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Passive eruption patterns in first molars

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PASSIVE ERUPTION PATTERNS IN FIRST MOLARS

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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INTRODUCTION

Growing old may be referred to as “getting long in the tooth.” The reference is adapted from horses due to the continued growth of their teeth. Though this idiom may relate to age it may also have some literal truth among the human population. The teeth do not continue to grow, as with horses, but the gingiva-tooth relationship is a dynamic association. The link between teeth and gingival tissue is integral in the design of the esthetic smile and as orthodontists treat patients they must be cognizant of the long-term changes that occur between the teeth and gingiva to aid in treatment planning for patients.

The process of eruption and the dental literature have a long history. For years studies have tried to determine at what point eruption ends. Many researchers have made the claim that eruption is a continuous process and there is ample supporting evidence. Two phases of eruption are commonly discussed: active eruption and passive eruption. This study focuses on the eruption of maxillary and mandibular first molars, to help define active and passive eruption and distinguish between the two.

Research by Bassey (1991) focused on clinical crown heights among the Nigerian population. He measured 2048 teeth from the ages of 21-45. 64 subjects/64 sets of plaster models made up the sample. All teeth from the central incisors to the second molars were measured. Bassey’s study found significant changes in clinical crown height over time from 21-45 years of age. This study, however, was not longitudinal. It did not follow the individual subjects over time.

A longitudinal study was completed by Morrow et al. (2000). They investigated the relationship between age, gender and clinical crown height using a longitudinal study design. It included subjects aged 12-19 years old. Their results did not allow them to determine if the gingival levels were stable at age 18-19 years. They reported that passive eruption in females was essentially complete by 18-19 years; however, males did not appear to be complete at the same age. The deficiency in this study was the age limit.

Volchansky and Cleaton-Jones (1976) performed two studies relating to passive eruption. One non-longitudinal study examined Caucasian children between ages 6 and 16 years. They stated, “We realize that our study was not a longitudinal one, which would be the ultimate proof of changing clinical crown height with age.” Their next study addressed the deficiency in the first study. They performed a longitudinal study on students starting at age 18 and continued for the next 3 years (Volchansky 1979). They concluded, “This indicates that by the age of 20 years passive eruption had not yet ceased in the individuals studied. The study needs to be continued to see what will happen after 20 years of age and to determine whether an age will be reached, when passive eruption will cease.”

This study addresses the deficiencies in the previous studies mentioned. The sample is comprised of records taken in the subject’s twenties, with some records continuing into their forties. The study also tries to account for the changes that occur in the bone level as the subjects age using radiological measurements. A non-longitudinal and a longitudinal sample are included in the study.

PURPOSE OF THE STUDY

The purpose of this study is to determine the eruption patterns of permanent first molars from the first occlusal contacts to adulthood. Previous studies have failed to obtain measurements into adulthood or have not been longitudinal in design. By using a measurement during the subjects' adulthood, a better estimate of the changes that occur between the tooth and the gingival margin throughout growth and aging can be obtained.

This study will compare the eruption of maxillary and mandibular first molars. Particular attention will be paid to the apical migration of the gingiva after occlusal contact. The study will attempt to separate normal changes from pathological changes using differences in alveolar bone height to cemento-enamel-junction at youth and adulthood. Measurements will be made on models and radiographs collected during the Meredith Facial Growth Study at the University of Iowa. Achieving experimental purpose will be accomplished by measuring the teeth at successive time points to track eruption over years of maturity. Statistical analysis will determine whether crown height differences are significantly different with time and between genders and whether the changes can be attributed to alveolar bone loss and recession or a result of passive eruption.

REVIEW OF THE LITERATURE

The literature review covers the eruption of teeth and its main corollaries including; passive eruption, active eruption, and altered passive eruption. A brief consideration of alveolar bone loss and its relation to radiographic measurement is discussed. It will also include an appraisal of implant placement in the young adult for tooth replacement. Finally, studies similar to the one being presented are discussed in detail.

Eruption

The process of eruption of human teeth has been of considerable interest to man since early times. The regularity with which each tooth appears has allowed even ancient peoples to consider the dates of eruption as a chronology of life. Many authors have attempted to study eruption throughout life. The measurement has taken many forms. Bjork and Skieller (1955, 1972) used implanted metallic markers to study eruption. Carlson (1944) used the lower border of the mandible and Darling and Levers (1975) used the inferior alveolar canal. Sequential observations of plaster casts have also been employed. One of the unsolved mysteries in dentistry remains the pre-emergent process of eruption. There is little known of the actual mechanism for teeth to erupt. Many hypotheses have been proposed though none seem to hold the single answer.

As time has passed the understanding of the process has grown more sophisticated. Brodie (1934) described the movement of the crypt toward the gingival crest and then the crypt would rupture as the tooth emerged from the gingiva. Weinmann (1941) broke the process up into three phases. The first phase was pre-emergence as the tooth makes its way gingival and just pierces the gingiva. The second phase was the emergence through the tissue to contact with the opposing tooth. Finally, the third phase was the post occlusal contact phase in which the tooth would continue to erupt over time as attrition occurred.

Carlson (1944) also separated the eruption of a tooth into three phases. First is the formation of the crown of the tooth. Second is a period of rapid eruption and finally a phase in which the occlusal plane is moving as a unit. Darling and Levers (1975) expanded on Carlson's theory. They began with an observation that the dental follicle grows in a concentric fashion. This is the first phase of eruption as the tooth is growing and enlarging equally towards the occlusal plane and the lower border of the mandible. Once the root begins to form, the tooth begins to move towards the occlusal plane. This is the beginning of active eruption. When the tooth comes into contact with its opposing tooth it stops erupting and this begins the third phase according to Darling and Levers (1975). A second phase of active eruption begins during the adolescent growth spurt and will continue for a period of years. Around 18 years of age the teeth settle into an equilibrium phase in which the occlusal relationship is set. They did not find any significant changes in the subjects studied once the equilibrium was reached. Steedle and Proffit (1985), through a histological study, agreed with the centered growth of the dental follicle. During the second phase they found a pre-emergent eruptive spurt in the occlusal direction in which the tooth moves at an increasing rate towards the gingiva. A post-emergent eruptive spurt follows. The eruption speed decreases in 75% of teeth examined as the teeth approached the occlusal plane. After occlusion the tooth enters a juvenile equilibrium while the occlusal plane remains constant in its relation to the inferior alveolar canal. Another eruptive spurt then takes place between 11 and 16 years old. Lower face height increases during this period. Finally, like Darling, Steedle and Proffit discuss an adult occlusal equilibrium around 18 years of age. The equilibrium is attributed to the corresponding slowing of the growth rate in adults.

Continuous/Active Tooth Eruption

In 1927 Gottlieb wrote in a classic work on the gingival margin that in reference to the eruption of teeth, "just for how long it continues we have been so far unable to discover (but) I would say that it is a fact that the teeth erupt continuously." Newman (1979), fifty years later, studied 190 skulls and found that as attrition occurs so does eruption. The paper also claims that no change in clinical crown height occurred or a change in the alveolar crest in relation to the inferior alveolar canal. He determined that the rates of eruption and attrition were similar and therefore the cause of the apical migration of the gingiva was strictly due to the attrition and the tooth moving past a vertically stable soft tissue apparatus.

Whittaker et al (1982) studied tooth attrition in a Romano-British population. They used 517 skulls with intact mandibles and maxillae. The skulls were separated according to age determined independently of the study. The teeth were measured from alveolar crest to cemento-enamel-junction (CEJ). The measurements confirmed the hypothesis that with increasing age and attrition the teeth continue to erupt to maintain occlusion. This supported the results of Newman (1979). In a follow-up study in 1985 Whittaker et al found skulls with no attrition and standardized the normal crown heights in the Romano-British population from above. They used this to measure the amount of wear among the other subjects and then were able to confirm their previous results that the amount of wear approximated the amount of eruption. Finally, just because they wanted to measure more skulls, Whittaker et al (1990) conducted another study on the excavations from the vaults of the Spitalfields near London. This study found that a small amount of bone may be laid down on the alveolar crest in compensation of the continued tooth eruption. In this study little attrition was noted yet there was still continued eruption of the teeth and so the authors concluded that there must be continued eruption through life even when occlusal wear is not present. This phenomenon would therefore lead to an increase in face height.

Varrela et al (1995) disputed this notion that the alveolar crest is increasing in height. They studied the remains of 244 individuals and measured from the inferior alveolar canal to the alveolar crest and also from alveolar crest to CEJ and found that alveolar crest height did not increase accordingly with the increased distance between CEJ and alveolar crest. They also found a lack of bony changes due to inflammatory processes.

A year later Iseri and Solow (1996) published a study using cephalograms from the Bjork study of 1968 in which metallic implants were placed as fixed reference points. They looked at 147 female subjects ranging from 9-25 years of age. Their study focused on the central incisors and first molars. They found significant eruption in the age range studied. The incisors moved on average 6mm down and 2.5mm forward. The molars moved 8mm down and 3mm forward. The significant changes led them to warn of potential problems with implants in the adolescent or young adult.

In 1933 Gottlieb and Orban presented an abstract in the Journal of dental research where they defined “active eruption” as the movement of the tooth towards the occlusal line. More recently active eruption has been described as the eruption process of a tooth and their alveoli through the gingival tissues (Moshrefi 2000) with the phase ending when the tooth makes contact with the opposing dentition, but it may continue with occlusal wear or loss of opposing teeth (Dolt 1997). Active eruption was divided into two types: prefunctional active eruption and functional active eruption by Weinberg (2000). Prefunctional active eruption is defined by the movement of the tooth from the developmental position inside the jaw, through the oral epithelium, into the oral cavity, to a final position of functional occlusion. Functional active eruption begins when the tooth is in a functional occlusion and continues throughout life. Normal attrition of a tooth is compensated by slight tooth eruption for occlusal contact maintenance and for the continued vertical growth of the face (Weinberg 2000).

Newman (1999) published “Attrition, Eruption, and the Periodontium,” in which he reviewed the current view of eruption. He concluded that the evidence available definitely confirms the continuous eruption of teeth throughout life. He also states that the current evidence supports continuous eruption without concomitant attrition. This would therefore lead to the notion that the periodontal attachment could lie on cementum through a physiologic process without any past or current periodontitis. This conclusion challenges the idea that the apical migration of the gingival is due to a pathologic process. It should instead be taken into consideration that part of the change may be due to the normal continuation of tooth eruption. Recognizing the possibility that the changes are physiologic gives credence to the term “passive eruption.”

Passive Eruption

Gottlieb (1927) was well ahead of his time when he proposed continuous eruption of the dentition over time. Not only did he propose the continued eruption of the teeth, but he laid out the basis for a theory of “passive eruption,” though he did not use the same terms in this paper. His studies led him and his colleagues to theorize that the connection of the gingival margin to the tooth was a dynamic association. They did not accept the notion that the apical movement of the gingiva margin was purely pathological. In their study of patients they did not see the typical signs associated with inflammation or tissue change due to traumatic occlusion. Gottlieb wrote that “eruption not only progresses by the operation of raising of the tooth from the alveolus, for at the gingival margin we can observe that the epithelial attachment, as well as the ligamentum circulare and the margin of the alveolus, are moving apically. The lower part of the gingival trough passes beyond the amelo-cemental junction not only in different teeth of the same patient but also round the circumference of the same tooth at different points.” Despite the observations and claims, there was little quantitative evidence to support his theories. He acquiesced by writing, “the explanation I have tried to give you is an attempt to demonstrate this. It may be true, but it can also be wrong.” Six years later, in 1933, Orban and Gottlieb defined the term “passive eruption” as the movement towards the apex of the tooth.

The passive eruption process has been historically characterized by four stages (Gargiulo 1961). Stage 1: The dentogingival junction is located on enamel. Stage 2: The dentogingival junction is located on enamel as well as cementum. Stage 3: The dentogingival junction is located entirely on cementum, extending coronally to the CEJ. Stage 4: The dentogingival junction is on cementum, and the root surface is exposed as a result of further migration of the dentogingival junction on the cementum (gingival recession).

Stages 1 through 3 are physiological processes. Stage 4 is typically caused by inflammation and is known as a pathological process. Throughout this whole process the width of the junctional epithelium diminishes. The width of the connective tissue remains relatively constant with a mean average of 1.07 millimeters. The length of the junctional epithelium has a mean average of .97 millimeters (Gargiulo 1961). This is commonly known as the biological width (Cohen 1962).

