.355)	0.973
Total Beighton Score **Max Left+Right Lat [mm]**	0.178	(-0.195, 0.506)	0.347

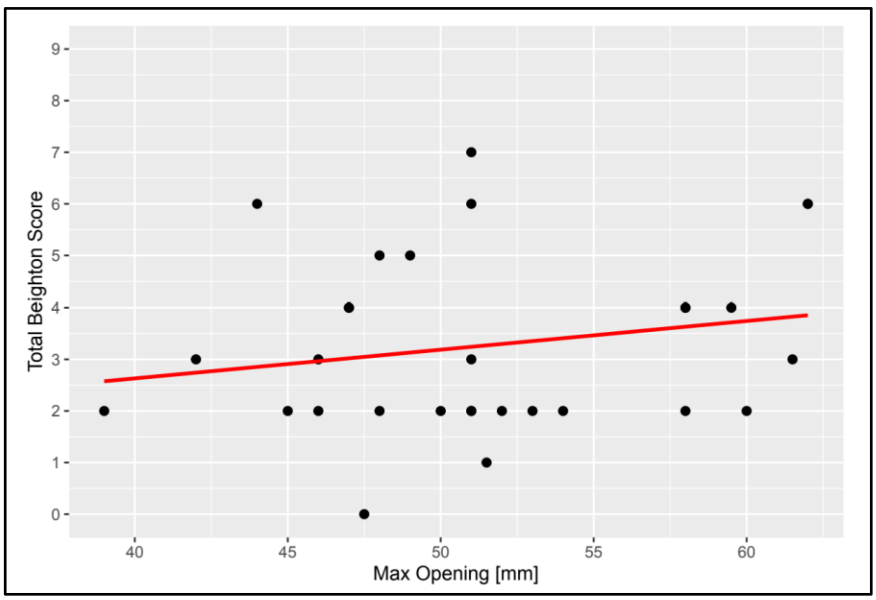

Figure 5: Maximum opening without overbite correlated to the total Beighton score. The red line on this and all subsequent figures is the regression line. R = 0.196

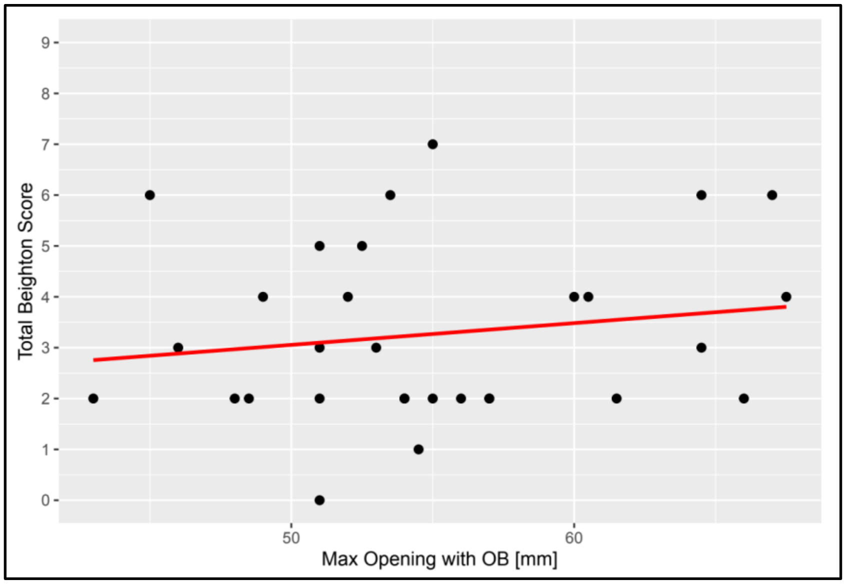

Figure 6: Maximum opening with overbite correlated to the total Beighton score. R=0.161

Maximum Lateral Excursives to Beighton Score

There was no statistically significant relationship between the left (p = 0.177) or right (p=0.973) maximum lateral excursive measured against the Beighton score. Even when the two values were added together, the relationship did not exist (p=0.347). However, there were positive correlation coefficients for left lateral (0.253) and total lateral (0.178). Right lateral had a nearly zero correlation coefficient (-0.007). (Table 7 and Figures 7, 8, and 9).

