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Changes in marginal ridge alignment from early childhood to late adulthood in an untreated Caucasian population using the Iowa growth study sample

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CHANGES IN MARGINAL RIDGE ALIGNMENT FROM EARLY CHILDHOOD TO LATE ADULTHOOD IN AN UNTREATED CAUCASIAN POPULATION USING THE IOWA GROWTH STUDY SAMPLE.

by

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

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has been approved by the Examining Committee for
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ABSTRACT

Introduction: The purpose of this study was to evaluate the changes in marginal ridge alignment occurring through normal growth and development from early childhood to late adulthood and to examine if any statistical variation exists between males and females.

Methods: Dental casts of 38 subjects (15 females and 23 males) from the Iowa Growth Study were selected. The marginal ridge discrepancy was measured as the absolute value difference between adjacent marginal ridges of 20 interproximal contacts with both the ABO tool (data not shown) and a vertically mounted digital caliper. Upper and lower casts were tripoded to a level plane defined by the most posterior tooth and central point of the most erupted central incisor. A 15 subject calibration was used to measure inter-examiner reliability using the Cronbach's Alpha and Kappa tests. The independent samples *t* test was used to examine the correlation of marginal ridge discrepancies between males and females.

Results: Cronbach alpha ($p \le .001$) and Kappa test ($p \le .01$) show excellent inter-rater reliability. The independent sample *t* test showed no statistical significance, with minimal exception, in marginal ridge discrepancies between males and females matched for age ($p > .05$). Group 1 showed significantly higher number of marginal ridge discrepancies within ABO range of 0 – 0.5 mm of males and females compared to Group 2.

Conclusion: Based on this study, no statistically significant differences were found in marginal ridge discrepancies between males and females. Also, the magnitude of marginal ridge discrepancies of erupting permanent teeth shows a decrease as an individual proceeds through growth and development and they remain relatively "level" during primary dentition.

PUBLIC ABSTRACT

Due to the limited amount of research about the alignment of a person's bite as they grow, it was important to look at how teeth erupt into the mouth from a child to an adult (2^{nd} decade). Therefore, we used dental models from 38 people from the Iowa Growth Study to measure height differences as the teeth erupt into the mouth and align themselves as each person grows and matures. Also, we wanted to see if any differences occurred between males and females in their tooth alignment measurements. A specific tool was fabricated to make accurate measurements to reduce the risk of ambiguity that could introduced with a less accurate tool. Because a large age range existed we split the ages into three groups: Group1 (5 – 9yrs), Group 2 (>9 – 14) and Group 3(15 – 29). Our findings indicated little to no differences between males and females in how the teeth erupt and align during growth. Also Group 1 had a much higher number of level (0 – 0.5 mm) teeth compared to Group 2. In addition to little differences between males and females, height differences between permanent teeth showed a levelling trend as the individuals proceeded through growth into adulthood (2^{nd} decade).

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INTRODUCTION

The earliest of beginnings for the primary, and ultimately, permanent dentition, can be observed as early as six weeks in utero. Over the next four to six months, the twenty primary tooth buds are forming beneath the oral epithelium of an individual, soon to erupt into the oral cavity. The dental lamina, an epithelial thickening, is directed by local growth factors and genes to establish the proper anteroposterior axis and the appropriate placement of these twenty tooth buds (Nanci, 2013; Fuller 2001). As cell proliferation and differentiation continues from the dental lamina, the primary tooth buds begin to resemble the crown of a tooth while the attachment to the lamina disappears and gives rise to twenty permanent tooth buds on the lingual aspect of the primary buds. The remaining four to eight permanent tooth buds (four second molars and four third molars) originate from a distal extension of the aforementioned dental lamina pushing beneath the oral epithelium (Nanci, 2013). Until approximately two to three years of age, the primary dentition continues with root formation and eruption into the oral cavity, giving rise to a latent period until age 6 or 7 years.

As crown formation comes to completion, the initial stages of root formation begin with tooth eruption initiating simultaneously. On average, root formation lasts about one year for the deciduous dentition with eruption continuing until 2 to 3 years of age (Ash, 1993). The transitional dentition is marked by eruption of first molars and central incisors, following the guidance of primary teeth as a foundation for the future permanent occlusion, at an approximate age of 6 to 7 years of age (Ash, 1993). As permanent teeth erupt and primary teeth exfoliate, a naturally occurring phenomenon occurs in the development of the curve of Spee. This was noted and discovered in the 1890's by Ferdinand Graf von Spee as a naturally occurring downward convex curve along the maxillary molars and a compensating upward concave curve formed from the mandibular molars (Spee, 1980).

A natural byproduct of orthodontic treatment is leveling of the curve of Spee, ideally, leveling marginal ridges. Andrews et al (1972) noted that the best intercuspation was when the occlusal plane was relatively flat, giving evidence for the importance of leveling the curve of Spee, even to the extent of overtreatment. While there may be little correlation between depth of curve of Spee and upper incisor position and lower incisor crowding, there is significance in depth of curve of Spee and overjet and overbite (Baydas, 2004). However, as seen repeatedly, aspects of orthodontic treatment seem to show some degree of relapse. The large question here being what does long term stability appear to be with leveling the curve of Spee? De Praeter et al and Shannon et al both investigated this topic. The definition of "long term" may be relative to each practitioner but De Praeter examined stability at a mean time point of 6.7 years following treatment while Shannon looked at a mean of 2 years 8 months post treatment. Both authors concluded that leveling the curve of Spee is a relatively stable procedure with somewhat conflicting results. De Praeter concluded that the initial depth of curve of Spee was an indication for amount of relapse and the amount of leveling was not correlated with amount of relapse of curve of Spee and three other parameters (overjet, overbite, and irregularity index). Shannon, however, found the greater the amount of leveling the greater the chance of relapse. This was in conjunction with the more molar up righting performed the more curve of Spee relapse.

Leveling the curve of Spee must involve, to some extent, alignment of adjacent marginal ridges of posterior teeth. Comprehensive orthodontic treatment involves producing an occlusal table with proper tooth to tooth contacts. In doing so, many authors have debated the importance of leveling adjacent marginal ridges for a variety of reasons. Burch et al for example, reasoned that arch integrity and prevention of food impaction warranted marginal ridge alignment. Along with establishing proper occlusal contacts, Palamara et al noted that "The marginal ridge is considered fundamental to the ability of the tooth to resist functional and parafunctional occlusal loads without damage." However, authors on the other side of the debate give several reasons as to why it shouldn't be of major concern to level marginal ridges without other clinical purposes. One argument is that the presence of plaque and calculus is of much more concern in establishing and maintaining a healthy periodontium and even if gross discrepancies exist, the periodontal tissues and papilla will stay healthy with little to no attachment loss (Kepic, 1977). Additionally, no statistical difference is shown between periodontal attachment loss in patients with even and uneven marginal ridges and individuals can show a normal variation of ridge discrepancy up to 2 mm (Prince, 1969).

Multiple methods of bracket placement exist to which an attempt is made to level not only the curve of Spee but also marginal ridges. Brackets can be bonded in the center of the anatomic crown or in relation to the marginal ridge discrepancy as it presents clinically. Manni et al suggested that bracket placement should mirror the marginal ridge discrepancy for that interproximal contact, as an attempt to level marginal ridges. Also, Suárez et al revealed that bracket placement utilizing a measured or fixed distance from the incisal or occlusal surface would result in deterioration of marginal ridge alignment much more often than proper alignment. The study showed that marginal ridges deteriorated 41% to 71.4% and improved in only 22.8% to 48.7% of cases.

The American Board of Orthodontists, referred to as the 'ABO', utilizes the Model Grading System to score dental casts and panoramic radiographs. The Model Grading System was developed in an attempt to find a precise testing method to objectively evaluate posttreatment dental casts and radiographs. This grading system is comprised of eight criteria: alignment, marginal ridges, bucco-lingual inclination, occlusal relationships, occlusal contacts, overjet, interproximal contacts, and root angulation (ABO, 2012).