Gargiulo et al. (1961) studied apical migration on the permanent dentition. They took measurements on 30 jaws using 287 teeth. The age range was from 19 to 50 years. A total of 325 surfaces where measured. There were 6 measurements on each from each surface. They were: 1) depth of the gingival sulcus, 2) length of the attached epithelium, 3) most apical point of the epithelial attachment from the cemento-enamel-junction, 4) distance from the base of the sulcus to the cemento-enamel-junction, 5) distance of the cemento-enamel-junction from the alveolar bone, 6) distance from the most apical point of the epithelial attachment to the alveolar bone (connective tissue). They concluded that "one can no longer speak of passive exposure only being associated with the apical migration of the epithelial attachment. The correct interpretation of the gingiva and its relation to the tooth with increasing age can only be understood if the connective tissue attachment is also considered. The physiologic apical shift of the dentogingival junction from stage to stage during passive eruption, is responsible for the passive exposure of the tooth and is not merely due to the "peeling back" of the epithelial attachment."

Barker (1975) wrote that "there is widespread acceptance of the theory that, with advancing age, there is continuous eruption of the teeth from their sockets with recession of the gingiva onto the cementum, and this so-called 'passive eruption' may lead to elongated clinical crowns in the absence of attritional wear" as an opening line to a study on Aboriginal skulls. Though Barker began the article with this seeming endorsement of the theory, he went on to criticize the notion that the process is physiologic. Barker's study found little evidence that passive eruption occurs or does not occur. With attrition, he found, there was significant eruption of the tooth in response. The action of the epithelial attachment, he postulated, may have more to do with the inability of the alveolar crest to grow which would lead to the attachment coming to rest on cementum.

Newman (1994), in an opinion paper, laid out what he saw was the main evidence for passive eruption and concluded that eruption continues on throughout life; "The evidence clearly indicates that tooth eruption, in both ancient and modern human population does not stop once the teeth reach the occlusal plane, but continues through adult life, and apparently, in modern dentitions, in the absence of marked functional tooth wear. As a result, the attachment apparatus may come to lie on cementum, in the absence of chronic periodontitis." His paper criticized the conclusions of Barker and cited the multitude of studies that found changes in the distance from CEJ to alveolar crest as teeth erupt as evidence that the gingival apparatus must come to lie on cementum normally.

Altered Passive Eruption

Perhaps the most convincing evidence for continued apical migration of the gingiva once active eruption is complete is the instance in which the process does not occur. This is referred to as altered passive eruption and is seen as a retardation of a normal process. Altered passive eruption has been labeled many ways: retarded passive eruption, incomplete passive eruption, and delayed passive eruption (Dolt 1997, Hempton 1999, Coslet 1977). It occurs when the gingival margin is incorrectly positioned occlusally on the anatomic crown in adulthood and does not approximate the CEJ (Dolt 1997). Altered passive eruption has been divided into two main types dependent upon the relationship of the gingiva to the anatomic crown and then subdivided into classes according to the position of the osseous crest (Coslet 1977). Types I and II are based on their gingival/anatomic crown relationship: Type I – gingival margin occlusal to the CEJ, where there is a noticeably wider gingival dimension from the margin to the mucogingival junction. Type II – dimension from the gingival margin to the mucogingival junction which appears to be within the normal mean width. Subtypes A and B are based upon the alveolar crest/CEJ relationship: Subtype A- alveolar crest – CEJ distance is approximately 1.5mm. This allows for normal attachment of the gingival fibers into the cementum. Subtype B – alveolar crest is at the level of the CEJ.

During Type 1 and Type 2 altered passive eruption, when the alveolar crest is at or near the CEJ, there is an insufficient amount of cementum apical to the CEJ and coronal to the alveolar crest for the gingival fiber apparatus to attach. This causes a failure of the attachment apparatus to migrate apically and passive eruption is hindered (Moshrefi 2000).

Proper diagnosis and clinical appearance are extremely important with altered passive eruption. There is controversy surrounding the age at which a diagnosis of altered passive eruption can be made. Evian (1993) believes the age of the patient is significant "Normal passive eruption may continue throughout the teen-age years. Gingiva may be present on the crown of the tooth in adolescents because the dentogingival unit has not fully receded to its final position. Therefore, a diagnosis of altered passive eruption cannot be made until one is sure that passive eruption is complete. The anterior teeth typically undergo passive eruption in the early teen years."

Volchansky and Cleaton-Jones (1979) felt it took longer for passive eruption to be completed. In a 3-year longitudinal study they found that by age 20, passive eruption had not yet stopped. Weinberg and Eskow (2000) state, "several studies have investigated the changing position of gingival margin in different age groups by measuring the clinical crown height… No study has determined what happens past 20 years of age and at what age passive eruption will stop."

Clinically, altered passive eruption can be described as a condition where the free gingival margin is located greater than 2 millimeters coronal to the CEJ (Hempton 1999). Volchansky and Cleaton-Jones (1976) observed a 12 percent incidence of altered passive eruption occurring in Caucasian children between the ages of 6 and 16. This condition is typically not pathologic, and has the appearance of short teeth. Evian (1993) described it as having the appearance of drug-induced gingival hyperplasia.

Measurement of Radiographs to Determine Periodontal Pathology

The use of radiographs to determine the amount of bone loss has been widely used in research. Many studies have looked at the most effective technique in the measurement. Bitewing, periapical, and panoramic radiographs have been compared to find the most accurate radiograph available for an accurate representation of the clinical condition. As early as 1977 Lang was examining the role of the radiograph in the detection of alveolar bone loss. He felt the radiograph grossly underestimated the extent of bone loss and that radiographs were an adjunctive tool and could not replace the clinical probe. Pepelassi et al. (1997) compared panoramic and periapical measurements of osseous destruction in cases where a surgical flap was completed. They found that periapical measurements were more accurate in cases where there was less osseous destruction. Both measures agreed as the destruction became more severe. Bitewings were assessed along with pantomographs and periapicals by Gedik et al. (2008) and they found that bitewing radiographic assessment had the highest accuracy in measurement of alveolar bone height distance from the cemento-enamel-junction. Their study contradicted the findings of Pepelassi, concluding that periapical radiographs were the least accurate method after bitewings and pantomographs. Albandar et al. (1985) found that both bitewings and periapicals could be used interchangeably in epidemiological studies of crestal bone loss. Reed and Polson (1984), however, found that these two methods of measurement should not be used interchangeably as they determined that the bitewing measurement was greater 94% of the time compared with the periapical.

Similar Studies

Morrow et al. (2000) conducted a study titled; "Clinical crown length (height) changes from age 12-19 years: a longitudinal study." They investigated the relationship between age, gender and clinical crown height using a longitudinal study design. Four hundred and fifty-six sets of study models initially obtained for a large prospective longitudinal cohort study of orthodontic needs by Shaw et al. (1986) were used for this study. Each model corresponded to subjects at three different time points. The first models were taken between 11-12 years old, then 3 years later between 14 and 15 years old and finally 4 years later between the ages of 18 and 19. Clinical crown heights of the maxillary right central incisor, maxillary right canine, maxillary left lateral incisor, and mandibular left central incisor were included in this study. Teeth with visible intra-coronal or extra-coronal restoration, impression/casting inaccuracies or fixed orthodontic appliances were excluded from the study. These presented difficulties measuring clinical crown heights accurately.

The results were calculated and the mean clinical crown height according to age and gender for each of the three time periods were calculated. They used factorial analysis and variance design with two factors, age and gender. Pairwise comparisons were made using the Scheffe S method. The level of significance for all comparisons was set at $p < 0.05$.

A significant age effect on crown height for all four study teeth was found. A significant gender effect was found in the maxillary right central incisor, maxillary right canine and maxillary left lateral incisor. There was no statistical significant gender effect for the mandibular left central incisor. Pairwise comparisons of the means for each age group for the maxillary right central incisor, maxillary right canine and maxillary left lateral incisor should increases in clinical crown height between each time point.

The process of passive eruption resulting in increased clinical crown height appears to continue throughout the teenage years. They report, “From the data it is not possible to determine whether or not the gingival levels are actually stable at age 18-19 years. It appears that the female population in the present study, passive eruption is essentially complete by age 18-19 years. In contrast, in the male patient population, it appears that passive eruption may not be complete at age 18-19 years.”

The results of Morrow et al. (2000) were not in agreement with a previous study of similar design conducted by Volchansky and Cleaton-Jones (1976). Volchansky and Cleaton-Jones measured two hundred and thirty-seven pre-treatment orthodontic study models of male and female Caucasian children between ages 6 and 16 years. Patient ages were rounded off to the nearest year. Digital calipers were used measuring to the nearest 0.5 millimeters. Clinical crowns of all the permanent teeth that had erupted were measured. Molar teeth were measured from the deepest curvature of the buccal gingival margin to the deepest point of the tooth crest between the mesio-buccal and disto-buccal cusps. Statistical analysis of the results consisted of an analysis of variance and Student’s *t* test.

In the mandibular arch there was no statistically significant increase in clinical crown height after the age of 10 years in the central incisors and after the age of 12 in canines. The maxillary arch was similar in that there was no statistical significant increase in clinical crown height after the age of 12 years in the central incisors. There was statistically significant increase in height of lateral incisors through age 16.

With increasing age there is a shift of the gingival margin towards the cemento-enamel-junction in all teeth except the second molar. This leveled off at age 12 for most teeth. In maxillary and mandibular lateral incisors and upper first premolars and second molars there was a continuous increase in clinical crown height up to age 16.

They did state; “We realize that our study was not a longitudinal one, which would be the ultimate proof of changing clinical crown height with age. Also, the numbers in our study are probably too small to define absolutely a normal clinical crown height for a given age.”

Soon after publication of their previous mentioned publication Volchansky and Cleaton-Jones performed a longitudinal study (1979). Their purpose was to determine the position of the gingival margin in a longitudinal study of dental students over a 3-year period, using a photographic technique. Dentitions of thirty dental students all 18 years of age were photographed. Photographs of the dentitions were projected onto a viewing table. The labial clinical crown height of the incisor and canine teeth were measured with digital calipers to the nearest 0.1 millimeters. The points of the measurements were from the deepest curvature of the labial gingival margin to the incisal edge of the incisor teeth or to the tip of the crown of the canine teeth.

Differences from one year to the next were analyzed using Student’s paired *t* tests. The level of statistical significance was $p < 0.01$. Only maxillary left central and lateral incisors and mandibular left and right central incisors showed statistically significant mean increases. There was a progressive increase in mean clinical crown height during this period, suggesting that a continual passive eruption of the teeth was occurring.

They had a slightly different position from their first study in stating, “This indicates that by the age of 20 years passive eruption had not yet ceased in the individuals studied. The study needs to be continued to see what will happen after 20 years of age and to determine whether an age will be reached, when passive eruption will cease.”

In 1991 Bassey published an article, "Clinical Crown Heights of Permanent Teeth in Nigerians”, in the *African Dental Journal*. Bassey studied clinical crown height in relation to the retention of fixed prostheses. He used 64 subjects between 21 and 45 years of age. The subjects were not followed over time, but were measured at individual time points and then the data collected was analyzed to determine population norms for clinical crown height changes. Bassey found no significant increases in crown height in the time periods of 21-35 years of age. He did, however, find that all Maxillary and Mandibular teeth increased in clinical crown height over time into the patients' forties. No significant differences were noted between genders for any tooth type.

Implant Placement and the Completion of Growth

It has become common practice for the orthodontist faced with a case of missing teeth to recommend implant placement. It has been suggested that the implants be placed once growth is complete. The focus on the placement of the implant centers on the esthetic requirements necessary for a satisfactory outcome. A 2007 article by Leblebicioglu et al. review the functional and esthetic requirements for dental implants. They discuss bone thickness, bone height, soft tissue shape and thickness, and space requirements. They also briefly touch on the changes in hard tissue and soft tissue during the first year following placement of the implant. They conclude that the implant is an excellent treatment option and with the proper preparation and planning the esthetic outcomes will be achieved. Few would argue that the dental implant is an excellent advancement and it is an excellent treatment choice for many patients, but the timing of implant placement and the long-term changes are often glossed over. Oates et al. (2002) found in a two year study on 39 patients that 24 showed a loss of soft-tissue height. Of the 24, the average loss was 1.6mm in 24 months. The study concludes that changes in soft tissue need to be addressed in the planning of implant therapy.