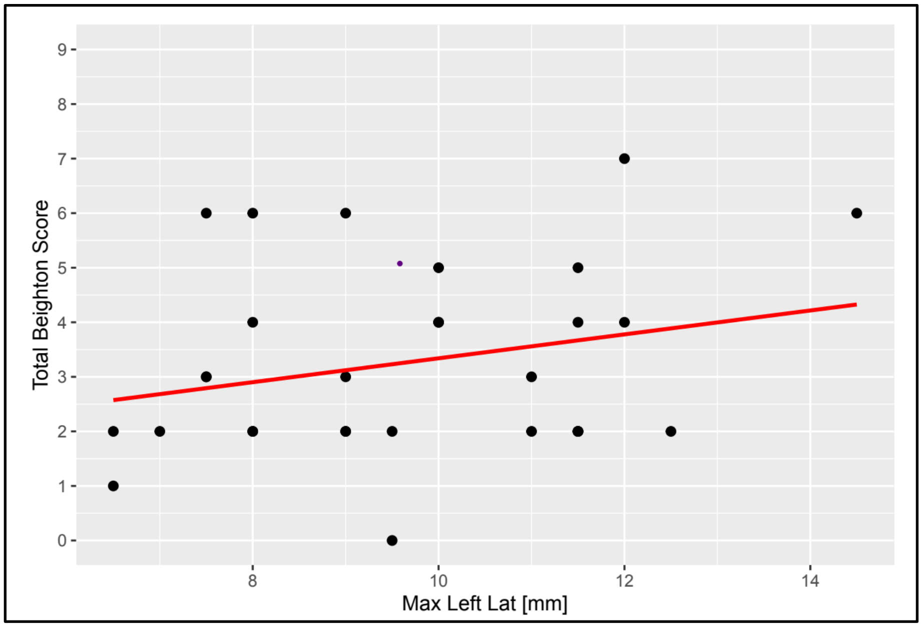

Figure 7: Maximum left lateral excursive correlated to the total Beighton score. R=0.253

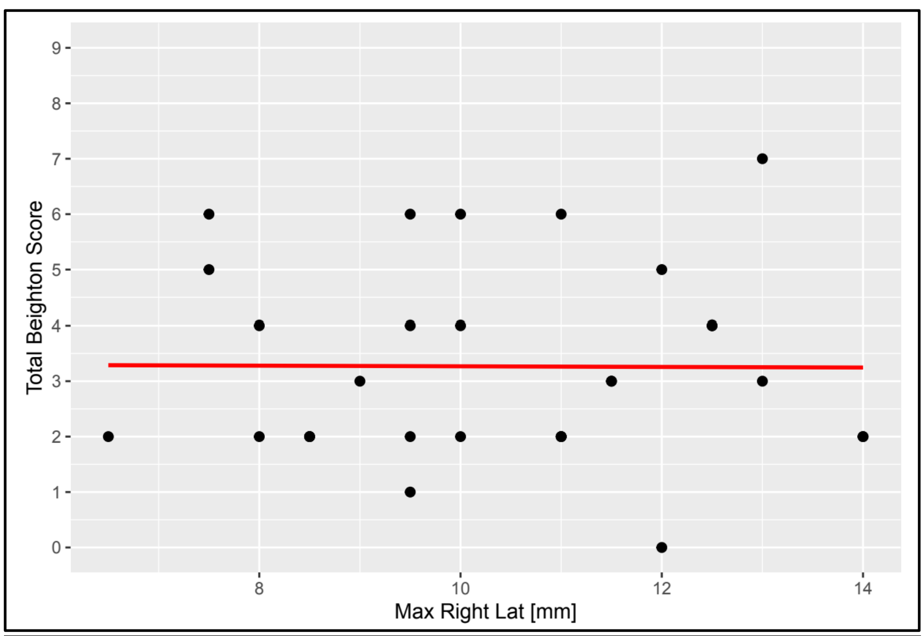

Figure 8: Maximum right lateral excursive correlated to the total Beighton score. R=-0.007

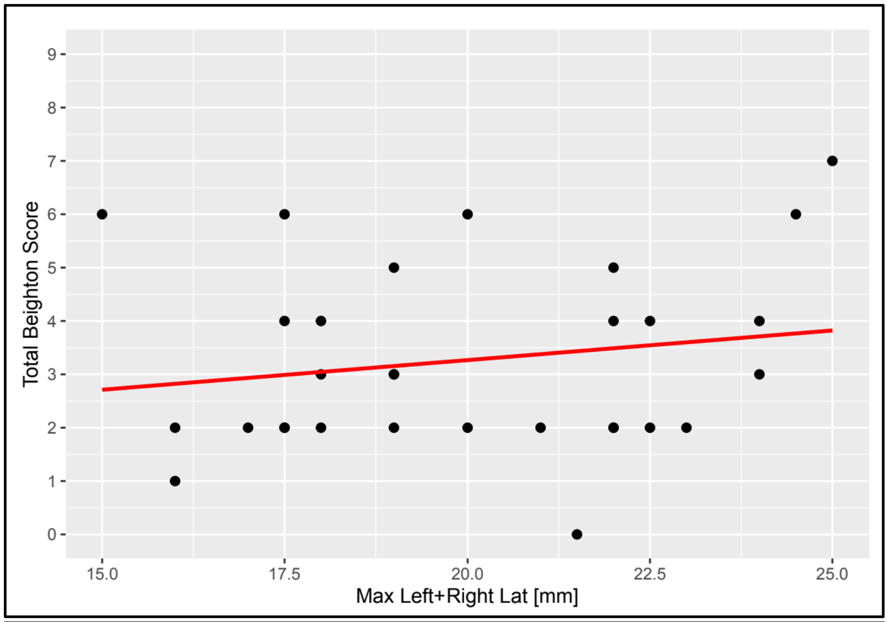

Figure 9: Maximum combined right and left lateral excursives correlated to the total Beighton score. R=0.178

<u>Grahame and Hakim Five Point Questionnaire</u>

Univariate analysis was performed for each individual question on the questionnaire against the Beighton score, as well as the whole questionnaire (Table 9). Question 2 (“Can you now or could you ever bend your thumb to touch your forearm?) had the only statistically significant relationship for an individual question ($p<0.001$). Question 3 (“Do you amuse your friends by making your body into weird shapes or can you do the splits?) had the lowest effect estimate of 0.04 ($p=0.956$). The overall Beighton score against the overall score on the questionnaire was statistically significant ($p = 0.02$).