Of particular importance to this study was the criteria of marginal ridge alignment. Insufficient literature exists documenting marginal ridge alignment in an orthodontically untreated population in relation to natural growth and development. The ABO grading system strives to have marginal ridges with a vertical discrepancy of 0.5mm or less in an effort to keep bone levels flat in a periodontal healthy individual. The rationale is that if marginal ridges are level, the cementoenamel junctions will be at the same level, producing bone levels that are flat. Another benefit of marginal ridge alignment is establishing proper occlusal contacts, in that marginal ridges allow for contact areas with opposing cusps (ABO, 2012). However, in contrast to the other seven ABO grading criteria, no cited literature is present for marginal ridge alignment as the ABO describes.

The purpose of this study was to evaluate the changes in marginal ridge alignment occurring through normal growth and development from early childhood to late adulthood and to examine if any statistical variation exists between males and females.

LITERATURE REVIEW

Tooth Development

Initial evidence of tooth formation can be seen as soon as the sixth week of intrauterine development. The origin of the dental organ in a process known as odontogenesis. This process can be described in two different classifying schemes, (1) morphologic stages or (2) physiologic processes (Fuller, 2001).

Morphologic Stages

The first stages of tooth development begin as early as 6 weeks in utero with formation of the dental lamina, an epithelial thickening. Mesenchymal markers such as LIM-homeobox (Lhx) domain genes, Lhx-6 and Lhx-7 are induced by fibroblast growth factor-8 (Fgf-8) to initiate tooth formation, establishing an oral-aboral (anteroposterior) axis (Nanci, 2013). Following formation and differentiation of the dental lamina, twenty tooth buds form from the epithelial thickening comprising the future primary dentition, thus resulting in the bud stage (Figure 1). The genes Fgf-8, previously mentioned as playing a role in the anteroposterior relationship, and Pax-9 both regulate and define the areas of these tooth buds (Nanci, 2013). As the bud stage progresses, the basal portion of the bud begins to invaginate and form a structure known as the dental organ, strongly resembling "…a cap sitting on a ball of condensed ectomesenchyme" (Nanci, 2013). The dental organ is more appropriately referred to as the enamel organ and is responsible for the formation of a tooth's enamel. The enamel organ forms a "cap" over the condensed ectomesenchyme, or dental papilla, and will form the tooth's dentin and pulpal tissues (Nanci, 2013). As seen in Figure 1, the enamel organ continues to develop and elongate, forming a structure resembling a bell. The bell stage is characterized by the majority of a tooth's dentin and enamel being laid down to form the crown with the dentinoenamel junction, or DEJ, being identifiable. As the crown continues to form, the connection with the dental lamina disappears with the bud of the succedaneous tooth forming from this remnant of the lamina on the lingual aspect of the deciduous tooth germ (Nanci, 2013). As the bell stage nears completion, ameloblasts and odontoblasts continue to lay down enamel and dentin until the cementoenamel junction is formed. However, the tooth germs or buds, of nonsuccedaneous teeth (1^{st}, 2^{nd}, 3^{rd} molars) do not originate the same as the succedaneous teeth. Once the jaws have grown sufficiently, the dental lamina pushes beneath the oral mucosa into the ectomesenchyme (Figure 2), giving rise to a backward extension of tooth germs of the first, second, and third molars (Nanci, 2013).

Root formation begins with the enamel organ forming the Hertwig's sheath, or Hertwig's epithelial root sheath. This apparatus functions to lay down the dentin and cementum vital for a tooth's root formation and persists "…only at the advancing root edge where cell division takes place and the process of root induction continues until the root is complete" (Nanci, 2013). Tooth eruption begins shortly after initial root formation and proceeds with the tooth breaking through the alveolar mucosa into the oral cavity, continuing until it contacts a tooth in the opposing arch. In general, root formation lasts approximately one year for each deciduous tooth, with all primary teeth being completely formed by about age 3 (Fuller, 2001).

Physiologic Processes

Physiologic processes overlap with the above mentioned morphologic stages and can be described as Fuller et al does:

> "(a) Initiation – The initiation process includes the dental lamina and bud stages, and affects the presence or absence of tooth buds.
>
> (b) Proliferation – Proliferation occurs during the bud, cap, and bell stages, and influences the general size and proportions of the developing tooth.
>
> (c) Histodifferentiation – This process takes place from the advanced cap stage through the bell stage, and involves the formation of potential enamel and dentin forming cells.
>
> (d) Morphodifferentiation – The shape and size of the tooth is determined during this process, which takes place during the bud, cap, and bell stages. A disturbance during morphodifferentiation may influence the size and shape of a tooth, but have no effect on the enamel and dentin forming process.
>
> (e) Apposition – This process is active during the bell stage through the completion of the root, and involves the regular laying down of the enamel and dentin."

Timing of Tooth Eruption

On average, the eruption of the primary dentition spans from the 6th to 30th month of postnatal life and can span 2 to 3 years prior to completion. One important aspect is the timing of this eruption. Not all of the teeth erupt at the same time, but rather, develop sequentially due to formation and development of the enamel organs for each individual tooth. This sequential development mirrors into an individual's eruption sequence for groups of teeth (e.g., central or lateral incisors), but yet, can still show a wide variation in timing within the same individual (Figure 3A). It is important to note that eruption of the primary dentition plays an enormous role in establishing and influencing neurobehavioral mechanisms such as jaw movements and proper mastication.

In the article titled *Tooth-position, arch-size, and arch-shape in the primary dentition*, the importance of the dentition was described as follows:

"Normal dentofacial growth and development strongly suggest coordination in the development of the dentition of both jaws. The occlusal anatomy of the posterior teeth and their intercuspation are supposed to play a major role in this process." (Tsai, 2001)

Once the full complement of primary teeth have erupted, about 3 years of age, there is a latent period until the age 6 to 7 years in which few changes occur intraorally. During this time, dental arches remain constant in width and height. As an individual enters into the transitional dentition, marked by eruption of permanent first molars and exfoliation of primary incisors, the primary dentition establishes the future permanent occlusion (Figure 3B). The permanent first molar is guided into the oral cavity by the distal surface of the primary second molars. This can be problematic if a distal step is present with the primary second molars, resulting in a malocclusion. Once the primary dentition has completed around age 3, it lasts until about the age of 11 or 12 depending on an individual's variation of eruption (Ash, 1993). During this period of 8 to 9 years, primary teeth are exfoliated as permanent successors emerge into the oral cavity. After the last primary tooth has exfoliated, an individual is now in the permanent dentition (Figure 3B).

Eruption sequence of the permanent teeth shows a greater variation when compared to the primary predecessors. As a general observance, the mandibular teeth of a group of teeth (e.g., molars, incisors) erupt into the oral cavity prior to their maxillary counterpart. However, this eruption sequence is opposite when considering premolars. Maxillary premolars tend to erupt prior to the mandibular as a result of canine eruption differences between arches. Mandibular canines erupt prior to premolars but maxillary canines tend to erupt after premolars (Ash, 1993).

History of Curve of Spee

Just before the 1900s, Ferdinand Graf von Spee noted a curvature of the occlusal plane which existed in the natural dentition. Beginning with the incisors and extending back through the second molar, it ultimately finishing its' arc along the anterior surface of the condyle. If viewing the occlusal plane sagittally, Spee noted the maxillary molars forming a downward convex curve with the mandibular molars forming a compensating upward concave curve (Spee, 1980).

An alternative theory, which surfaced approximately 30 years following Spee's, was coined the spherical theory by George Monson. His theory originated as a result of numerous studies involving mandibular movements. In addition, he concluded that if the many developing factors were controlled, the mandible, and ultimately the teeth, would develop in a spherical arrangement from the mandibular teeth moving or following the occlusal surfaces (convex arc) of the maxillary teeth. Monson likened the "spherical" arrangement of the mandibular teeth as if they were arcing around the surface of an 8 inch sphere, with the radius in the region of the crista galli (Starke, 2002).

As a result of these, and numerous other, previous studies and literature we now know the curve of Spee to be a natural phenomenon occurring during, and as a result of, growth and development. The development of occlusion from primary to permanent dentition is vital in understanding the development of the curve of Spee.