Among the most notable changes that can have a negative effect on the final outcome of implant therapy in the esthetic zone is the continued eruption of teeth adjacent to the implant. Thilander et al. (1999) conducted an 8 year follow-up study of implants placed in the incisor region. Through the research conducted it was clear that the teeth adjacent to the implant will continue to erupt which will leave the implant in infraocclusion. The esthetic outcome is also damaged by this phenomenon.

Two years later Thilander et al. (2001) published a second long-term follow-up of oral implants in adolescents. They looked at 17 subjects that had single-tooth implants placed in adolescence. 10 subjects had an acceptable esthetic outcome. For 7of the 17 subjects the infraocclusion ranged from 0.6 to 1.6 mm in a 3 year period. The startling finding occurred in the post-adolescent phase, in which the subjects did not grow in body height, when the infraocclusion increased to an average of 0.98 mm. Not only did they find changes in the height of the crown but also apical soft tissue changes in some subjects. They propose that there is not a skeletal age marker or growth check that can prevent the negative changes from occurring. Proper management during the orthodontic phase is key to a successful outcome. Avoiding intrusive movements during treatment is suggested.

Bernard et al. (2004) discussed the long-term vertical changes of implants in adolescents and adults. All adolescent patients in their study had an infraocclusion ranging from 0.1 to 1.65 mm. All adult patients showed a difference between the implant supported crown and the adjacent tooth between 0.12 and 1.86 mm. This study reinforces the idea of continuous eruption throughout adulthood. In 2006 Heij et al. agreed with this assertion in their review of continuous eruption as a compromising factor for implant placement. They write that the continuous eruption creates a “serious risk” even after the age of 20 years.

MATERIALS AND METHODS

Sample

The material for this research project was obtained from the Meredith Facial Growth Study from the University of Iowa Orthodontics Department. This longitudinal study consists of 183 Caucasians (92 males and 91 females), 97% of whom are of northern European ancestry. Included in this study are lateral and anteroposterior cephalograms, complete mouth series radiographs, as well as intraoral models, taken every six months between the ages of 5 and 12 years and annually thereafter through age 17. Two sets of records were taken during adulthood. One set was taken in the subjects' twenties. A final set on a number of subjects was taken in their forties. All subjects had a normal Angle class I molar and canine relationship and were free of any facial or skeletal disharmony.

Records from a set of 64 subjects (35 males and 29 females) were used. Each of these patients had intraoral models taken throughout adolescence into adulthood. A final model was available for each subject in their twenties. Twenty-seven subjects had final records available in their forties (14 males and 13 females).

Measuring Device

All measurements were taken with a Mitutoyo Absolute Digimatic caliper which is a fine point caliper capable of measuring lengths to the nearest one-hundredth of a millimeter.

Cast Measurements

Measurements were recorded for the maxillary first molars (Teeth 3 and 14), and the mandibular first molars (Teeth 19 and 30). Measurement points were the mesio-buccal cusp tip of the tooth to the most apical (deepest) curvature of the gingival margin apical to the mesio-buccal cusp. Some subjects measured did not have models in perfect measuring condition; therefore, N values for each tooth were usually less than the total number of subjects. Those teeth with visible coronal restorations, impression inaccuracies, fractured models, or unreadable gingival margins were excluded from the study as these prevented an accurate measurement.

Measurements were taken at eleven time points for all sixty-four subjects starting at year 8 and yearly until age 18 with a final measurement taken on a model from the patient's twenties. A subset of twenty-seven subjects contained measurements in their forties.

Bitewing Radiograph Measurements

In addition to the cast measurements, bitewing radiographs were also used to measure the distance from the CEJ of the first molars to the alveolar crest. The radiographs used were taken at the age of 12 years and again in adulthood during the subject's 20s. Measurements were taken from the mesial CEJ, where the radiopaque enamel meets the more radiolucent cementum at the most apical point, to the crest of the alveolus in a vertical measurement.

Measurement Reliability

To evaluate measurement reliability, eight subjects were re-measured at all time points. This represented 12.5% of the casts measured.

Statistical Analyses

Statistical analyses were carried out with the statistical package SAS® System version 9.1(SAS Institute Inc, Cary, NC, USA). All tests employed a 0.05 level of statistical significance.

Gender Effects

Descriptive statistics of the clinical crown measurements were conducted. A two-sample t-test was used to detect a significant difference in mean clinical crown heights between females and males at each age.

The linear mixed model was performed, and this analysis strategy employs a linear clinical crown height growth curve model for male and female subjects as well as a variance-covariance model that incorporates correlations for all of the measurements obtained from the same person. The missing observations were considered to be missing at random. In this study, the unconditional model, the most typical covariance structure for longitudinal data which requires no assumptions regarding the error terms and allows any correlations between the observations, was used to analyze the changes over time in clinical crown height data.

Subset Analysis at 11, 20s, 40s

Descriptive statistics were conducted for the average clinical crown measurement of teeth #3 and #14 and the average clinical crown measurements of teeth #19 and #30 at ages 11, 20 and 40.

A two-way repeated measures ANOVA was conducted to examine the effects of gender and time (age) on the clinical crown heights. An interaction between time (age) and gender was also explored.

A two-sample t-test was used to detect a significant difference in mean average clinical crown heights of two teeth (teeth #3 and #14 or teeth #19 and #30) between females and males at ages 11, 20 and 40.

A two-way repeated measures ANOVA was conducted to examine the effects of gender and time (age) on the clinical crown heights. An interaction between time (age) and gender was also explored.

Pearson correlation test was used to evaluate whether there was an apparent increasing or decreasing relationship between average crown heights of two teeth measured at ages 11, 20 and 40. The following is an approximate guide for interpreting the strength of the relationship between two variables, based on the absolute value of the Pearson coefficient:

i) ±1= perfect correlation,

ii) ±0.8=strong correlation,

iii) ±0.5=moderate correlation,

iv) ±0.2=weak correlation,

v) ±0.00=no correlation.

Change in Cast Measurement vs. Change in X-ray Measurements

Descriptive statistics were conducted for the average clinical crown measurement and CEJ to AC measurement of two pairs of teeth (#3 and #14 or #19 and #30) at ages 12 and 20 as well as for the change from age 12 to 20 in the average change in clinical crown measurement and change in CEJ to AC measurements of two pairs of teeth.

A paired-sample t-test was used to detect a significant difference between these cast and x-ray measurements for the change from age 12 to 20 in the average clinical crown measurements and CEJ to AC measurements of two pairs of teeth (#3 and #14 or #19 and #30).

Reliability Assessments

In regards to reliability, intraclass correlation coefficients were computed as a measure of agreement between two measurements which were made on the same tooth from the same subject by a single evaluator. The following is an approximate guide for interpreting an agreement between two measurements that corresponds to an intraclass correlation coefficient:

i) 1= perfect agreement

ii) 0.8=strong agreement

iii) 0.5=moderate agreement

iv) 0.2=weak agreement

v) 0=no agreement.

In addition, a paired-sample t-test was used to determine whether a significant difference existed between two measurements for a single evaluator.

To assess the reliability of duplicate measurements obtained from the same tooth of the same subject for a single examiner, 8 subjects (n=4 per gender group) were randomly selected. The measurement reliability was assessed separately by each tooth and by all teeth.

For tooth #3 intraclass correlation coefficient was computed to assess intra-observer agreement in tracing of crown height measurements for tooth3. Overall, there was very strong evidence that the intraclass correlation differed from zero (p<0.0001), and the correlation coefficient of 0.99 indicated a strong agreement between two measurements with a single evaluator for tooth3.

Additional analysis was conducted to determine if there was a significant difference between two measurements made by the same observer for tooth3. The data revealed that there was no statistically significant difference between two measurements (p=0.2735). The mean measurement difference between first and second measurements was -0.01mm (std =0.04).

For tooth #14 intraclass correlation coefficient was computed to assess inter-observer agreement in tracing of crown height measurements for tooth14. Overall, there was very strong evidence that the intraclass correlation differed from zero (p<0.0001), and the correlation coefficient of 0.99 indicated a strong agreement between two measurement with a single evaluator for tooth14.

Additional analysis was conducted to determine if there was a significant difference between two measurements made by the same observer for tooth14. The data revealed that there was no statistically significant difference between two measurements ($p=0.1478$). The mean measurement difference between first and second measurements was -0.01mm (std =0.03).

For tooth #19 intraclass correlation coefficient was computed to assess inter-observer agreement in tracing of crown height measurements for tooth19. Overall, there was very strong evidence that the intraclass correlation differed from zero ($p<0.0001$), and the correlation coefficient of 0.99 indicated a strong agreement between two measurements with a single evaluator for tooth19.

Additional analysis was conducted to determine if there was a significant difference between two measurements made by the same observer for tooth19. The data revealed that there was no statistically significant difference between two measurements ($p=0.3517$). The mean measurement difference between first and second measurements was 0.01mm (std =0.11).

For tooth #30 intraclass correlation coefficient was computed to assess inter-observer agreement in tracing of crown height measurements for tooth30. Overall, there was very strong evidence that the intraclass correlation differed from zero ($p<0.0001$), and the correlation coefficient of 0.99 indicated a strong agreement between two measurements with a single evaluator for tooth30.

Additional analysis was conducted to determine if there was a significant difference between two measurements made by the same observer for tooth30. The data revealed that there was no statistically significant difference between two measurements ($p=0.2278$). The mean measurement difference between first and second measurements was 0.00mm (std =0.04).

When Four Teeth were combined Together the intraclass correlation coefficient was computed to assess intra-observer agreement in tracing of crown height measurements. Overall, there was very strong evidence that the intraclass correlation differed from zero ($p<0.0001$), and the correlation coefficient of 0.94 indicated a strong agreement between two measurements.

Additional analysis was conducted to determine if there was a significant difference between two measurements made by the same observer as four teeth were considered together. The data revealed that there was no statistically significant difference between two measurements ($p=0.7235$). The mean measurement difference between first and second measurements was 0.00mm (std =0.06).

RESULTS

Tooth 3

Figures 1a-1b shows the within-subject profile graphs according to gender by each age. Figure 2 illustrates mean clinical crown heights over time by gender.

Based on the two-sample t-test, the data revealed that there was no significant difference in mean clinical crown height between males and females at each age for tooth 3 ($p>0.05$ for each instance).

For tooth 3, the regression model for each subject can be assumed to be a random deviation from some population regression model; the standard random coefficient model involves a random intercept and slope for each subject. This allows each individual to have a person-specific trajectory on the measure of clinical crown heights across time. In this model, the intra-subject regression coefficients were considered to be random. Time (age) was considered to be continuous. The interests in this analysis is to test for difference in grow rates between the genders, and the parameters estimates for the crown height measurements.

The results indicated that there was no significant mean crown height difference between the genders over time ($p=0.6200$). The non- significant gender by age interaction ($p=0.2456$) which demonstrated that the males and females did not differ in their growth rates across time. The age effect ($p<0.0001$) was highly significantly demonstrating that there were significant changes in the crown height over time.

Moreover, the results indicated that the estimate of males' intercept is 4.4527, while for the females is 4.3796 (4.4527-0.0731). Similarly, the estimate for the males' slope is 0.152, while that for the females is 0.1333 (0.152-0.0187). Thus males' starting point was larger than that for the females, and their growth rate was greater than the females as well. Table 2 summarizes the results of this analysis.