To evaluate the validity of the questionnaire against the Beighton score in this population, a correlation analysis was performed for those participants who scored either greater than or equal to a 5/9, 6/9, or 7/9 on the Beighton test and at least a 2 on the questionnaire. The relationship was not significant at any of the cutoffs. The relationship was nearly significant (p=0.09) when comparing the overall Beighton mean to the number of positive responses on the questionnaire though, with those scoring 2 or more having a higher Beighton score than those who scored 0 or 1 on the questionnaire: 3.9 versus 2.8 (Table 8). There was, however, a statistically significant relationship (p=0.02) between a participant's Beighton score and their overall questionnaire score (Table 9 and Figure 10).

Table 8: Validity analysis of the varying Beighton cutoffs scores to the number of positive responses on the Grahame and Hakim questionnaire.

	Total of Q1-Q5		
	0-1	2-3	p-value
n	16	14	
Beighton ≥5, n (%)	2 (12%)	5 (36%)	0.20
Beighton ≥6, n (%)	1 (6%)	4 (29%)	0.16
Beighton ≥7, n (%)	0 (0%)	1 (7%)	0.47
Beighton, mean (SD)	2.8 (1.4)	3.9 (1.9)	0.09

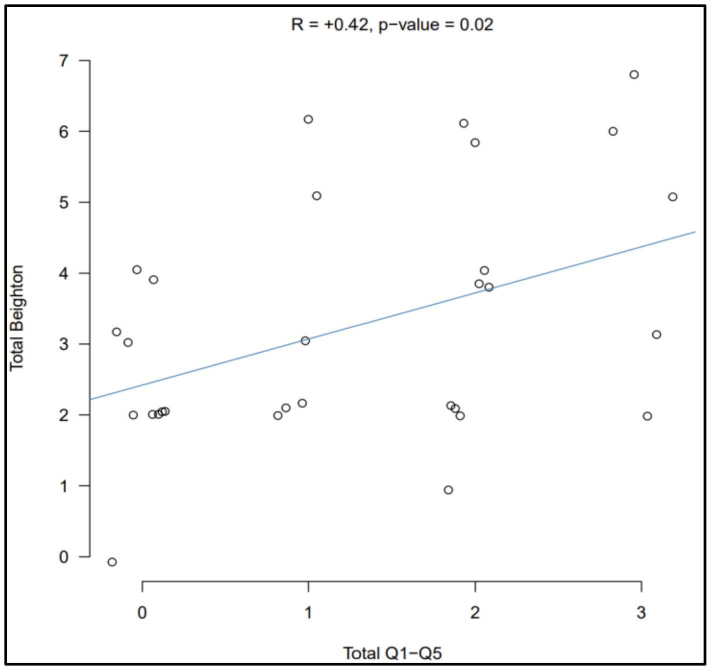

Figure 10: Correlation between Total Beighton Score and Number of Positive Responses on Grahame and Hakim Questionnaire. R = 0.42

Frena and Gorlin Sign

No participants were missing any maxillary frena, nor were any missing their lower labial frena. Two individuals were missing their lingual frena (Beighton scores of 2/9 and 4/9). One participant was missing both their lingual and lower left frena (Highest recorded Beighton score of 7/9). Two were missing only their lower right (Beighton scores of 0/9 and 2/9), and one was missing only their lower left (Beighton score of 4/9). Because so few subjects were missing any frena, it was not possible to do a sub-analysis on just these subjects. See Table 6.

Only two participants had a positive Gorlin sign, one being the child with the highest Beighton score of 7/9 and the other 4/9. Again, it was not possible to do a sub-analysis due to so few subjects. See Table 6.

<u>Other Correlated Demographic Information</u>

Relationships that were determined to have no statistical significance to Beighton score in a univariate regression included sex (p=0.752), weight (0.683), and height (0.872). (Table 9).

One of the few statistically significant relationships noted was the participants' answer to Question 6: "Do you bruise easily?" Those who answered yes had a Beighton score that was 1.56 points less than those who answered no (p=0.012). (Table 9).