Relationship between Curve of Spee and Orthodontics

As described previously, the curve of Spee is a naturally occurring phenomenon with the mandibular teeth forming an arc or curve tangential to the occlusal surfaces of the posterior teeth and incisal surfaces of anterior teeth. However, while there has yet to be any clear guidelines set for finishing orthodontic treatment with level occlusal planes, the natural result of orthodontic treatment is leveling of the curve of Spee. While the curve of Spee has been cited as mild to moderate in the primary dentition, it can vary from mild to severe in the adult dentition (Ash, 1993). In a study (Andrews, 1972) examining casts of 120 nonorthodontic patients with normal occlusion, Andrews noted that the curve of Spee ranged from generally flat to mild with not all of the individuals possessing a flat occlusal plane. However, he firmly believed that a goal of treatment, even to the extent of overtreatment, would be to level the occlusal plane. His reasoning was as follows:

Intercuspation of teeth is best when the plane of occlusion is relatively flat. There is a tendency for the plane of occlusion to deepen after treatment…It seems only reasonable to treat the plan of occlusion until it is somewhat flat or reverse to allow for this tendency.

A deep curve of Spee results in a more contained area for the upper teeth, making normal occlusion impossible.

Baydas et al investigated the relationship between the depth of curve of Spee and overjet, overbite, lower arch crowding, and position and inclination of the upper and lower incisors. He selected 137 untreated subjects: 76 girls and 61 boys in the age range of 13 to 16 years. Three Spee groups (normal, flat and deep) were organized and curve of Spee measured. There was no statistical significance found between depth of curve of Spee and position of upper incisors and lower anterior crowding. However, there was clinical significance found between depth of curve of Spee and overjet and overbite. Overjet and overbite measurements were much larger in the deep curve of Spee group when compared to the flat or normal Spee groups. Also, the largest discrepancy of overjet and overbite was between the deep Spee and flat Spee groups. They summarized their findings as follows:

…the findings of the present study suggested that the positions and inclinations of the lower and upper incisors and anterior lower crowding were not affected by the variation of the depth of curve of Spee, whereas the amount of overjet and overbite was significantly influenced by the variation of the curve.

Once the curve of Spee has been leveled (in most instances) as a result of opening the bite, it's important to remember the possibility of relapse, but how much? One author, De Praeter, examined just this. Long term stability of leveling the curve of Spee was investigated by measuring 149 dental casts of 57 males and 92 females orthodontically treated. Casts were taken at three different intervals: pre-treatment (T1), post-treatment (T2) and

6.7 years (mean) following treatment (T3). Both the curve of Spee and irregularity index of digital photographs of the dental casts were measured and changes in curve of Spee were compared to the irregularity index, overjet, and overbite from T1 to T3. Results found:

(1) *Leveling of the curve of Spee is a relatively stable treatment procedure compared with a return of incisor crowding and deepening of the bite*

(2) *Neither the initial depth of the curve of Spee nor the initial irregularity index is an indicator for the amount of relapse*

(3) *The amount of leveling is not correlated with the relapse of the 4 tested parameters (curve of Spee, irregularity index, overjet, and overbite)*

(4) *There is a mild correlation between the relapse of the curve of Spee and the relapse of the irregularity index, overjet, and overbite*

Similar to De Praeter, another author, Shannon (Shannon, 2004), examined long term stability of curve of Spee leveling in an orthodontically treated population at least 2 years posttreatment. The study sample examined was 50 individuals split into groups based on Angle classification: 23 Class I, 21 Class II division 1, and 6 Cl II division 2 with 20 being extraction and 30 nonextraction. Lateral cephalograms and dental casts were taken for each patient pretreatment, posttreatment and at least 2 years posttreatment (postretention). The mean for postretention was 2 years 8 months and ranged from 2 years to 5 years 8 months. Dental casts of all individuals were tripoded and the vertical position of each tooth was measured using a vertical push dial indicator. Vertical measurements were obtained from the buccal cusp tips of posterior teeth (maxillary and mandibular), but excluding the canines due to variability of eruption status, common ectopic positions and how frequently they erupt above the occlusal plane. Lateral cephalograms were traced and digitized from pretreatment, posttreatment and postretention, along with measurements of irregularity index and intercanine width of mandibular casts at these same three time points. Cephalogram tracings were utilized for evaluation of treatment changes and relapse of curve of Spee. Pretreatment FMA, lower mandibular plane angles, more mesially inclined molars, overbite, and overjet were all positively correlated with a deeper curve of Spee. Also, as one might expect, due to unimpeded eruption of the lower incisors and increased overjet, Class II patients revealed deeper curves of Spee when compared to Class I patients.

Results from posttreatment measurements show curve of Spee leveling occurred through up righting of molars, extrusion of premolars and incisor flaring or intrusion. Postretention revealed no significant differences in curve of Spee relapse between Class I and II patients, or between extraction and nonextraction patients. There was, however, a significant correlation between amount of molar up righting and relapse. Also, a significant correlation between amount of leveling and relapse. The greater the extent of leveling during treatment the greater the amount of relapse.

Although the ABO has yet to establish a guideline of leveling the curve of Spee, it is clear that marginal ridge leveling will inevitably play a major role in leveling the curve of Spee. Therefore, it's important to understand not only the importance of marginal ridges but also the ABO requirement of leveling marginal ridges and reasoning behind it.

Importance of Marginal Ridges

There have been suggestions for multiple reasons why the practice of aligning marginal ridges is important to the final occlusion. One of which would be to aid in prevention of food impaction and arch integrity (Burch, 1975). Other proposed reasons include aligning marginal ridges for occlusal contacts of a cusp on either a flat plane (bottom of a fossa or marginal ridge) or a combination of flat plane and inclined planes (Ziebert, 1979). In fact, the structural make up and occlusal loading of marginal ridges of mandibular premolars was examined. Palamara et al stated "The marginal ridge is considered fundamental to the ability of the tooth to resist functional and parafunctional occlusal loads without damage." Eleven previously extracted, but intact, mandibular premolar teeth were used to develop a three-dimensional FEA model of a human mandibular premolar in an effort to compute strains of loading from processes such as clenching and chewing. Results revealed the marginal ridges and contact areas were points of low strain values. Also, the structural make up of marginal ridges reveals an increased thickness of enamel in these areas and noted "loss of tooth structure in this area associated with restorative procedures is generally regarded as the major factor in weakening teeth." Therefore, combining these with the findings of Andrews on leveling the curve of Spee for proper occlusion and occlusal contacts, would suggest that it would benefit to have the occlusal plane level to establish the highest number of contacts on marginal ridges to distribute forces and loading more evenly.

Consequently, there needs to be a system in place to establish alignment of adjacent marginal ridges utilizing proper bracket placement. Some suggest that bracket placement should be correlated with the marginal ridge discrepancy in an attempt to level ridges (Manni, 2007). In addition, other studies have compared the difference between bracket slot placement at a measured distance from incisal edge and transferring the embrasure height difference to bracket slot height difference (Eliades, 2005). These, among others, have shown support for bonding brackets in relation to marginal ridge height differences to achieve an ideal functional occlusion with appropriate occlusal contacts.