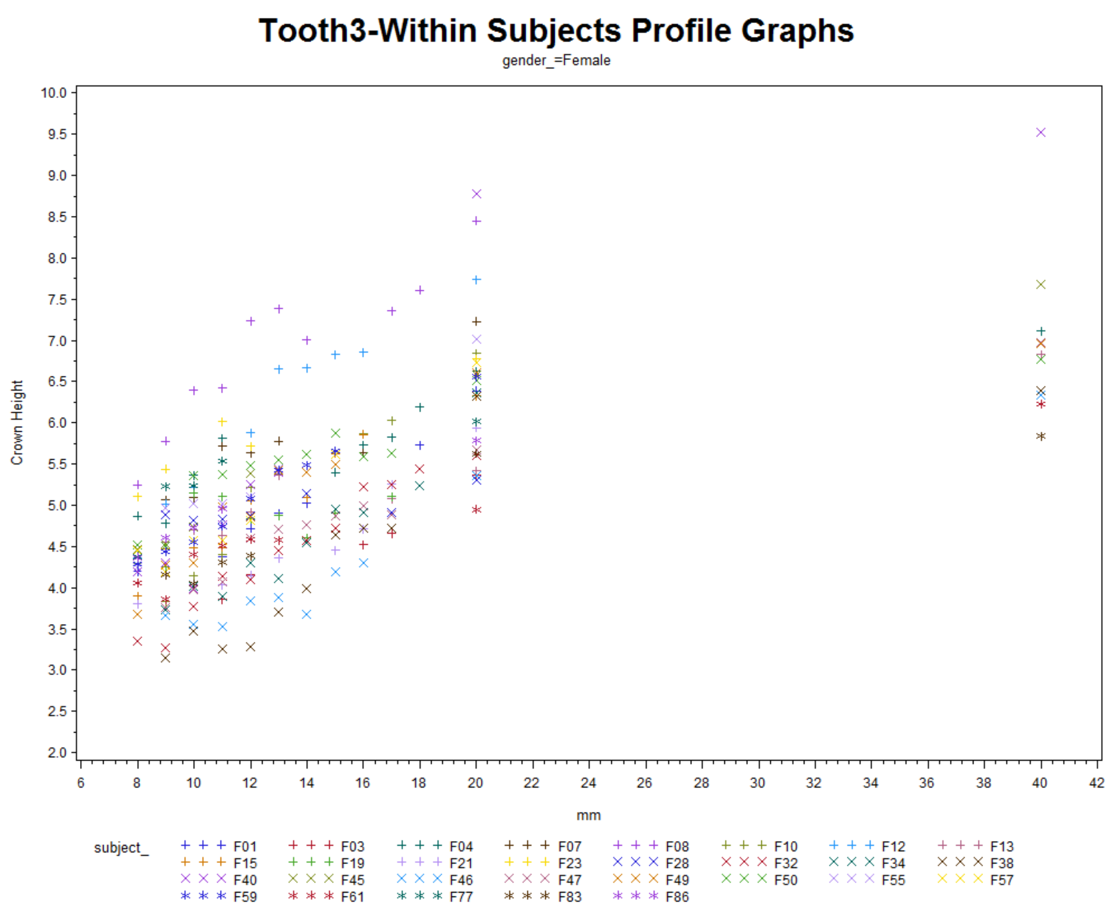

Figure 1 – Within subjects profile graphs for tooth 3 females

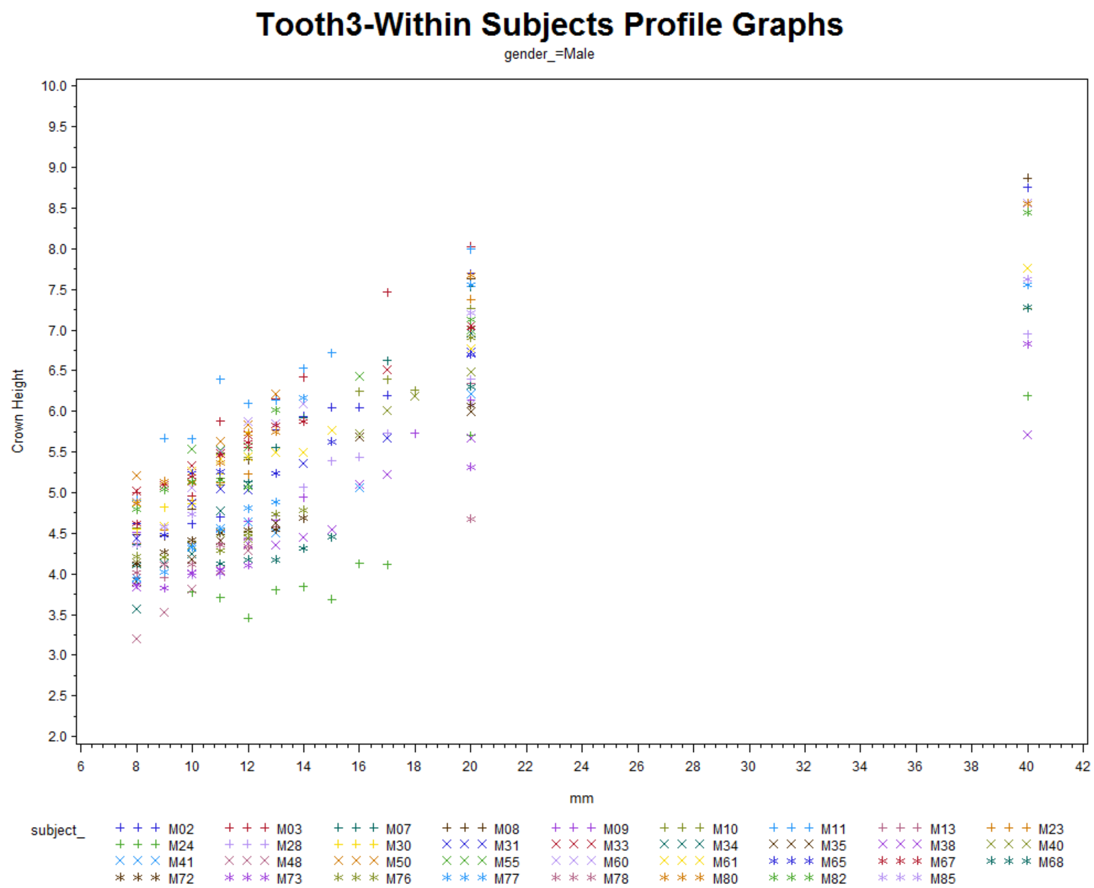

Figure 2 – Within subjects profile graphs for tooth 3 males

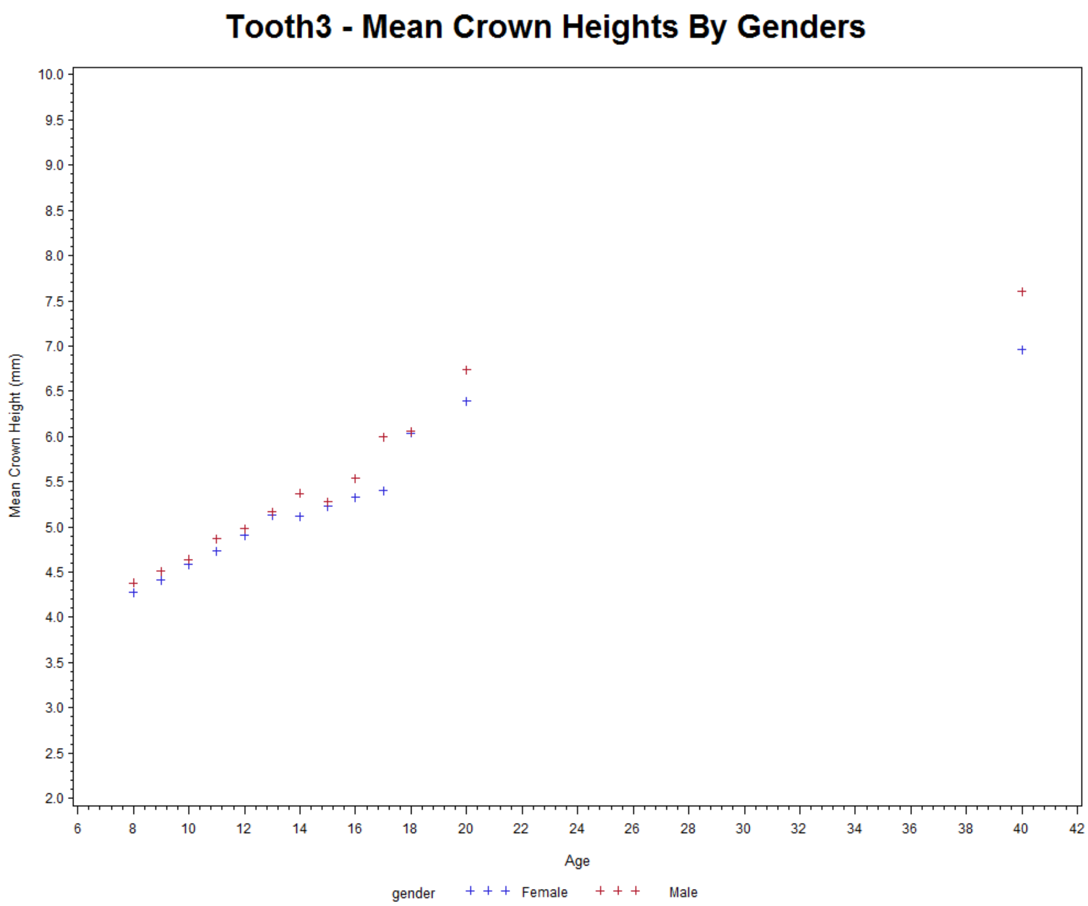

Figure 3 –Mean crown height by gender for tooth 3

Table 1 –Descriptive Statistics for the Clinical Crown Heights of Tooth 3

A. Tooth 3: For All Subjects (n=64)

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age8___Crown_height	52	4.34	0.46	3.21	5.25	4.37
Age9___Crown_height	45	4.45	0.60	3.15	5.78	4.47
Age10__Crown_height	58	4.62	0.59	3.48	6.40	4.60
Age11__Crown_height	62	4.81	0.68	3.26	6.42	4.76
Age12__Crown_height	60	4.95	0.69	3.29	7.24	4.90
Age13__Crown_height	41	5.15	0.81	3.71	7.39	5.24
Age14__Crown_height	30	5.25	0.85	3.68	7.01	5.12
Age15__Crown_height	22	5.25	0.79	3.69	6.83	5.40
Age16__Crown_height	23	5.41	0.69	4.13	6.86	5.59
Age17__Crown_height	22	5.67	0.86	4.12	7.47	5.66
Age18__Crown_height	8	6.05	0.73	5.24	7.61	5.96
Age20__Crown_height	60	6.58	0.86	4.68	8.78	6.58
Age40__Crown_height	26	7.30	0.99	5.71	9.53	7.05

Table 1 – Continued

B. Tooth 3: For Female Subjects (n=29)

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age8___Crown_height	12	6.96	0.94	5.84	9.53	6.83
Age9___Crown_height	26	4.41	0.64	3.15	5.78	4.46
Age10__Crown_height	26	4.59	0.67	3.48	6.40	4.57
Age11__Crown_height	28	4.73	0.75	3.26	6.42	4.70
Age12__Crown_height	26	4.91	0.77	3.29	7.24	4.87
Age13__Crown_height	19	5.13	0.90	3.71	7.39	5.36
Age14__Crown_height	14	5.12	0.91	3.68	7.01	5.06
Age15__Crown_height	14	5.23	0.69	4.19	6.83	5.18
Age16__Crown_height	14	5.33	0.68	4.31	6.86	5.41
Age17__Crown_height	12	5.40	0.75	4.66	7.36	5.18
Age18__Crown_height	5	6.04	0.94	5.24	7.61	5.73
Age20__Crown_height	28	6.39	0.91	4.95	8.78	6.38
Age40__Crown_height	20	4.28	0.46	3.36	5.25	4.30

Table 1 – Continued

C. Tooth 3: For Male Subjects (n=35)

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age8___Crown_height	14	7.60	0.98	5.71	8.87	7.60
Age9___Crown_height	19	4.51	0.54	3.53	5.67	4.48
Age10__Crown_height	32	4.64	0.53	3.78	5.66	4.68
Age11__Crown_height	34	4.87	0.63	3.71	6.40	4.92
Age12__Crown_height	34	4.98	0.63	3.46	6.10	5.06
Age13__Crown_height	22	5.17	0.73	3.80	6.22	5.07
Age14__Crown_height	16	5.37	0.81	3.85	6.53	5.43
Age15__Crown_height	8	5.28	0.98	3.69	6.72	5.51
Age16__Crown_height	9	5.54	0.71	4.13	6.43	5.69
Age17__Crown_height	10	6.00	0.90	4.12	7.47	6.11
Age18__Crown_height	3	6.06	0.29	5.73	6.26	6.19
Age20__Crown_height	32	6.74	0.79	4.68	8.03	6.84
Age40__Crown_height	32	4.38	0.47	3.21	5.22	4.41

Table 2---Summary of the Full Model Used in the Random Coefficient Regression Analysis of Tooth 3

Effect	Gender	Estimate	Std. Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Intercept		4.4527	0.0992	62	44.89	<.0001	0.05	4.2544	4.6509
gender	f	-0.0731	0.1473	381	-0.50	0.6200	0.05	-0.3627	0.2165
gender	m	0	.	.	.	.	.	.	.
age		0.1520	0.0110	62	13.78	<.0001	0.05	0.1300	0.1741
age*gender	f	-0.0187	0.0161	381	-1.16	0.2456	0.05	-0.0504	0.0129
age*gender	m	0	.	.	.	.	.	.	.