Table 9: List of univariate analyses that were run against the Beighton score

Univariate Regression Analyses

	Effect Estimate	95% CI	p-value
Total Beighton Score **Max Opening [mm]**	0.06	(-0.05, 0.16)	0.3
Total Beighton Score **Max Opening with OB [mm]**	0.04	(-0.06, 0.14)	0.395
Total Beighton Score **Max Left Lat [mm]**	0.22	(-0.11, 0.54)	0.177
Total Beighton Score **Max Right Lat [mm]**	-0.01	(-0.34, 0.33)	0.973
Total Beighton Score **Max Left+Right Lat [mm]**	0.11	(-0.13, 0.35)	0.347
Total Beighton Score **Ratio Max Opening to Subnasale-Menton**	2.57	(-2.28, 7.43)	0.287
Total Beighton Score **Ratio Max Opening with OB to Subnasale-Menton**	1.91	(-2.44, 6.27)	0.376
Total Beighton Score **Female [Ref. Male]**	-0.21	(-1.54, 1.13)	0.752
Total Beighton Score **Weight [lbs]**	0.01	(-0.02, 0.03)	0.683
Total Beighton Score **Height [cm]**	-0.01	(-0.08, 0.06)	0.872
Total Beighton Score **Subnasale-Menton [mm]**	-0.04	(-0.15, 0.07)	0.465
Total Beighton Score **Q1: Yes [Ref. No]**	0.25	(-1.19, 1.7)	0.721
Total Beighton Score **Q2: Yes [Ref. No]**	2.63	(1.44, 3.82)	<0.001
Total Beighton Score **Q3: Yes [Ref. No]**	0.04	(-1.29, 1.36)	0.956
Total Beighton Score **Q4: Yes [Ref. No]**	0.76	(-2.92, 4.44)	0.676
Total Beighton Score **Q5: Yes [Ref. No]**	1.17	(-0.26, 2.6)	0.104
Total Beighton Score **Q6: Yes [Ref. No]**	-1.56	(-2.75, -0.36)	0.012
Total Beighton Score **Total Questionnaire Score**	0.65	(0.10, 1.20)	0.02

Discussion

Clinical Characteristics

In terms of the collected measurements, this population of 9–12-year-olds had a mean maximum mandibular opening of 55 ± 6.6 mm with and 51.4 ± 6.1 mm without overbite included. These values align well with other age-matched studies. Hirsch *et al* found a 50 mm mean in a 10–13-year cohort, although whether this value included overbite was not mentioned in his methods[51]. Ingervall *et al*, who did include overbite, recorded a mean of 51 mm for their population of 10-year-olds[40]. Quyen Vu Ying *et al* found a mean of 55.81 mm (including overbite) in 10-11 years[46]. The difference between the two measurements in this study suggests that this population was prone to mild/moderate excess overbite, but otherwise is fairly representative of children this age.

For maximum lateral excursives, this population had an average right lateral excursive of 10.3 ± 2 mm and average left excursive of 9.7 ± 2 mm. Again, this is similar to the established literature. Hirsch *et al* found right laterals to measure about 10.1 mm and left laterals to be 10.4 mm in a 10–13-year-old cohort[51]. Ingervall et al didn't differentiate between left and right in his population of 10-year-olds, but found a range between 10-10.5 mm, depending on sex[40]. Stoustrup et al provide a year-by-year breakdown for 4-17 year olds, and found similar laterotrusive means in the 9-12 year old cohorts, with boys having a somewhat higher average, although this sex difference was questioned[43]. While these numbers are within reason, it should be noted that like previous researchers have noted, it was difficult to coach the participants to properly perform this maneuver, especially the youngest ones[40,43,47]. Even when demonstrating visually and providing repeated coaching during the 2 warm-up stretches, multiple children attempted to open more vertically than horizontally. Therefore, these numbers are likely slightly lower than they should be. In the future, it may be helpful to use an oral aid, such as a popsicle stick to provide a repeatable surface to slide against[47]. There is also the option to use advanced computer software and extraoral devices to determine all maximum border movements[64], but this study was attempting to provide a more clinically approachable method.

In terms of the breakdown of Beighton scores, 23.3% of the children in the present study scored 5/9 or above. Previous studies have found values of 36.09%[28], 35.6%[6], and 5.8%[26] when 5/9 is the cutoff for hypermobility, so it can be considered a reasonable estimate of the greater population. However, the wide range in the literature is difficult to account for. One potential factor could include ethnicity[11,26], as some studies use a mostly homogenous population and others do not. In this study, ethnicity was not included as a background descriptor. In the future, it may be beneficial to record this as well, since the population that the University of Minnesota's dental clinics serve is relatively diverse. Another factor could be the sex of the patients. As previously discussed, women are generally acknowledged to have greater mobility at all stages of life, with it becoming statistically significant in the early teens[26]. This study did have a cohort slightly skewed towards females (17:13), which may have resulted in a slightly higher percentage of hypermobile individuals than is truly present in the larger population. However, this study, like previous studies, did not investigate the role that first menses may play in mobility. Therefore, it may be better to use age in combination with menarchal status when evaluating female cohorts in the future as this is the age range that it is likely to occur and may affect the results.