Suárez et al (Suárez, 2010) sought to examine the method of bracket placement utilizing digitized models with fixed values from the incisal and occlusal surfaces in leveling marginal ridges. Forty-seven digitized models (5 were excluded) were selected, at random, of Caucasian individuals interested in orthodontic treatment for Class I, Class II division I or division II. The OrthoCAD software was utilized in a digital setup of all casts and used the ABO grading system to digitally measure marginal ridge discrepancies prior to treatment (T1). All models were treated (virtually) with MBT Victory brackets of 0.022 inch slot size with final arch wire size as 0.019 x 0.025 inch stainless steel. At completion of virtual treatment (T2), marginal ridges were measured, utilizing the ABO grading system, to evaluate leveling of the arches. In addition, any values above 0.5 mm were set as clinically significant and needing correction, per ABO standards of grading. The authors summarized their results as follows:

"The results of the present study show a tendency for marginal ridge values to deteriorate after leveling using computer prediction, when brackets are positioned at fixed heights from the incisal or occlusal edges…It should be noted that, in the upper arch, the points that initially showed the best marginal ridge relationship experienced the greatest deterioration compared with the other points…Marginal ridges deteriorated between 41 and 71.4 per cent of cases and improved in 22.8-48.7 per cent"

Numerous other studies show little significance in establishing level marginal ridges in the prevention of food impaction or periodontal attachment loss. For example, one such study revealed that the presence of plaque and calculus deposits is much more important in maintaining a healthy periodontal apparatus. Also, that even if gross marginal ridge discrepancies were present but patient maintained proper oral hygiene practices, periodontal tissues and papilla remained healthy and little to no loss of periodontal attachment (Kepic, 1977). Others have shown that no statistical difference exists between periodontal attachment loss in patients with even marginal ridges and uneven marginal ridges. In addition, it has been shown that an individual can display a normal variation in marginal ridge heights of up to 2mm (Prince, 1969).

The American Board of Orthodontics (ABO) established a unique Model Grading System after a series of four field tests to determine the reliability of such system. Its' first use was at the February 1999 ABO clinical examination in St. Louis, MO. The ABO Model Grading System, which involves scoring both dental casts and panoramic radiographs, is composed of eight criteria: alignment, buccolingual inclination, interproximal contacts, marginal ridges, occlusal contacts, occlusal relationships, overjet, and root angulation (ABO, 2012). Of particular importance to this paper is marginal ridge alignment and root angulation in establishing marginal ridge alignment.

Marginal ridges are to be used in assessing proper vertical positioning of the posterior dentition. If adjacent marginal ridges are aligned at the same level, in a periodontally healthy individual, the cementoenamel junctions (CEJs) of these teeth should be level, resulting in alveolar bone levels that are flat. In addition, level marginal ridges will allow for proper occlusal contacts with the opposing dentition. To assess the degree of marginal ridge discrepancy, the ABO has established a point system in grading alignment. Ideally, marginal ridges should be at the same level or within 0.5mm of each other. If the discrepancy is between 0.5 to 1mm, 1 point is scored. If it becomes greater than 1mm then 2 points will be scored for that interproximal contact (ABO, 2012).

It is well known by the ABO and others that the traditional panoramic radiograph is less than ideal in showing accurate root angulation due to the anatomic morphology of the jaws and the rotational path of the radiograph. Multiple studies cite their results showing the traditional panoramic radiograph is not reliable in showing accurate root angulation as it truly is anatomically. The panoramic radiograph tends to overestimate mesial root angulation in the anterior teeth and distal angulation in posterior teeth (Owens, 2007). An excellent alternative does exist with the cone beam computed tomography (CBCT) showing an accurate anatomic model of the teeth, jaws and supporting structures (Peck, 2009). These are important points to remember when deciding whether to move roots mesial or distal in achieving level marginal ridge alignment.

MATERIALS AND METHODS

Subject Sample

The Iowa Growth Study, began in 1946 by L. Bodine Higley and Howard Meredith, and consisted of 86 female and 89 male individuals. All of which, were of Northern European descent with normal, acceptable occlusions as determined by Higley. Dental records including dental casts, lateral cephalograms, and anterior cephalograms were taken twice a year from age five to twelve. Following that, these same records were taken annually and then taken once in early adulthood (mean age 26 years). Of these 175 individuals from above, 57 had dental casts spanning primary to permanent dention (27 females, 30 males), 55 had casts from primary to transitional dentition, 15 had casts only in the primary dentition, 40 had casts from primary to early permanent (permanent teeth not fully erupted), and 8 had no casts. Exclusion criteria included: orthodontic intervention, missing casts and individuals who did not have casts spanning the primary to adult dentition. After applying the exclusion criteria, 15 females and 23 males were selected for this study.

Measuring of Marginal Ridge Discrepancies

The marginal ridge discrepancy was measured as the difference in adjacent marginal ridges of that interproximal contact. A total of twenty interproximal marginal ridge discrepancies were measured for each of the 38 subjects using a digital caliper (Carrera Precision 6-inch digital LCD caliper) vertically mounted to a surveying table (Figure 4) and the ABO grading tool (Figure 5). For purposes of the digital caliper, mandibular dental casts were then tripoded with the distobuccal cusps of the most posterior teeth and the most central point of the most erupted central incisor. Maxillary dental casts were tripoded with the mesiolingual cusps of the most posterior teeth and the most central point of the most erupted central incisor. Primary central incisors were used to level the dental casts of primary dentition rather than its' permanent successor.

To accurately assess marginal ridge discrepancies with the digital caliper, the marginal ridge of adjacent posterior teeth composing an interproximal contact were measured and recorded. For example, the interproximal contact between the lower left second molar and lower left first molar is composed of two marginal ridges: mesial marginal ridge of the second molar and distal marginal ridge of the first molar. Therefore, each of those were measured to within 0.01 mm and recorded with the discrepancy calculated as the difference between those two marginal ridges. This protocol was repeated consistently for all twenty posterior interproximal contacts of the primary, transitional, and permanent for each of the 38 subjects.

Marginal ridges were measured with the ABO tool (Figure 5) (only raw data shown) as described in the American Board of Orthodontics Grading System for Dental Casts. As pictured, the ABO tool is fabricated with 1mm incremental steps (Figure 5) to determine approximate marginal ridge discrepancy. ABO scoring guidelines indicate that adjacent marginal ridges should be level or within 0.50 of being level (Figure 6A). If adjacent marginal ridges are between 0.50 and 1 mm (Figure 6B), then that interproximal contact receives 1 point. If the discrepancy is above 1 mm (Figure 6C), 2 points are given to that contact area. Although the ABO does not routinely include measuring marginal ridge discrepancies between the distal of lower first premolars and mesial of lower second premolars, it was decided to include this discrepancy in the data collection.

Additionally, the ABO has no criteria for grading or scoring marginal ridge discrepancies in the primary dentition for obvious reasons of not going through comprehensive orthodontic treatment. However, it was decided to measure ridge discrepancies in the primary and transitional dentitions so as to keep measurements reliable and consistent. Therefore, only the marginal ridge discrepancy between upper and lower primary first and second molars were recorded. In the transitional dentition, measurements between upper and lower primary second molars and permanent first molars were recorded. No measurements were made between primary second molars and permanent first premolars. A total of twenty interproximal marginal ridge discrepancies were measured and recorded for dental casts corresponding to each time point of a subject.

Statistical Methods for Marginal Ridge Measurements

The age time points were divided into three groups to make comparison between males and females.

Group 1: 5 – 9 yrs (Table 1)

Group 2: 9.5 – 14 yrs (Table 2)

Group 3: 15 – 20s

The Independent Samples *t* Test (Tables 3-5) was performed to measure the correlation of marginal ridge discrepancies between males and females. The Independent Samples *t* Test serves to compare the means of two independent groups to determine statistical evidence that the population means are significantly different. The Levene's test was used to test the equality of assumptions between males and females.

Reliability Measurement

A random sample of 15 individuals, 7 females and 8 males, were selected for reliability measurements. A set of dental casts (upper and lower) were selected for each individual from the primary dentition and permanent dentition. Measurements of the same 20 marginal ridge discrepancies as mentioned above, were performed and recorded for both the ABO tool and digital caliper. To measure reliability for each tool and its measurements, the Cronbach's Alpha (Table 6) test was used for the digital caliper and Kappa test for the ABO tool (Table 6). The Intraclass correlation coefficient was then calculated for the digital caliper measurements and recorded. The Intraclass correlation is a statistical measure of intra-rate agreement between quantitative outcomes, in this study, between first and second measurements by two examiners. A coefficient of 0 indicates a complete lack of agreement between the two measures while a coefficient of 1 indicates perfect agreement.