Note: DF=Degree of Freedom
**Males as the reference group

Tooth 14

Figures 3a-3b shows the within-subject profile graphs according to gender by each age. Figure 4 illustrates mean clinical crown height over time for each gender.

Based on the two-sample t-test, the data revealed that there was no significant difference in mean clinical crown heights between males and females at each age for tooth 14 ($p>0.05$ for each instance), except for at age 40 ($p=0.0232$). The data showed that the mean clinical crown heights for males were significantly greater than that observed for females at age 40 (mean clinical crown height: 7.34 vs. 6.65, respectively).

For tooth14, the regression model for each subject can be assumed to be a random deviation from some population regression model; the standard random coefficient model involves a random intercept and slope for each subject. This allows each individual to have a person-specific trajectory on the measure of clinical crown heights across time. In this model, the intra-subject regression coefficients were considered to be random. Time (age) was considered to be continuous. The interests in this analysis is to test for difference in grow rates between the genders, and the parameters estimates for the crown height measurements.

The results indicated that there was no significant mean crown height difference between the genders over time ($p=0.4783$). The non- significant gender by age interaction ($p=0.4356$) which demonstrated that the males and females did not differ in their growth rates across time. The age effect ($p<0.0001$) was highly significantly demonstrating that there were significant changes in the crown height over time.

Moreover, the results indicated that the estimate of males' intercept is 4.6095, while for the females is 4.5104 (4.6095-0.0991). Similarly, the estimate for the males' slope is 0.1409, while that for the females is 0.1274 (0.1409-0.0135). Thus males' starting point was larger than that for the females, and their growth rate was greater than the females as well. Table 4 summarizes the results of this analysis.

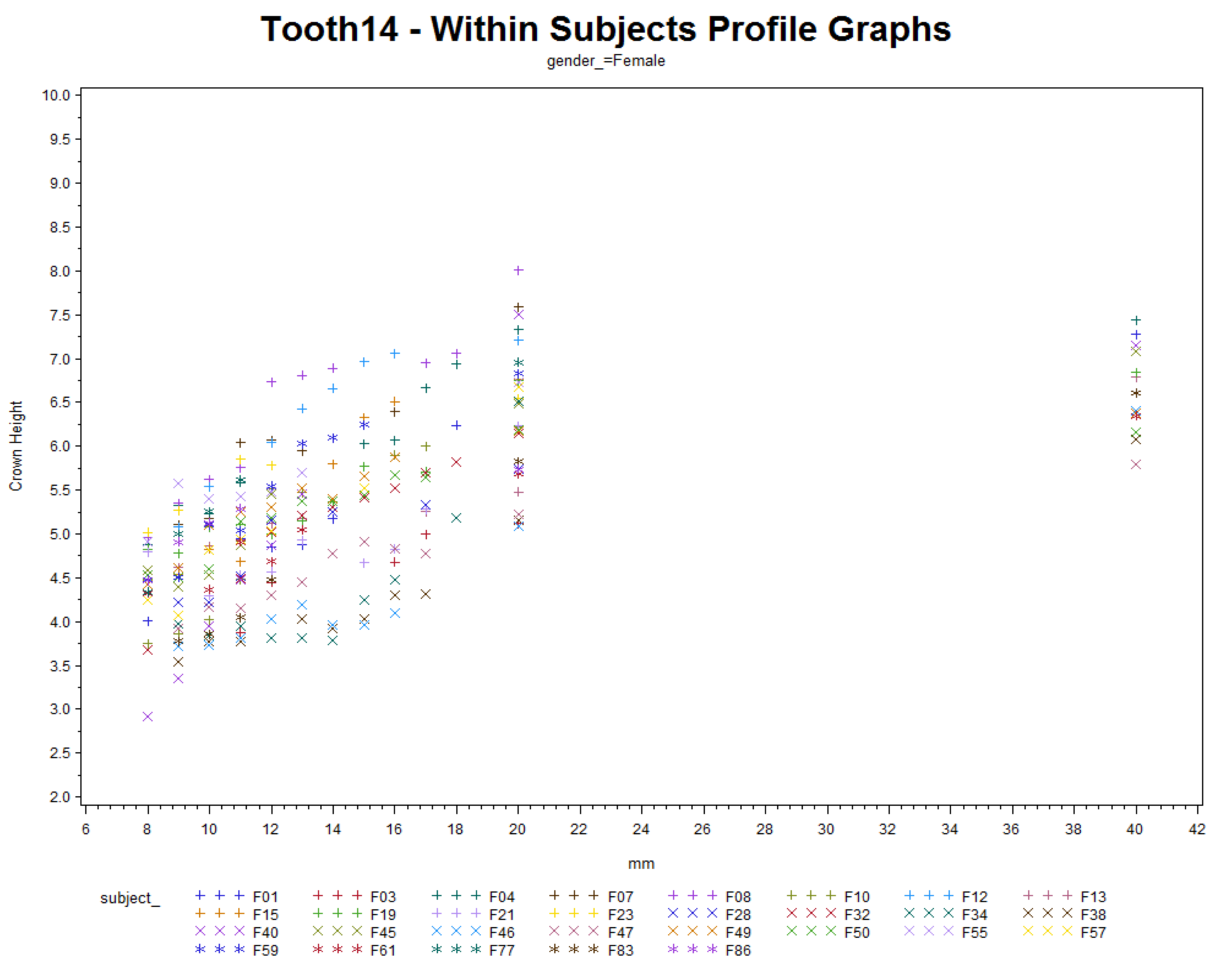

Figure 4 – Within subjects profile graphs for

tooth 14 females

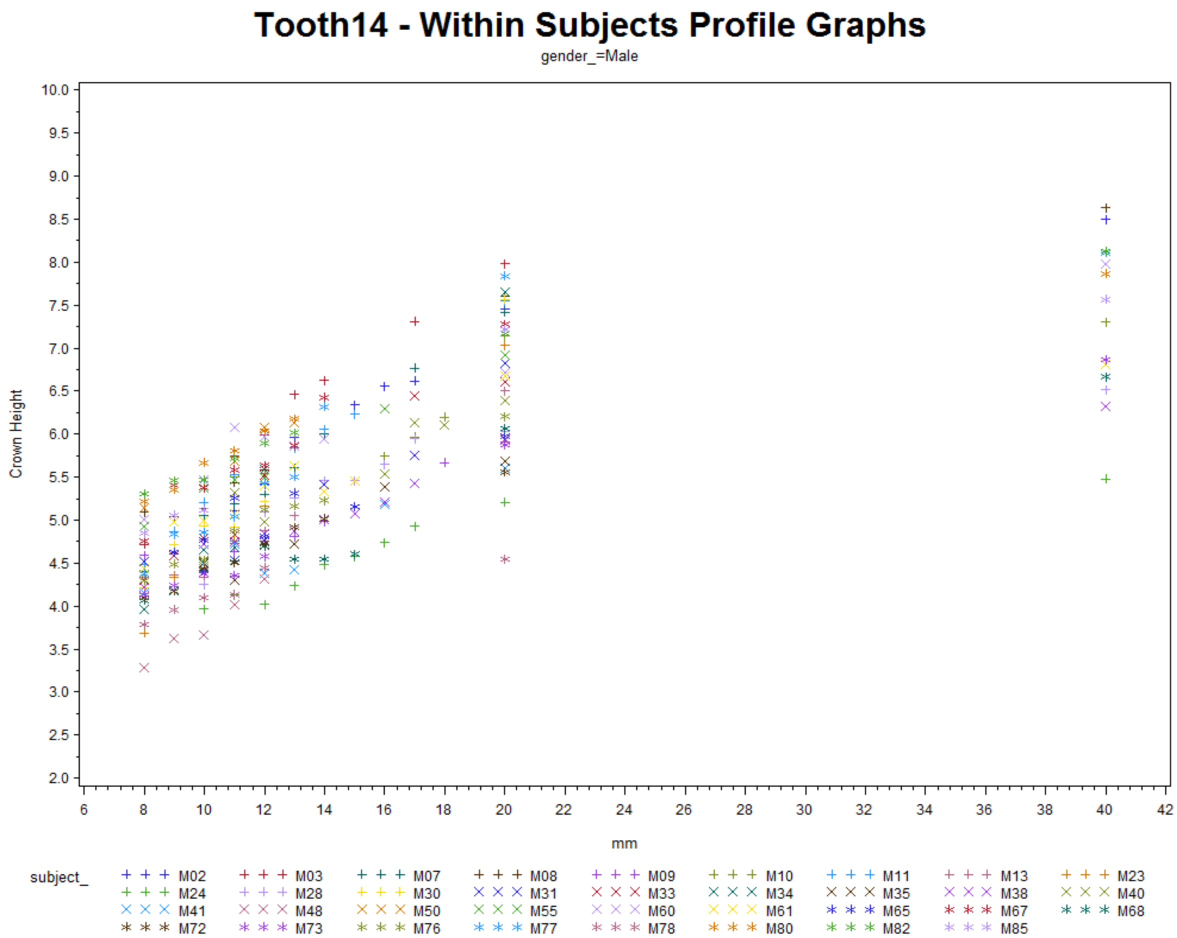

Figure 5 – Within subjects profile graphs for tooth 14 males

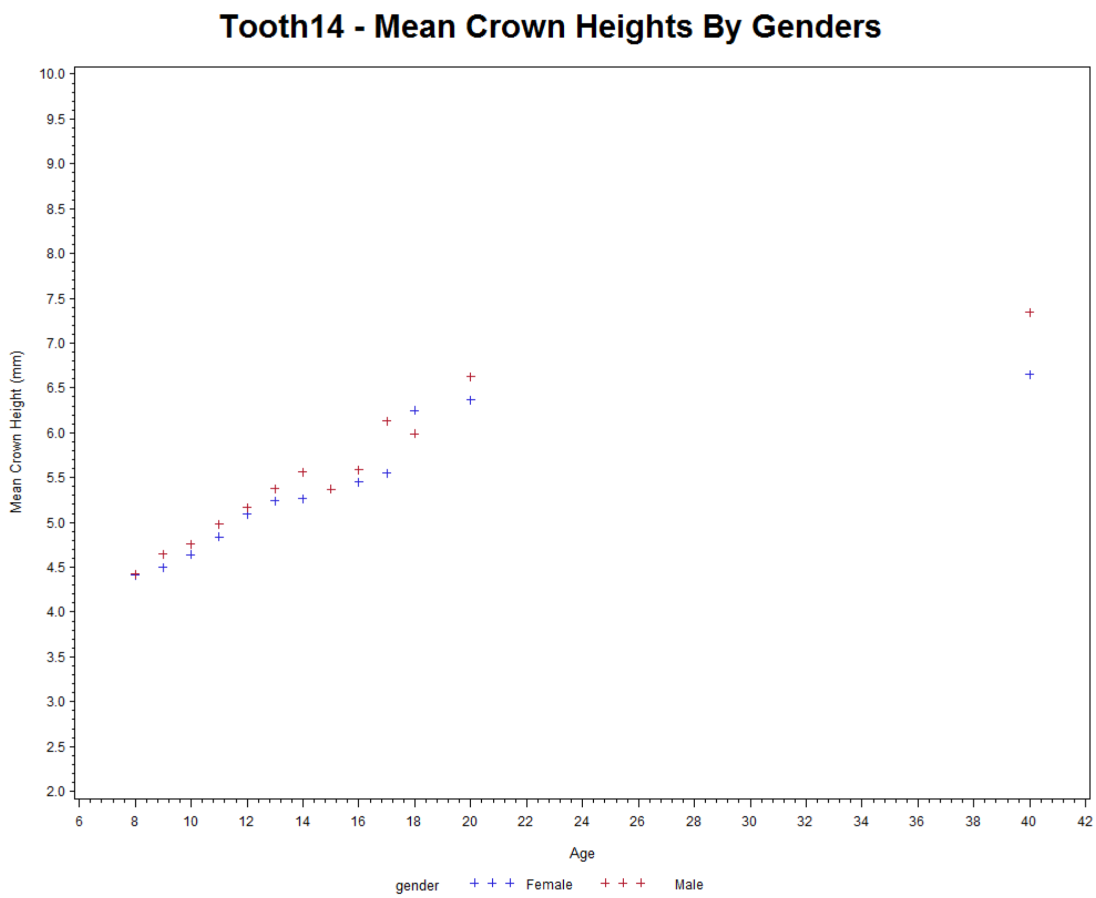

Figure 6 –Mean crown height by gender for tooth 14

Table 3 – Descriptive Statistics for the Clinical Crown Heights of Tooth 4

A. Tooth 14: For All Subjects (n=64)

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age8___Crown_height	52	4.42	0.47	2.92	5.31	4.42
Age9___Crown_height	45	4.56	0.57	3.36	5.58	4.59
Age10__Crown_height	58	4.71	0.53	3.67	5.67	4.75
Age11__Crown_height	62	4.92	0.59	3.78	6.08	4.92
Age12__Crown_height	59	5.13	0.61	3.82	6.73	5.13
Age13__Crown_height	41	5.32	0.70	3.82	6.81	5.32
Age14__Crown_height	30	5.42	0.80	3.79	6.89	5.37
Age15__Crown_height	22	5.37	0.81	3.97	6.97	5.46
Age16__Crown_height	23	5.50	0.78	4.10	7.06	5.54
Age17__Crown_height	22	5.82	0.76	4.32	7.31	5.74
Age18__Crown_height	8	6.15	0.63	5.18	7.06	6.16
Age20__Crown_height	63	6.51	0.81	4.55	8.01	6.55
Age40__Crown_height	27	7.01	0.82	5.48	8.63	6.84