With regards to the individual components of the Beighton score, some interesting trends emerged. Only 2 of the 30 children had no hypermobility at all in either elbow, with 25 having hypermobility in both, as defined by the cutoff of 10°. This suggests that either there was measurement inaccuracy and/or that elbow mobility in this cohort is generally high. In terms of the first argument, the elbow measurements are typically harder to perform accurately and tend to have lower reproducibility, with a kappa hovering around the upper 0.50s[29]. However, in the Smits-Engelsman *et al* validity study, even the average degree of elbow hyperextension for kids with a low Beighton Score of 0-4 was 9°, which is only one degree away from a positive result. Therefore, it appears more likely that this is simply a common finding in this age group.

Conversely, only a small number of children had hypermobile knees, with only 1 child testing positive for both, and 4 testing positive for just one knee. It seems unlikely that this is a measurement error since the kappa is in the upper 0.80s for knees[29]. This study's protocol followed that of Smits-Engelsman *et al*, which was unusual in that it reported taking the knee measurements when the participants were lying down[6]. In that study, the only children to have an average 10° displacement of the knees were those who had an overall Beighton score of 7 or higher. In discussion with the Doctor of Physical Therapy who provided training to the researcher in this study, the result of performing this maneuver in a supine position is that the natural body weight adding to the hyperextension of the knees is removed, resulting in a lower measurement reading, and thus likely excluding those who would have had a positive reading and instead only including the most mobile of joints. Therefore, future studies should revert to the protocol of taking this measurement when standing, since upon visual examination, many children appeared to have hypermobile knees when upright, but tested negative when recumbent.

Based on the responses to the Grahame and Hakim Questionnaire, there is the possibility that it may be able to be validated in children in future studies. The data overall showed that a positive relationship existed between the Beighton Score and the Grahame and Hakim Questionnaire (Figure 10), but this study was not able to correlate specific Beighton cutoffs to those who answered 2 or more questions in the affirmative. Several issues became apparent during data collection that may explain this and thus warrant discussion. In general, most participants seemed to understand the question about bruising and question #1 about placing the hands on the floor, #2 about bending the thumb to the forearm, and #4 about dislocating the knee or shoulder more than once, as well as the part of #3 asking if they could do the splits. The part of question #3 about "contorting your body into strange shapes" and question #5 about being "double-jointed" often required further clarification. Frequently, the children would attempt to make shapes with their fingers to "prove" their double-jointedness, but these maneuvers were all very different and usually not indicative of hypermobility. Additionally, with many participants, there appeared to be an element of showmanship to their answers. Many would express that they could make these "shapes", but when asked to demonstrate what they could do, they often demurred or said they weren't sure. Perhaps if visual aids were provided, young people would be better equipped to copy the movement and provide a clear positive or negative response. Additionally, question #2 is likely not helpful in a young population since the response received from patients who tested negative for thumb hypermobility was often that they had never thought to perform the movement before the exam and thus didn't know. Therefore, it likely only has utility in people who have previously been tested with the Beighton criteria, which is rare in a pediatric population. The wording should also be slightly adapted to account for the age of each participant, since none of the tested children in this study's cohort were teenagers. Rothenberg *et al* are some of the few authors who have also attempted a questionnaire (a "temporomandibular joint awareness" questionnaire) in a young population of 4-14 year olds, and also experienced similar difficulties[47].

Regression Analyses

Overall, this study was unable to reject the null hypothesis for all specific aims. This is likely a result of not having a large enough sample size. Part of this was due to institutional issues, resulting in limited time for data collection. Additionally, the exclusion criteria proved to be more onerous than expected, as many age-screened children had a history of trauma or presented with signs of TMD, such as clicking or popping, and were thus excluded. (While there is evidence to suggest that this mild clicking and popping makes no difference to overall TMJ mobility[40,42,43,45,51,65], it was desirable to remove it as a confounding factor just in case.) Finally, the willingness and/or time constraints of parents to enroll their children resulted in very few qualified participants, with only about 1 in 4 screened patients consenting. Therefore, only 30 of the anticipated participants were enrolled.

As to specific aims 1 and 2 of this study, no statistically significant relationship was found for the maximum mandibular opening or maximum lateral excursives to the Beighton score, per a Pearson Correlation. It is not possible to determine if this is due to a lack of data or if there is indeed no relationship. However, it seems unlikely that the TMJ is not subject to the same forces of hypermobility that govern the other joints in the body. As briefly mentioned in the literature review, several authors make the argument that the TMJ should be measured in the same way that other joints are, i.e. angularly and not linearly[44,47,52,54]. Dijkstra *et al* posit that linear mouth opening is dependent on mandibular length and angular opening, and thus linear opening is not truly representative of a person's TMJ mobility (Figure 11). No studies appear to have used an angular measure of TMJ mobility against the Beighton score at this point, which would be worth investigation.

The methods of using angular TMJ measurement are clinically more involved (Figure 12), which did not fit within the parameters of this present study. However, to acknowledge the different facial morphologies of patients (brachycephalic, mesocephalic, and dolichocephalic), the ratio of maximum mandibular opening with and without overbite was correlated to the linear measurement from subnasale to menton (under the nose to under the chin). Even with this adjustment, no statistically significant correlation was found.