RESULTS

Reliability Analysis

Results from the reliability analysis, using the Cronbach and Kappa test, show excellent inter-rater reliability with both the ABO tool and vertically mounted digital caliper (Table 6). As for the Cronbach analysis, numerical values 0.8 and above correlate with excellent reliability, 0.6 – 0.8 moderate reliability and below 0.6 reliability would be in question. The Kappa test is deemed reliable with numerical values exceeding 0.4, as are all values from this study's reliability analysis (Table 6).

Group 1

Based upon the independent sample *t* test, the mean of marginal ridge discrepancy was minimal with some outliers (Table 1). Excluding the outliers, the range of mean differences for males and females (0.27 mm – 0.5 mm) was at or below the ideal ABO standard of 0.5 mm with a standard deviation range (0.19 mm – 0.39 mm) respectively. The outliers range of mean differences (0.57 mm- 1.88 mm) with a standard deviation range (0.46 mm – 0.17 mm) respectively. The Levene's test for equality of assumptions showed that equal variances could not be assumed ($p < 0.05$) for two of the contacts (URe-M/URd-D and LR6-M/LRe-D), thus rejecting the null hypothesis of equal variances assumed between males and females of those two contacts. All other contacts had p values greater than 0.05 and thus, assumed equal variances (Table 3).

Group 2

Group 2 had a much wider range of mean marginal ridge discrepancies for males and females. Nine contact points (Table 2) had mean discrepancies below 0.5 mm for both males and females. Another seven contact points had marginal ridge discrepancies above 0.5 mm for both males and females and the remaining four contact points had either males or females with marginal ridge discrepancy above 0.5 mm and the other below 0.5 mm (Table 2). Four contact points (URe-M/URd-D, LRe-M/LRd-D, LLe-M/LLd-D, LL6-M/LLe-D), with the Levene's test, rejected the null hypothesis of equal variances assumed ($p < 0.05$). All other contact points had p values above 0.05 and thus assumed equal variances between males and females, accepting the null hypothesis (Table 4).

Group 3

Three of the contacts (UR7M/UR6D, UL6M/UL5D, LL7M/LL6D) showed p values less than 0.05 and thus rejected the null hypothesis of equal variances assumed. All other contact points assumed equal variances between males and females, accepting the null hypothesis ($p > 0.05$) (Table 5).

Results from each of the three groups indicate little to no statistical significance in marginal ridge discrepancies between males and females. Although each group did show some statistical significance ($p < 0.05$), the standard deviation was typically similar in value, thus reducing and significance.

DISCUSSION

The principal finding in this study was that the marginal ridge discrepancy between males and females with age matched, is not statistically significant. While some contact points within each of the three groups did show statistical significance for marginal ridge discrepancy, the vast majority of other contacts and the level of standard deviation showed an overall insignificance statistically.

When examining the group statistics for Groups 1 and 2, the first had 14 out of 19 mean marginal ridge discrepancy values within the ideal range of the ABO of 0 – 0.5 mm. The largest of these were between the permanent 1st molars and second premolars, possibly suggesting the process of eruption as this age group was from 5 – 9 years old. Group 2 showed almost half (22 of 40) of the mean marginal ridge discrepancies within the range of ABO standards with the remaining 18 above 0.5 mm discrepancy. The largest marginal ridge discrepancies from Group 2 were, again, between erupting permanent teeth such as maxillary 1st and 2nd molars and 1st molars and 2nd premolars.

With the largest of marginal ridge discrepancies occurring between erupting permanent teeth and the age groups in which this occurs, could possibly suggest natural alignment of marginal ridges during growth and development. As evident by the statistical means between groups 1 and 2, one example would be the mean marginal ridge discrepancy of males for the UR6-M/UR5-D contact decreasing from 1.66 to 0.6975. Other examples similar to this are evident as Tables 1 and 2 show. Also, it is important to note the large number of marginal ridge discrepancy means which are relatively flat (within 0 – 0.5 mm) in the primary and transitional dentition (Group 1).

CONCLUSION

The purpose of this study was to increase the present knowledge of marginal ridge alignment as it presents in an orthodontically untreated Caucasian population from deciduous dentition to adulthood and if any statistical variation exists between males and females. The findings were as follows:

- Little to no statistical significance was found in identifying a difference in marginal ridge discrepancies between males and females
- The data suggest that marginal ridge discrepancies, within this study, of erupting permanent teeth tend to decrease through growth and development from primary to permanent dentition
- The marginal ridge discrepancy means tend to show a "flatter" or more level arrangement within the primary and transitional dentition

This is the first study which we are aware of that documents a longitudinal analysis of marginal ridge discrepancies throughout an individual's growth and development without orthodontic intervention, limited or comprehensive. This study offers an area for further studies to examine a more detailed analysis of eruption and marginal ridge alignment and how it corresponds to the development of the curve of Spee. We hope this study of marginal ridge discrepancies and the correlation between males and females will help further studies involving development of the dentition during growth and development.

While the results show little to no statistical significance between males and females, they should be interpreted with caution due to a relatively small sample size (n=38). Consequently, the power of the study would be much greater with an increased sample size to more accurately determine any statistical variation between males and females.

Tables

Table 1: Group Statistics[a]

Gender		N	Mean	Std. Deviation	Std. Error Mean
UR e-M/UR d-D	Male	151	.2990	.27232	.02216
	Females	94	.2674	.19483	.02009
UR6-M/UR e-D	Male	99	.6260	.54666	.05494
	Females	62	.4792	.33555	.04261
UR7 -M/UR6-D	Male	0[b]			
	Females	0[b]			
UR6-M/UR5-D	Male	1	1.6600		
	Females	0[b]			
UR5-M/UR4-D	Male	1	.2800		
	Females	0[b]			
UL e-M/UL d-D	Male	156	.2954	.22929	.01836
	Females	98	.2802	.19370	.01957
UL6-M/UL e-D	Male	94	.5029	.39157	.04039
	Females	58	.5659	.46345	.06085
UL7-M/UL6-D	Male	0[b]			
	Females	0[b]			
UL6-M/UL5-D	Male	0[b]			
	Females	0[b]			
UL5-M/UL4-D	Male	0[b]			
	Females	0[b]			
LR e-M/LR d-D	Male	156	.3870	.31975	.02560
	Females	90	.4029	.34279	.03613
LR6-M/LR e-D	Male	102	.4346	.34029	.03369
	Females	62	.3339	.29025	.03686
LR7-M/LR6-D	Male	0[b]			
	Females	0[b]			
LR6-M/LR5-D	Male	0[b]			
	Females	0[b]			
LR5-M/LR4-D	Male	0[b]			
	Females	0[b]			
LL e-M/LL d-D	Male	149	.4072	.25286	.02072
	Females	95	.3448	.39069	.04008
LL6-M/LL e-D	Male	101	.4528	.35479	.03530
	Females	65	.4000	.32255	.04001

Table 1 Continued

LL7-M/LL6-D	Male	0[b]			
	Females	0[b]			
LL6-M/LL5-D	Male	0[b]			
	Females	3	1.8800	.17436	.10066
LL5-M/LL4-D	Male	0[b]			
	Females	0[b]			

a. Age Group = 5 ot 9 years
b. t cannot be computed because at least one of the groups is empty.