Table 3 – Continued

B. Tooth 14: For Female Subjects (n=29)

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age8___Crown_height	13	6.65	0.50	5.80	7.44	6.61
Age9___Crown_height	26	4.50	0.61	3.36	5.58	4.53
Age10__Crown_height	26	4.64	0.60	3.74	5.62	4.71
Age11__Crown_height	28	4.84	0.64	3.78	6.04	4.92
Age12__Crown_height	26	5.09	0.70	3.82	6.73	5.08
Age13__Crown_height	19	5.24	0.78	3.82	6.81	5.21
Age14__Crown_height	14	5.27	0.94	3.79	6.89	5.34
Age15__Crown_height	14	5.37	0.91	3.97	6.97	5.49
Age16__Crown_height	14	5.45	0.92	4.10	7.06	5.60
Age17__Crown_height	12	5.55	0.74	4.32	6.95	5.49
Age18__Crown_height	5	6.25	0.78	5.18	7.06	6.24
Age20__Crown_height	29	6.37	0.78	5.09	8.01	6.49
Age40__Crown_height	20	4.41	0.51	2.92	5.02	4.48

Table 3 – Continued

C. Tooth 14: For Male Subjects (n=35)

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age8___Crown_height	14	7.34	0.92	5.48	8.63	7.44
Age9___Crown_height	19	4.65	0.51	3.63	5.46	4.63
Age10__Crown_height	32	4.76	0.47	3.67	5.67	4.75
Age11__Crown_height	34	4.98	0.55	4.02	6.08	4.90
Age12__Crown_height	33	5.17	0.54	4.02	6.08	5.16
Age13__Crown_height	22	5.38	0.63	4.24	6.46	5.42
Age14__Crown_height	16	5.56	0.66	4.48	6.63	5.44
Age15__Crown_height	8	5.37	0.66	4.58	6.34	5.31
Age16__Crown_height	9	5.59	0.56	4.74	6.56	5.54
Age17__Crown_height	10	6.13	0.69	4.93	7.31	6.06
Age18__Crown_height	3	5.99	0.28	5.67	6.20	6.11
Age20__Crown_height	34	6.63	0.84	4.55	7.98	6.70
Age40__Crown_height	32	4.42	0.46	3.29	5.31	4.38

Table 4---Summary of the Full Model Used in the Random Coefficient Regression Analysis of Tooth 14

Effect	Gender	Estimate	Std. Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Intercept		4.6095	0.0940	62	49.02	<.0001	0.05	4.4215	4.7974
gender	f	-0.0991	0.1396	384	-0.71	0.4783	0.05	-0.3735	0.1754
gender	m	0	.	.	.	.	.	.	.
age		0.1409	0.0117	62	12.01	<.0001	0.05	0.1175	0.1644
age*gender	f	-.0135	0.0173	384	-0.78	0.4356	0.05	-0.0474	0.0205
age*gender	m	0	.	.	.	.	.	.	.

Note: DF=Degree of Freedom
**Males as the reference group

Tooth 19

Figures 5a-5b shows the within-subject profile graphs according to gender by each age. Figure 6 illustrates mean clinical crown height over time for each gender.

Based on the two-sample t-test, the data revealed that there was no significant difference in mean clinical crown heights between males and females at each age for tooth 19 ($p>0.05$ for each instance), except for at age 9 ($p=0.0016$). The data showed that the mean clinical crown heights for males were significantly greater than that observed for females at age 9 (mean clinical crown height: 5.38 vs. 4.90, respectively).

For tooth19, the regression model for each subject can be assumed to be a random deviation from some population regression model; the standard random coefficient model involves a random intercept and slope for each subject. This allows each individual to have a person-specific trajectory on the measure of clinical crown heights across time. In this model, the intra-subject regression coefficients were considered to be random. Time (age) was considered to be continuous. The interests in this analysis is to test for difference in grow rates between the genders, and the parameters estimates for the crown height measurements.

The results indicated that there was no significant mean crown height difference between the genders over time ($p=0.1583$). The non- significant gender by age interaction ($p=0.6397$) which demonstrated that the males and females did not differ in their growth rates across time. The age effect ($p<0.0001$) was highly significantly demonstrating that there were significant changes in the crown height growth over time.

Moreover, the results indicated that the estimate of males' intercept is 5.1736, while for the females is 4.9855 (5.1736-0.1881). Similarly, the estimate for the males' slope is 0.1315, while that for the females is 0.1241 (0.1315-0.0074). Thus males' starting point was larger than that for the females, and their growth rate was greater than the females as well. Table 6 summarizes the results of this analysis.