Debate exists in the literature whether factors such as age, height, or weight matter for children in regards to their maximum mandibular border movements[40,41,46,47,49,51]. This study did not find a correlation existing between Beighton score and height or weight, nor was one found for sex. The latter is an unusual result since as previously discussed, girls have a well-documented tendency towards having higher Beighton scores at all stages of life.[18] Again, this is likely due to small sample size. As for height and weight, since this cohort has a much narrower age range relative to other studies, it seems reasonable that there would be no statistical difference; however, this could be affected by sample size as well.

Lastly, for specific aim 3, at this time, no definitive statements can be made about the Gorlin sign or lack of frena in this population. The literature suggests that although it seems likely that the two are related, since a missing lingual frenum likely leads to greater mobility of the tongue, it may also be related to overall greater TMJ mobility as the jaw often slides forward to accomplish the task.[62] Larger cohorts can hopefully provide more illumination on the topic in the future.

Perhaps, the most surprising finding in the present study though is that participants responding positively to the question concerning their tendency to bruise had a statistically significant ($p=0.012$) inverted relationship with the Beighton score. The presence of bruising is considered an indicator of hypermobility in the Hospital del Mar criteria, and it is difficult to say why the opposite is true here. One explanation may be that the Hospital del Mar criteria merely evaluates patients for current bruising and does not ask the patient "Do you bruise easily?" While all the children appeared to understand the question, some may have over or under-estimated their tendency. Additionally, many patients appeared to be of east African background with darker complexions, which is consistent with the greater Twin Cities metropolitan area. Research suggests that bruising may not stand out visually in normal lighting on darker-skinned individuals in the same way that it does on someone of lighter complexion[66] (Figure 13). Therefore, it may be best to include a physical examination of bruising, in addition to the question.

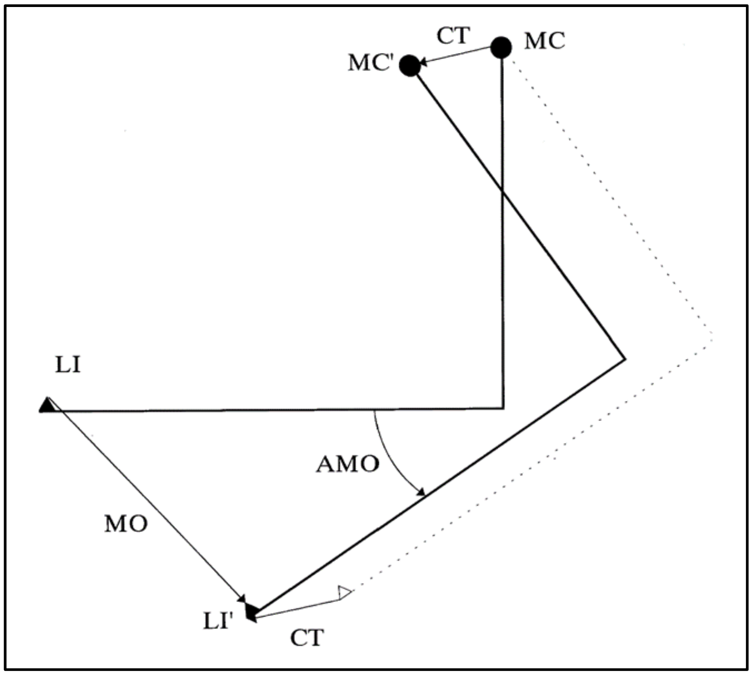

Figure 11: Diagramatic representation of the mandible showing that maximum opening (MO) is related to mandibular length (LI) and the maximum angular opening (AMO). MC = Mandibular condyle. CT = Condylar translation. From Dijkstra et al.[44]

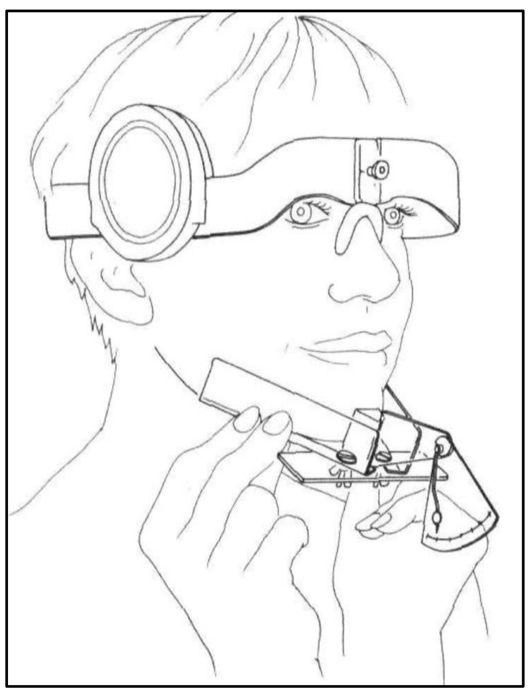
Figure 12: Mandibular and cervical goniometers in position to determine angular maximum opening. From Dijkstra et al[53].