Table 2: Group Statistics[a]

Gender		N	Mean	Std. Deviation	Std. Error Mean
UR e-M/UR d-D	Male	44	.3316	.26275	.03961
	Females	28	.2025	.18448	.03486
UR6-M/UR e-D	Male	81	.3059	.31722	.03525
	Females	47	.3447	.24331	.03549
UR7 -M/UR6-D	Male	43	1.0116	.73171	.11158
	Females	35	1.0783	.66705	.11275
UR6-M/UR5-D	Male	59	.6975	.71613	.09323
	Females	43	.5902	.59459	.09067
UR5-M/UR4-D	Male	57	.5691	.44008	.05829
	Females	43	.4793	.29896	.04559
UL e-M/UL d-D	Male	37	.2576	.22075	.03629
	Females	20	.3475	.18538	.04145
UL6-M/UL e-D	Male	75	.2953	.23296	.02690
	Females	40	.3825	.30953	.04894
UL7-M/UL6-D	Male	40	1.0818	.70065	.11078
	Females	38	.9337	.65711	.10660
UL6-M/UL5-D	Male	64	.5370	.48705	.06088
	Females	43	.5814	.62861	.09586
UL5-M/UL4-D	Male	62	.6469	.33680	.04277
	Females	41	.3761	.26015	.04063
LR e-M/LR d-D	Male	32	.5306	.39105	.06913
	Females	15	.2133	.14191	.03664
LR6-M/LR e-D	Male	70	.3574	.26677	.03189
	Females	39	.2923	.23499	.03763

Table 2 Continued

LR7-M/LR6-D	Male	63	.4095	.34346	.04327
	Females	46	.4620	.33765	.04978
LR6-M/LR5-D	Male	75	.9431	.72064	.08321
	Females	46	.5346	.64780	.09551
LR5-M/LR4-D	Male	74	.6389	.44016	.05117
	Females	46	.3970	.37276	.05496
LL e-M/LL d-D	Male	34	.3806	.32045	.05496
	Females	15	.2313	.14426	.03725
LL6-M/LL e-D	Male	72	.3618	.23319	.02748
	Females	41	.3949	.34256	.05350
LL7-M/LL6-D	Male	69	.5197	.40458	.04871
	Females	47	.5366	.41845	.06104
LL6-M/LL5-D	Male	72	.9163	.66986	.07894
	Females	52	.6017	.56287	.07806
LL5-M/LL4-D	Male	72	.4579	.30633	.03610
	Females	52	.4296	.39667	.05501

a. Age Group = >9 to 14 years

Table 3: Independent Samples Test[a]

						95% Confidence Interval of the Difference	
		Sig.	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
UR e-M/UR d-D	Equal variances assumed	.006					
	Equal variances not assumed		.293	.03156	.02992	-.02737	.09049
UR6-M/UR e-D	Equal variances assumed	.057	.059	.14677	.07723	-.00576	.29929
	Equal variances not assumed						

Table 3 Continued

UL e-M/UL d-D	Equal variances assumed	.473	.585	.01524	.02788	-.03966	.07015
	Equal variances not assumed						
UL6-M/UL e-D	Equal variances assumed	.511	.371	-.06299	.07018	-.20167	.07569
	Equal variances not assumed						
LR e-M/LR d-D	Equal variances assumed	.691	.715	-.01590	.04346	-.10151	.06971
	Equal variances not assumed						
LR6-M/LR e-D	Equal variances assumed	.023					
	Equal variances not assumed		.046	.10074	.04994	.00203	.19944
LL e-M/LL d-D	Equal variances assumed	.306	.131	.06241	.04118	-.01872	.14353
	Equal variances not assumed						
LL6-M/LL e-D	Equal variances assumed	.721	.334	.05277	.05447	-.05479	.16033
	Equal variances not assumed						

a. Age Group = 5 ot 9 years

Table 4: Independent Samples Test[a]

		Sig.	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
UR e-M/UR d-D	Equal variances assumed	.023					
	Equal variances not assumed		.017	.12909	.05277	.02383	.23435

Table 4 Continued

UR6-M/UR e-D	Equal variances assumed	.390	.471	-.03875	.05362	-.14486	.06735
	Equal variances not assumed						
UR7 -M/UR6-D	Equal variances assumed	.862	.678	-.06666	.16016	-.38564	.25233
	Equal variances not assumed						
UR6-M/UR5-D	Equal variances assumed	.484	.425	.10723	.13390	-.15843	.37288
	Equal variances not assumed						
UR5-M/UR4-D	Equal variances assumed	.085	.252	.08982	.07796	-.06489	.24453
	Equal variances not assumed						
UL e-M/UL d-D	Equal variances assumed	.565	.127	-.08993	.05806	-.20629	.02643
	Equal variances not assumed						
UL6-M/UL e-D	Equal variances assumed	.096	.092	-.08717	.05128	-.18877	.01443
	Equal variances not assumed						
UL7-M/UL6-D	Equal variances assumed	.810	.339	.14807	.15400	-.15864	.45477
	Equal variances not assumed						
UL6-M/UL5-D	Equal variances assumed	.473	.682	-.04436	.10807	-.25865	.16992
	Equal variances not assumed						
UL5-M/UL4-D	Equal variances assumed	.051	.000	.27084	.06215	.14756	.39412
	Equal variances not assumed						
LR e-M/LR d-D	Equal variances assumed	.003					
	Equal variances not assumed		.000	.31729	.07824	.15954	.47504

Table 4 Continued

LL7-M/LL6-D	Equal variances assumed	.043					
	Equal variances not assumed		.256	1.36221	1.17187	-1.04638	3.77080
LL6-M/LL5-D	Equal variances assumed	.119	.753	.03107	.09821	-.16551	.22765
	Equal variances not assumed						
LL5-M/LL4-D	Equal variances assumed	.086	.056	.20203	.10371	-.00528	.40935
	Equal variances not assumed						

a. Age Group = >14 to 29 years

Table 5: Independent Samples Test[a]

						95% Confidence Interval of the Difference	
		Sig.	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
UR7 -M/UR6-D	Equal variances assumed	.029					
	Equal variances not assumed		.009	-.21742	.07924	-.37674	-.05810
UR6-M/UR5-D	Equal variances assumed	.426	.852	-.01258	.06729	-.14718	.12202
	Equal variances not assumed						
UR5-M/UR4-D	Equal variances assumed	.308	.024	.15201	.06560	.02070	.28331
	Equal variances not assumed						
UL7-M/UL6-D	Equal variances assumed	.075	.065	-.16516	.08780	-.34078	.01046
	Equal variances not assumed						
UL6-M/UL5-D	Equal variances assumed	.046					
	Equal variances not assumed		.937	.00555	.06990	-.13465	.14575
UL5-M/UL4-D	Equal variances assumed	.259	.104	.13678	.08268	-.02886	.30242
	Equal variances not assumed						
LR7-M/LR6-D	Equal variances assumed	.593	.777	.02323	.08179	-.14038	.18683
	Equal variances not assumed						
LR6-M/LR5-D	Equal variances assumed	.231	.211	.08766	.06940	-.05116	.22648
	Equal variances not assumed						
LR5-M/LR4-D	Equal variances assumed	.838	.865	.01374	.08054	-.14730	.17479
	Equal variances not assumed						

Table 5 Continued

LL7-M/LL6-D	Equal variances assumed	.043					
	Equal variances not assumed		.256	1.36221	1.17187	-1.04638	3.77080
LL6-M/LL5-D	Equal variances assumed	.119	.753	.03107	.09821	-.16551	.22765
	Equal variances not assumed						
LL5-M/LL4-D	Equal variances assumed	.086	.056	.20203	.10371	-.00528	.40935
	Equal variances not assumed						

a. Age Group = >14 to 29 years

Table 6: Reliability Analysis

Marginal Ridge	Cronbach's Alpha	Kappa
UR7M – UR6D	0.894**	0.851**
UR6M – UReD	0.155[NS]	1.000**
UR6M – UR5D	0.946**	1.000**
UReM – URdD	0.845**	1.000**
UR5M – UR4D	0.956**	0.652[NS]
UL7M – UL6D	0.975**	1.000**
UL6M – ULeD	0.987**	0.815*
UL6M – UL5D	0.888**	1.000**
ULeM – ULdD	0.780**	1.000**
UL5M – UL4D	0.919**	0.861**
LR7M – LR6D	0.893**	0.853**
LR6M – LReD	0.873**	0.808*
LR6M – LR5D	0.880**	1.000**
LReM – LRdD	0.957**	1.000**
LR5M – LR4D	0.964**	1.000**
LL7M – LL6D	0.890**	1.000**
LL6M – LLeD	0.289[NS]	1.000**
LL6M – LL5D	0.903**	0.706*
LLeM – LLdD	0.953**	1.000**
LL5M – LL4D	0.966**	0.872**