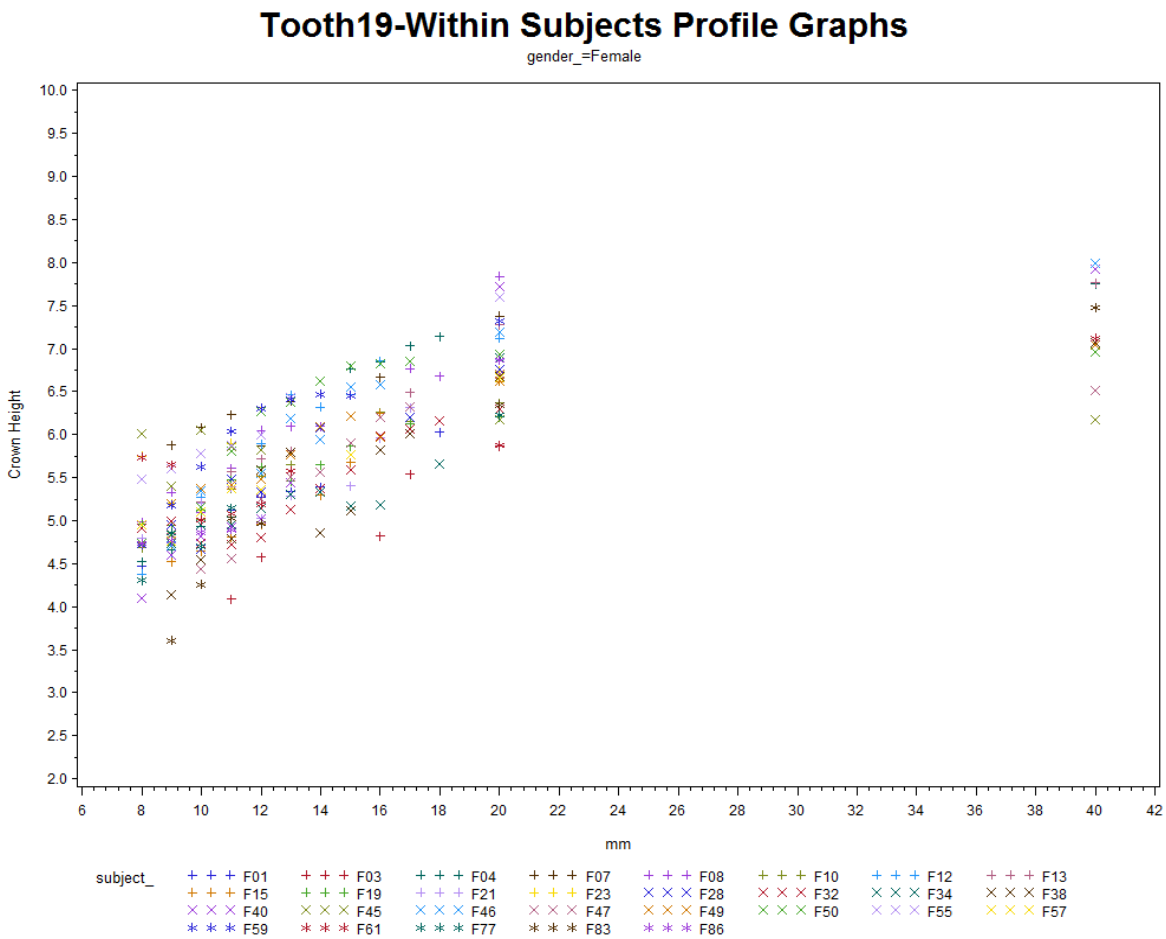

Figure 7 – Within subjects profile graphs for tooth 19 females

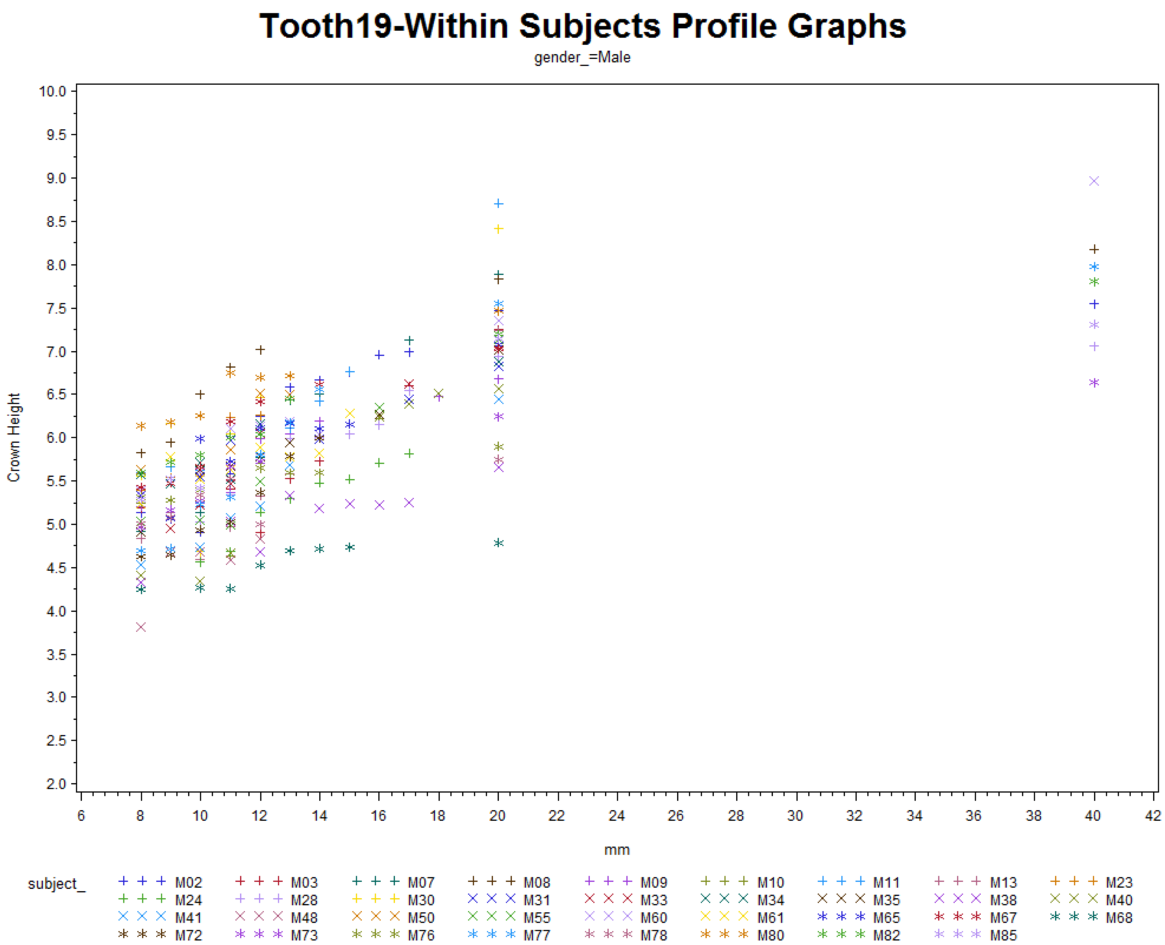

Figure 8 – Within subjects profile graphs for tooth 19 males

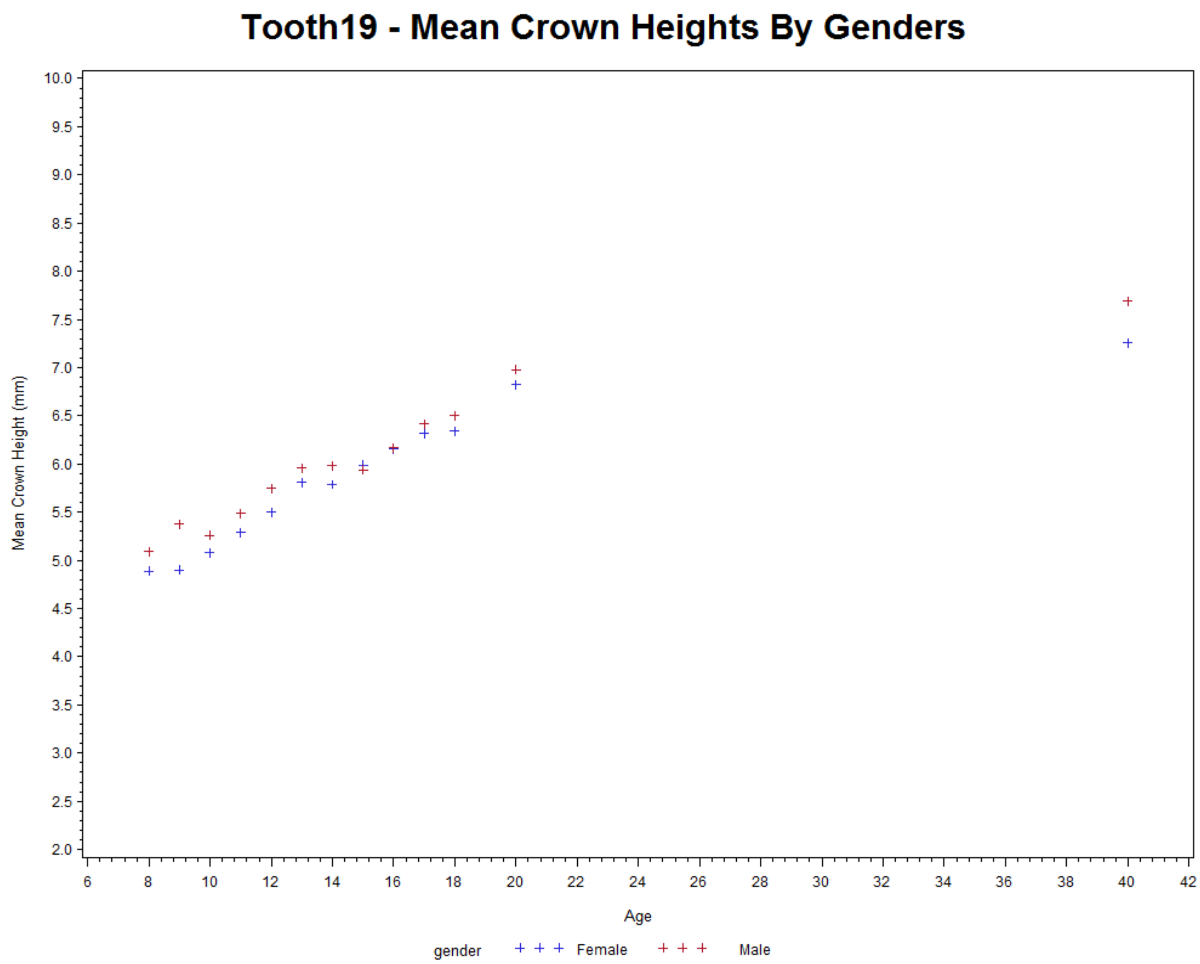

Figure 9 –Mean crown height by gender for tooth 19

Table 5 – Descriptive Statistics for the Clinical Crown Heights of Tooth 19

A. Tooth 19: For All Subjects (n=64)

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age8___Crown_height	52	5.01	0.51	3.82	6.14	4.97
Age9___Crown_height	45	5.10	0.52	3.61	6.18	5.07
Age10__Crown_height	58	5.18	0.50	4.26	6.50	5.15
Age11__Crown_height	62	5.40	0.55	4.09	6.82	5.42
Age12__Crown_height	59	5.64	0.57	4.53	7.02	5.70
Age13__Crown_height	41	5.89	0.48	4.70	6.72	5.81
Age14__Crown_height	31	5.90	0.52	4.72	6.67	6.00
Age15__Crown_height	22	5.97	0.61	4.74	6.80	5.98
Age16__Crown_height	23	6.16	0.55	4.82	6.96	6.25
Age17__Crown_height	21	6.37	0.48	5.26	7.13	6.40
Age18__Crown_height	7	6.38	0.48	5.66	7.14	6.48
Age20__Crown_height	57	6.91	0.69	4.79	8.71	6.94
Age40__Crown_height	19	7.44	0.66	6.18	8.97	7.48

Table 5 – Continued

B. Tooth 19: For Female Subjects (n=29)

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age8___Crown_height	11	7.26	0.59	6.18	7.99	7.12
Age9___Crown_height	26	4.90	0.47	3.61	5.88	4.85
Age10__Crown_height	26	5.08	0.45	4.26	6.08	5.06
Age11__Crown_height	28	5.29	0.49	4.09	6.23	5.37
Age12__Crown_height	26	5.50	0.47	4.58	6.31	5.51
Age13__Crown_height	19	5.81	0.45	5.13	6.46	5.77
Age14__Crown_height	14	5.79	0.52	4.86	6.62	5.80
Age15__Crown_height	14	5.99	0.57	5.12	6.80	5.89
Age16__Crown_height	14	6.16	0.61	4.82	6.86	6.23
Age17__Crown_height	12	6.32	0.41	5.54	7.03	6.26
Age18__Crown_height	5	6.34	0.58	5.66	7.14	6.17
Age20__Crown_height	28	6.82	0.55	5.87	7.84	6.75
Age40__Crown_height	20	4.89	0.50	4.10	6.01	4.74

Table 5 – Continued

C. Tooth 19: For Male Subjects (n=35)

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age8___Crown_height	8	7.69	0.72	6.64	8.97	7.68
Age9___Crown_height	19	5.38	0.47	4.65	6.18	5.47
Age10__Crown_height	32	5.26	0.53	4.27	6.50	5.25
Age11__Crown_height	34	5.49	0.59	4.26	6.82	5.52
Age12__Crown_height	33	5.75	0.61	4.53	7.02	5.81
Age13__Crown_height	22	5.96	0.50	4.70	6.72	6.02
Age14__Crown_height	17	5.98	0.53	4.72	6.67	6.00
Age15__Crown_height	8	5.94	0.72	4.74	6.77	6.10
Age16__Crown_height	9	6.17	0.47	5.23	6.96	6.25
Age17__Crown_height	9	6.42	0.57	5.26	7.13	6.54
Age18__Crown_height	2	6.50	0.02	6.48	6.51	6.50
Age20__Crown_height	29	6.98	0.81	4.79	8.71	7.07
Age40__Crown_height	32	5.09	0.51	3.82	6.14	5.20

Table 6---Summary of the Full Model Used in the Random Coefficient Regression Analysis of Tooth 19

Effect	Gender	Estimate	Std. Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Intercept		5.1736	0.0900	62	57.46	<.0001	0.05	4.9936	5.3536
gender	f	-0.1881	0.1330	369	-1.41	0.1583	0.05	-0.4496	0.0735
gender	m	0	.	.	.	.	.	.	.
age		0.1315	0.0109	62	12.01	<.0001	0.05	0.1096	0.1534
age*gender	f	-0.0074	0.0157	369	-0.47	0.6397	0.05	-0.0382	0.0235
age*gender	m	0	.	.	.	.	.	.	.

Note: DF=Degree of Freedom
**Males as the reference group

Tooth 30

Figures 7a-7b shows the within-subject profile graphs according to gender by each age. Figure 8 illustrates mean clinical crown height over time for each gender.

Based on the two-sample t-test, the data revealed that there was no significant difference in mean clinical crown heights between males and females at each age for tooth 30 ($p>0.05$ for each instance), except for at age 9 ($p=0.0065$). The data showed that the mean clinical crown heights for males were significantly greater than that observed for females at age 9 (mean clinical crown height: 5.14 vs. 4.73, respectively).

For tooth30, the regression model for each subject can be assumed to be a random deviation from some population regression model; the standard random coefficient model involves a random intercept and slope for each subject. This allows each individual to have a person-specific trajectory on the measure of clinical crown heights across time. In this model, the intra-subject regression coefficients were considered to be random. Time (age) was considered to be continuous. The interests in this analysis is to test for difference in grow rates between the genders, and the parameters estimates for the crown height measurements.

The results indicated that there was no significant mean crown height difference between the genders over time ($p=0.1652$). The non- significant gender by age interaction ($p=0.7957$) which demonstrated that the males and females did not differ in their growth rates across time. The age effect ($p<0.0001$) was highly significantly demonstrating that there were significant changes in the crown height growth over time.

Moreover, the results indicated that the estimate of males' intercept is 4.9156, while for the females is 4.7366 (4.9156-0.1790). Similarly, the estimate for the males' slope is 0.1288, while that for the females is 0.1245 (0.1288-0.0043). Thus males' starting point was larger than that for the females, and their growth rate was greater than the females as well. Table 4D summarizes the results of this analysis.