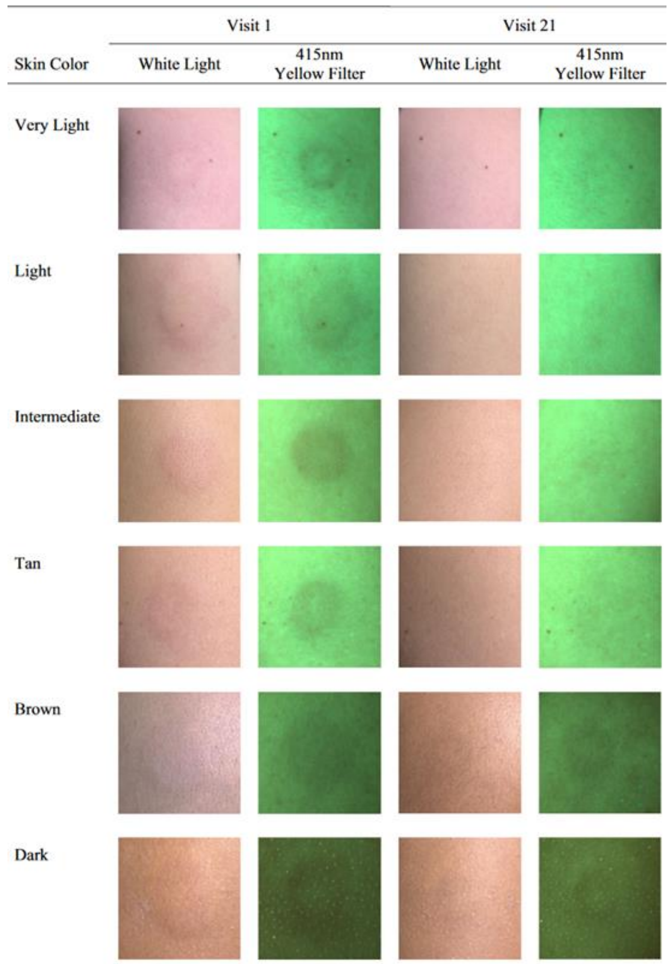

Figure 13: Comparison showing how different skin tones show bruising immediately after and 3 weeks after standardized inflicted injury from a paintball gun under white and filtered yellow light. From Scafide et al[66].

Conclusions

- Participants in this study had clinical characteristics well-matched to those in similar studies.
- A relationship between TMJ hypermobility, as defined by linear maximum mandibular border movements, and Beighton score could not be established in this population at this time.
- The Grahame and Hakim questionnaire may have validity in this population, but revisions are likely necessary to improve sensitivity and specificity.
- More participants will be needed to establish if frena and Gorlin sign are present in those who are hypermobile.

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Appendix

Table 10: Alternate analyses of the Beighton Score to the mandibular border movements

Relationship to Total Beighton Score				
	Spearman Rank Correlation		Ordinal Logistic Regression	
	r	p-value	OR (95% CI)	p-value
Max opening w/o OB	0.12	0.52	1.06 (0.95-1.17)	0.32
Max opening with OB	0.11	0.56	1.04 (0.95-1.15)	0.39
Max left lateral	0.23	0.23	1.29 (0.91-1.82)	0.16
Max right lateral	0.03	0.87	1.01 (0.73-1.42)	0.93
Max right + left lateral	0.2	0.28	1.16 (0.90-1.51)	0.27

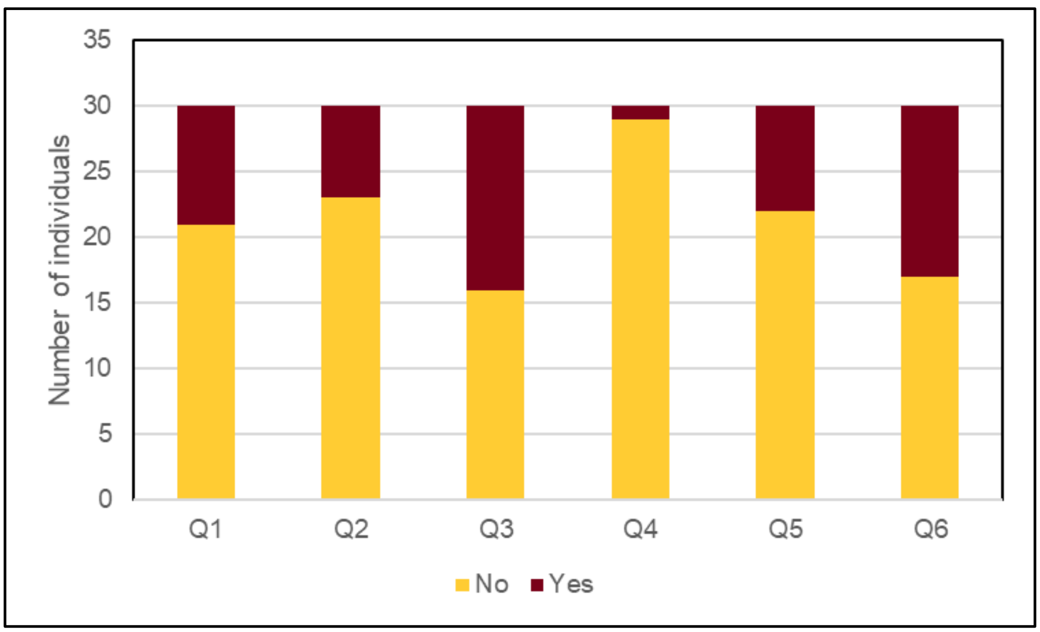

Figure 14: Graphical representation of responses to each individual question of the Grahame and Hakim questionnaire