* P ≤ .01; ** P ≤ .001; NS=Not significant

Figures

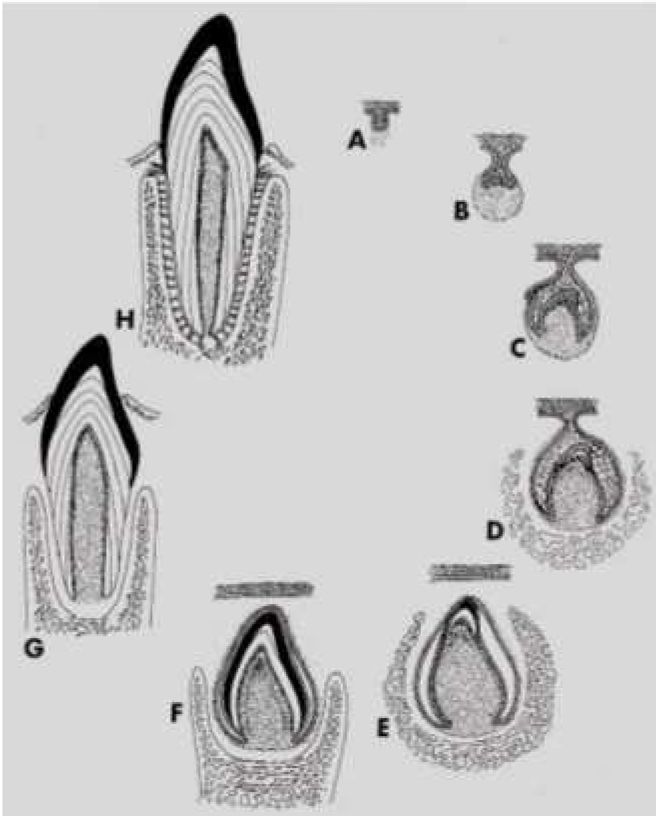

Figure 1**:** Tooth Formation: A. Bug Stage; B. Cap Stage; C. Bell Stage; D & E. Dentinogenesis and amelogenesis; F. Crown formation; G. Root formation and eruption; H. Function; Essentials of Oral Histology and Embryology, Ed: James Avery, 2nd edition. 2000.

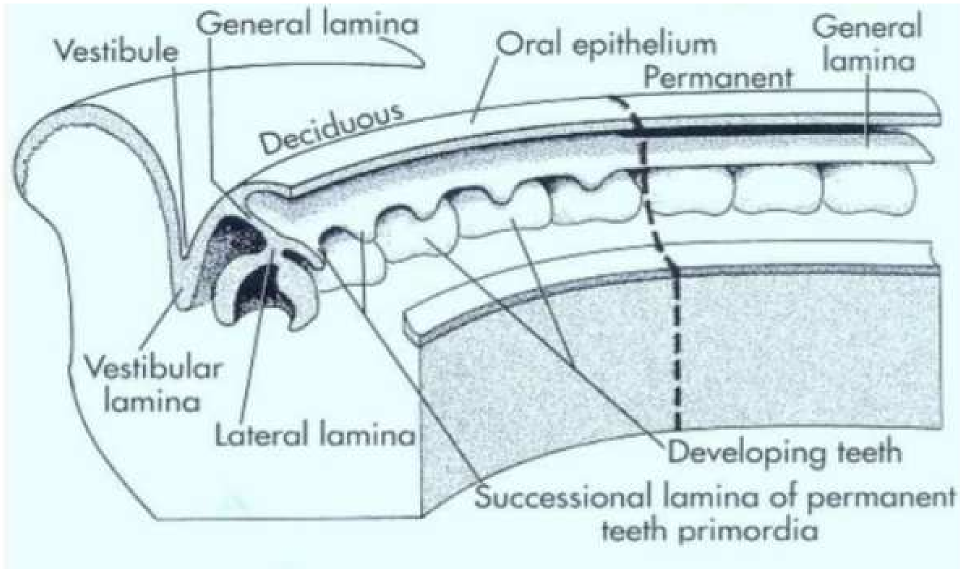

Figure 2**:** Schematic representation of tooth development. Tooth germs of the deciduous and permanent dentition in the mandible.

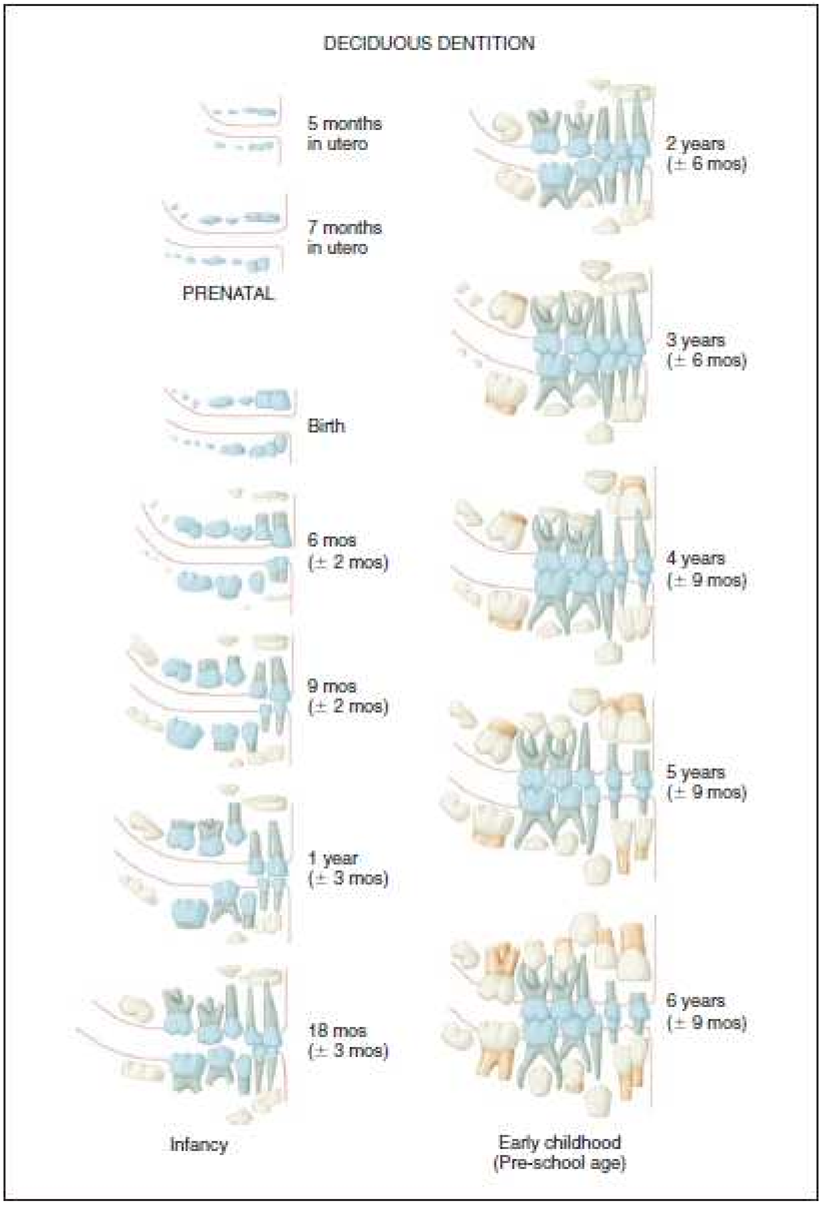

Figure 3A**.** Eruption sequence through the 6th year. (From Schour L, Massler M: The development of the human dentition, *J Am Dent Assoc* 28:1153, 1941.)

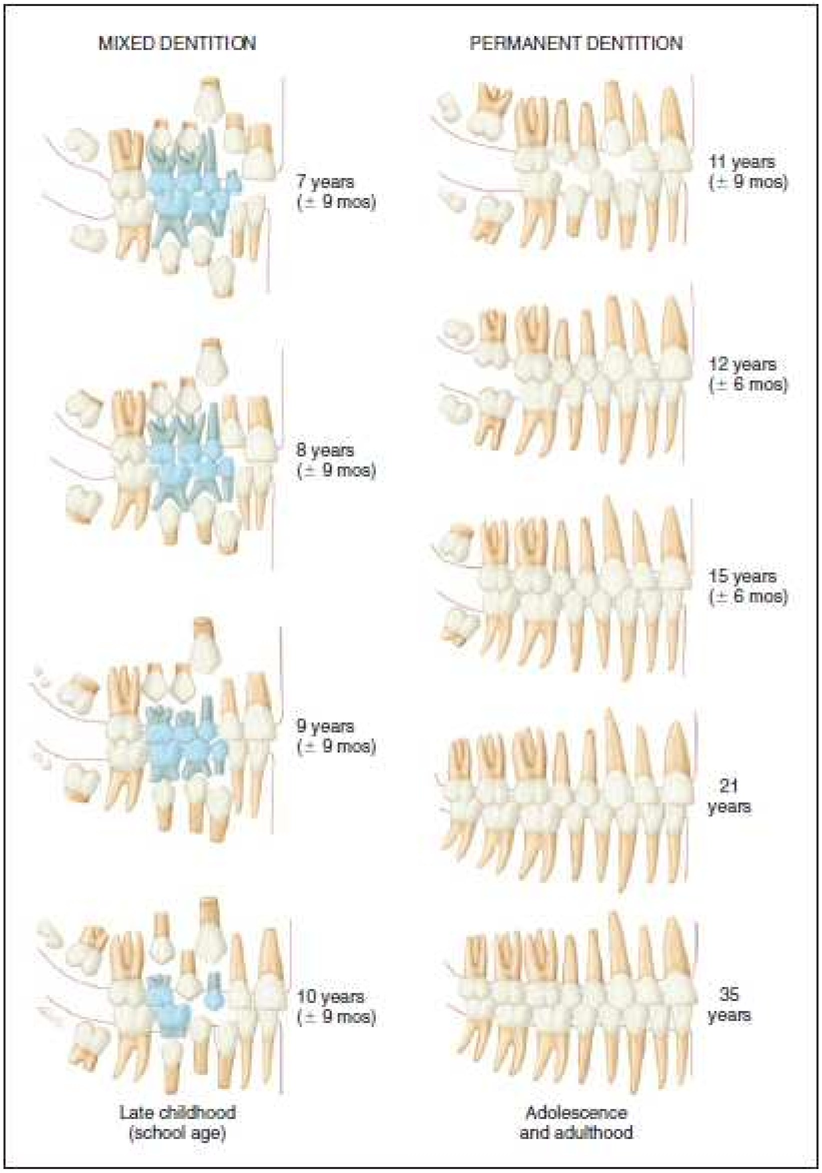

Figure 3B**.** Eruption sequence from 7th year to adulthood. (From Schour L, Massler M: The development of the human dentition, *J Am Dent Assoc* 28:1153, 1941.)

Figure 4: Measuring Apparatus: a digital caliper vertically mounted on a surveyor. The end of the digital caliper is enlarged (*inset*) to show the modification of the caliper arm to allow point contact with the dental cast.

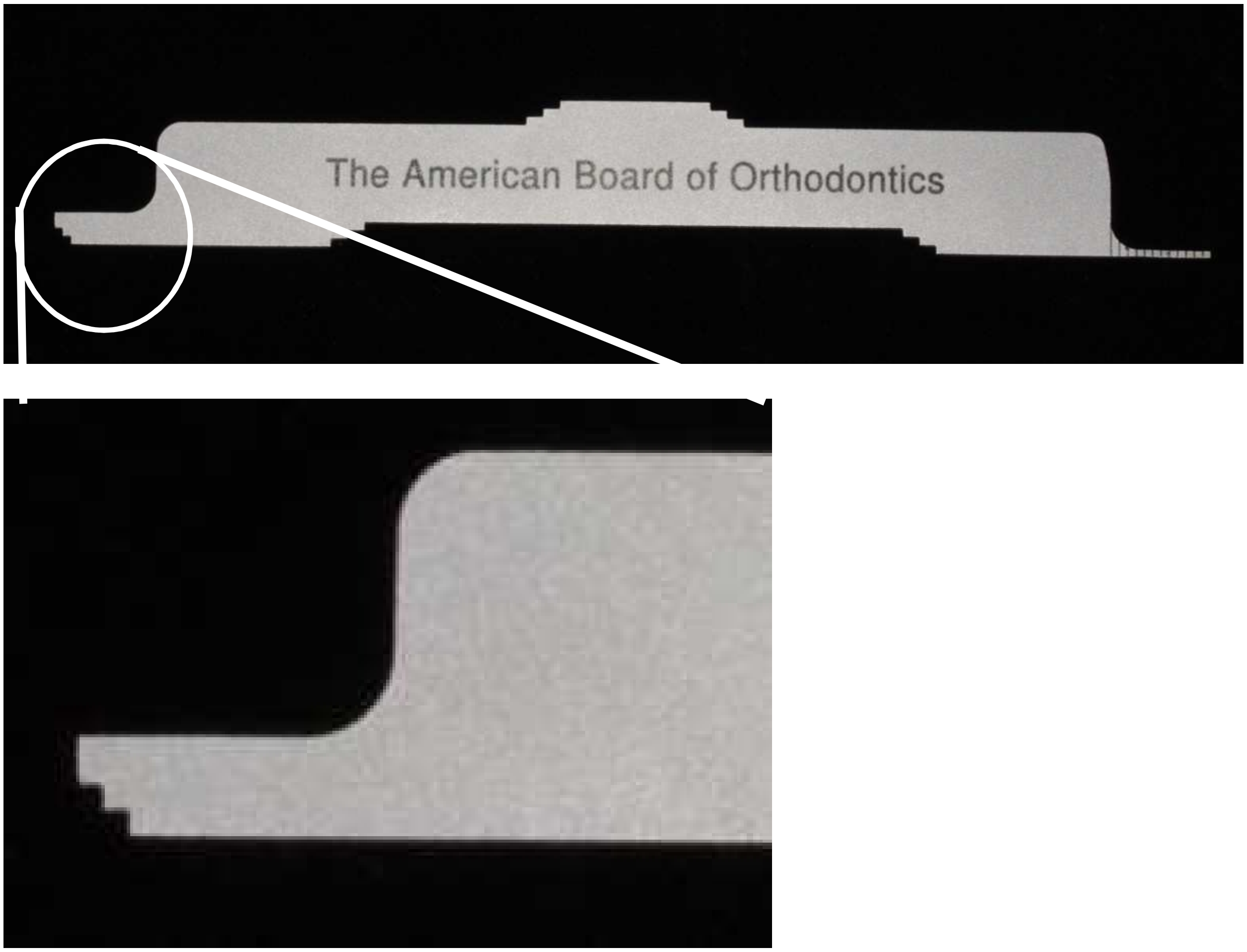

Figure 5: ABO Grading Tool; Zoomed in view showing 1mm incremental steps for measuring marginal ridge discrepancies

Figure 6A: Dental cast of level adjacent marginal ridges.

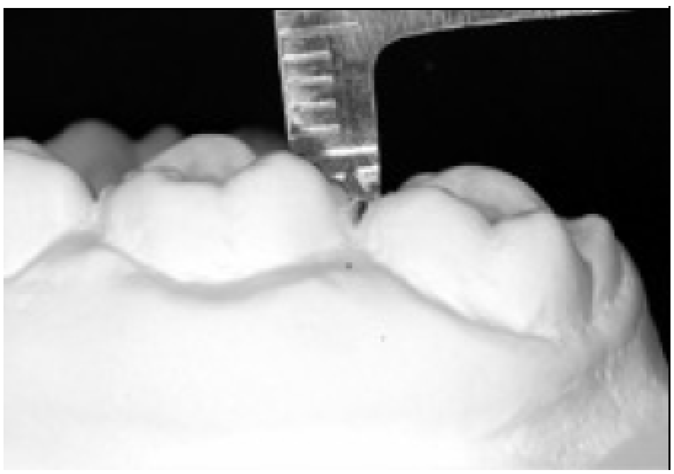

Figure 6B: Margin ridge discrepancy between 0.50 and 1.0mm.

Figure 6C: Marginal ridge discrepancy greater than 1mm.

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