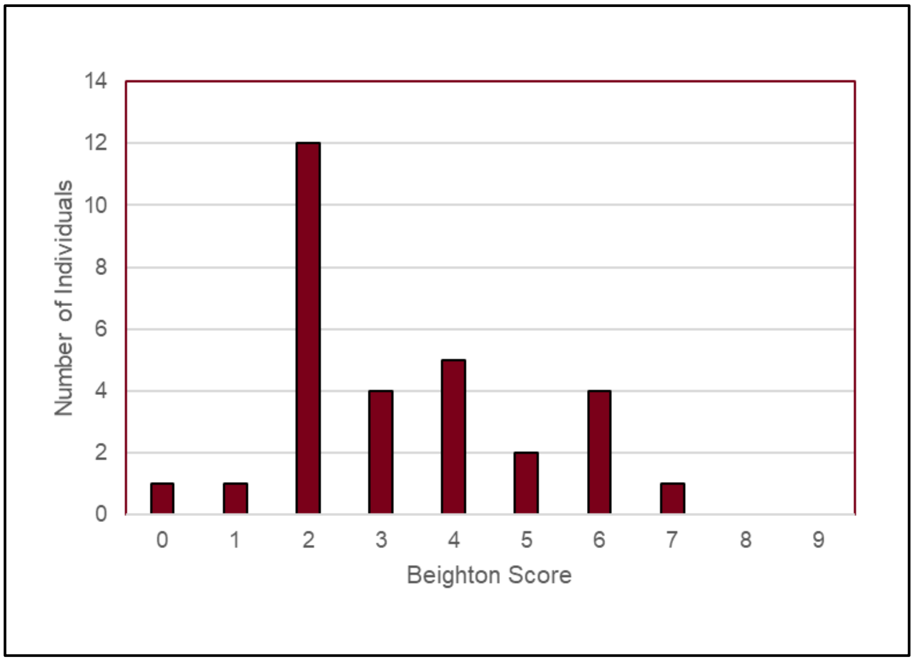

Figure 15: Graphical representation of the Beighton score population distribution

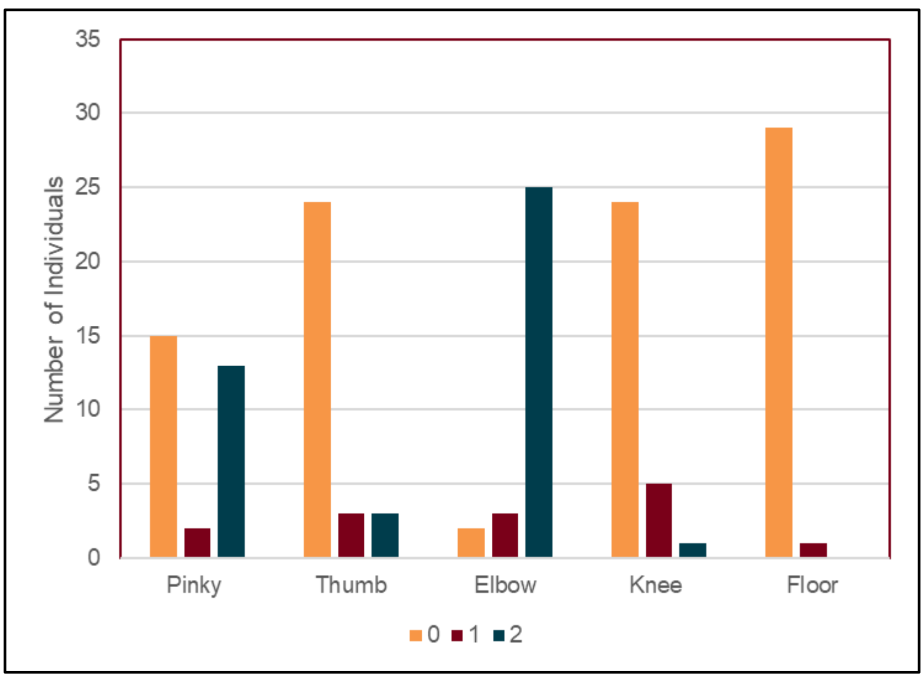

Figure 16: Graphical representation of how many participants scored a 0 for having no bilateral joint hypermobility, a 1 for having hypermobility in either the left or right joint, or a 2 for having bilateral joint hypermobility. Touching the floor is scored only as a 0 for being unable to complete the maneuver or a 1 for being able to do so.