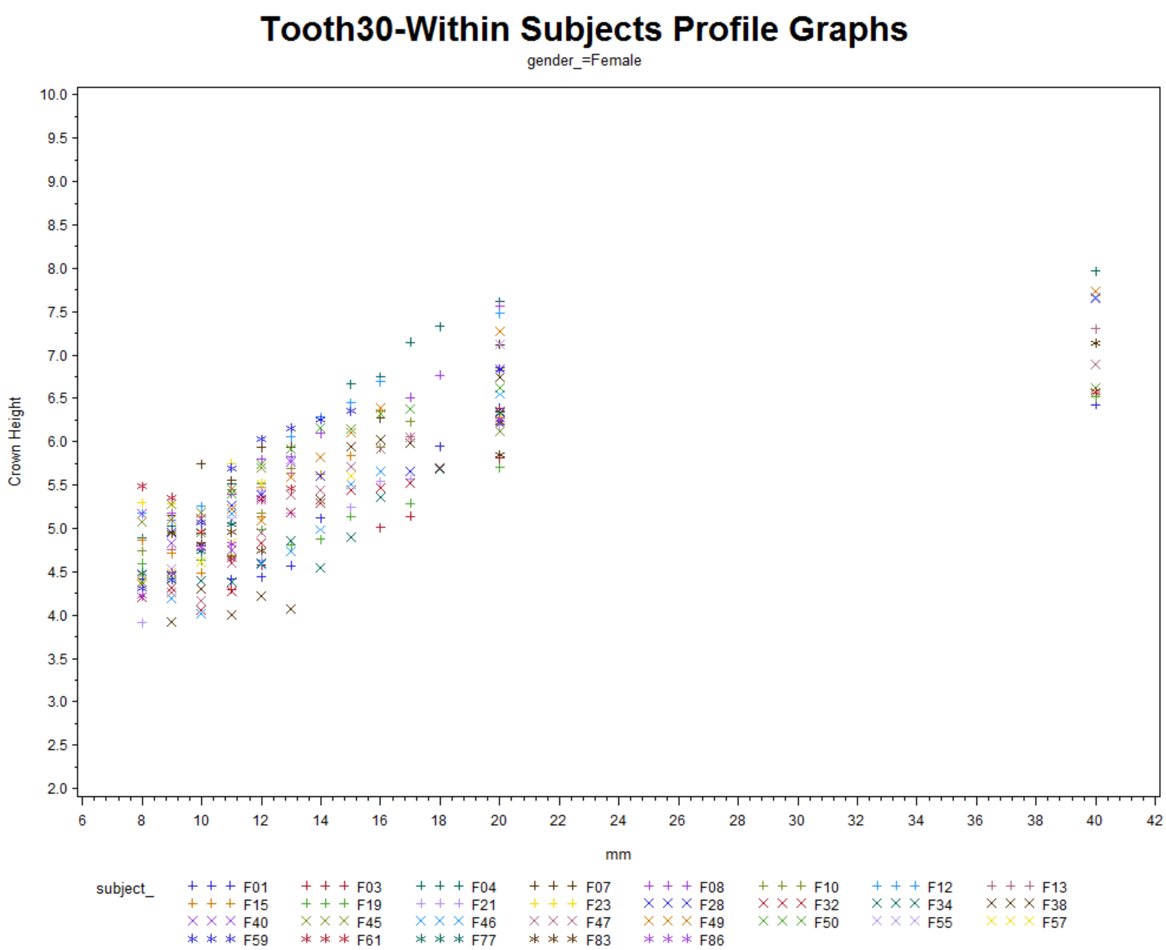

Figure 10 – Within subjects profile graphs

for tooth 30 females

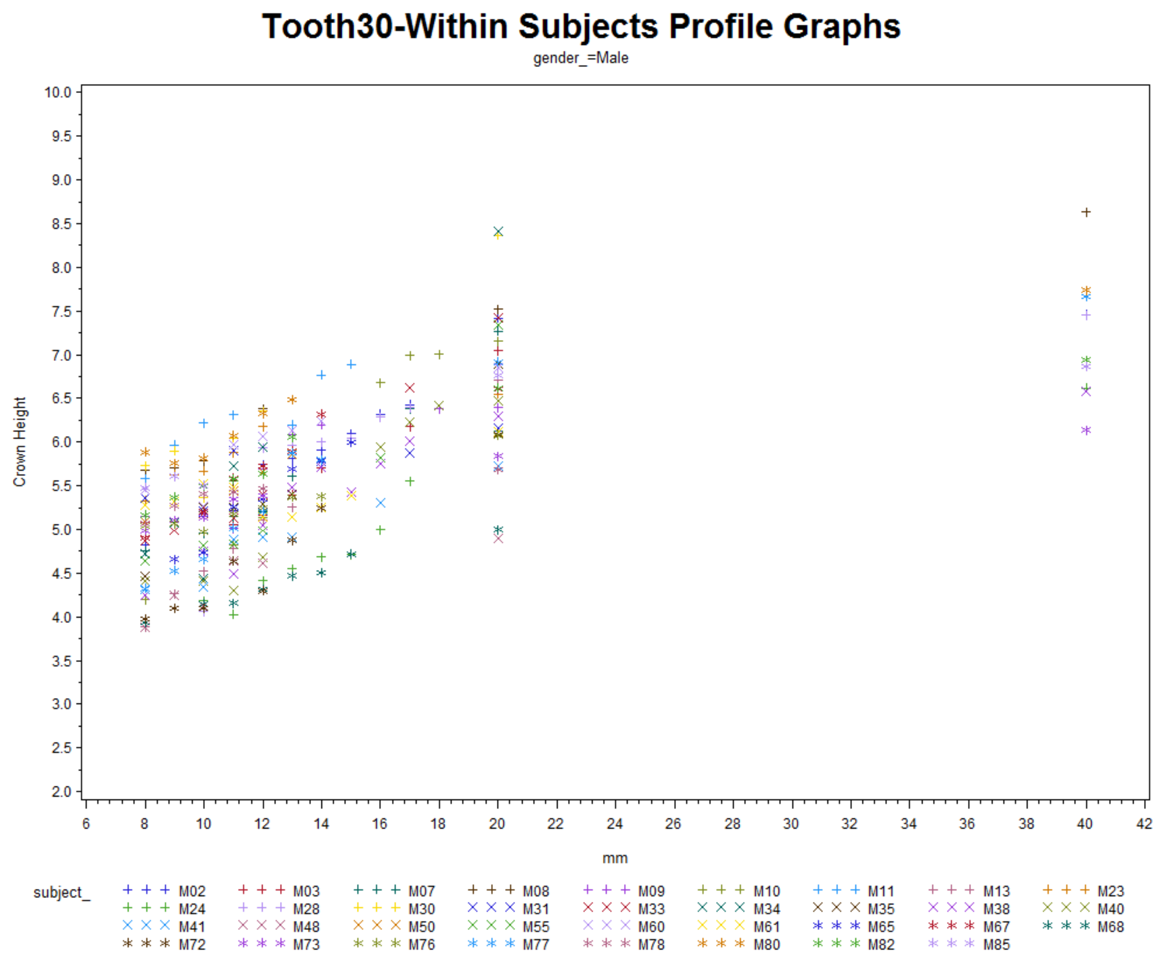

Figure 11 – Within subjects profile graphs for tooth 30 males

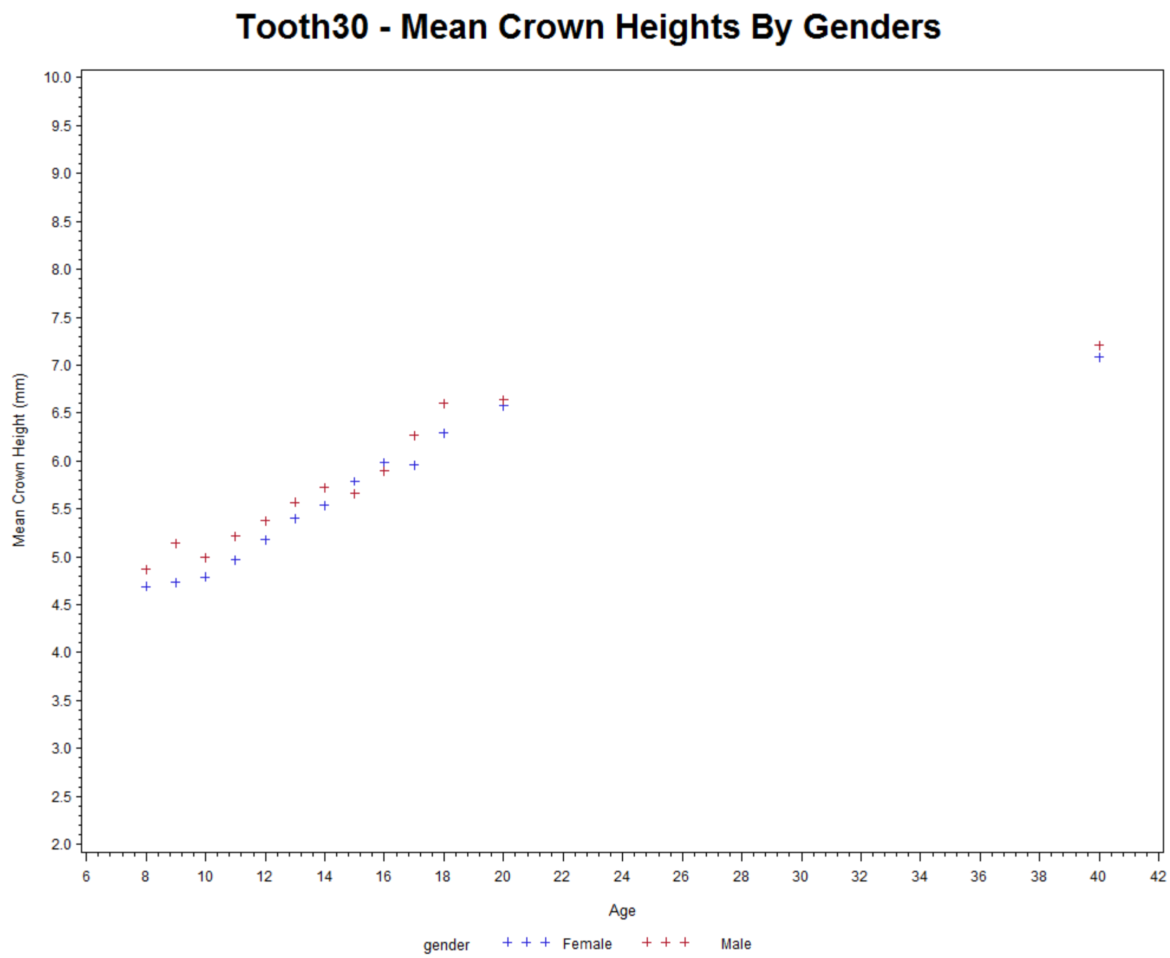

Figure 2 – Mean crown height by gender for tooth 30

Table 7 – Descriptive Statistics for the Clinical Crown Heights of Tooth 30

A. Tooth 30: For All Subjects (n=64)

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age8___Crown_height	52	4.80	0.52	3.89	5.89	4.85
Age9___Crown_height	45	4.91	0.51	3.92	5.97	4.95
Age10__Crown_height	58	4.90	0.50	4.02	6.22	4.89
Age11__Crown_height	62	5.11	0.53	4.01	6.31	5.14
Age12__Crown_height	58	5.29	0.54	4.23	6.38	5.32
Age13__Crown_height	41	5.49	0.55	4.07	6.49	5.61
Age14__Crown_height	31	5.64	0.56	4.51	6.77	5.72
Age15__Crown_height	22	5.74	0.60	4.71	6.89	5.78
Age16__Crown_height	23	5.95	0.51	5.00	6.75	5.94
Age17__Crown_height	22	6.10	0.51	5.14	7.15	6.12
Age18__Crown_height	8	6.41	0.61	5.69	7.33	6.40
Age20__Crown_height	62	6.61	0.66	4.90	8.42	6.62
Age40__Crown_height	23	7.14	0.61	6.14	8.63	6.94

Table 7 – Continued

B. Tooth 30: For Female Subjects (n=29)

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age8___Crown_height	13	7.08	0.54	6.43	7.97	6.90
Age9___Crown_height	26	4.73	0.39	3.92	5.36	4.73
Age10__Crown_height	26	4.79	0.39	4.02	5.74	4.81
Age11__Crown_height	28	4.97	0.47	4.01	5.75	5.01
Age12__Crown_height	26	5.18	0.49	4.23	6.03	5.25
Age13__Crown_height	19	5.40	0.57	4.07	6.16	5.60
Age14__Crown_height	14	5.54	0.55	4.55	6.29	5.53
Age15__Crown_height	14	5.79	0.52	4.90	6.67	5.78
Age16__Crown_height	14	5.98	0.52	5.01	6.75	5.98
Age17__Crown_height	12	5.96	0.57	5.14	7.15	6.02
Age18__Crown_height	5	6.29	0.73	5.69	7.33	5.95
Age20__Crown_height	29	6.58	0.51	5.70	7.62	6.39
Age40__Crown_height	20	4.69	0.43	3.91	5.49	4.55

Table 7 – Continued

C. Tooth 30: For Male Subjects (n=35)

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age8___Crown_height	10	7.21	0.72	6.14	8.63	7.20
Age9___Crown_height	19	5.14	0.57	4.10	5.97	5.11
Age10__Crown_height	32	4.99	0.57	4.06	6.22	5.15
Age11__Crown_height	34	5.22	0.56	4.03	6.31	5.22
Age12__Crown_height	32	5.38	0.57	4.30	6.38	5.33
Age13__Crown_height	22	5.57	0.54	4.47	6.49	5.66
Age14__Crown_height	17	5.72	0.57	4.51	6.77	5.79
Age15__Crown_height	8	5.66	0.74	4.71	6.89	5.72
Age16__Crown_height	9	5.90	0.52	5.00	6.68	5.94
Age17__Crown_height	10	6.27	0.40	5.55	6.99	6.31
Age18__Crown_height	3	6.60	0.35	6.38	7.01	6.42
Age20__Crown_height	33	6.64	0.78	4.90	8.42	6.71
Age40__Crown_height	32	4.87	0.57	3.89	5.89	4.95

Table 8---Summary of the Full Model Used in the Random Coefficient Regression Analysis of Tooth 30

Effect	Gender	Estimate	Std. Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Intercept		4.9156	0.0870	62	56.48	<.0001	0.05	4.7416	5.0896
gender	f	-0.1790	0.1288	379	-1.39	0.1652	0.05	-0.4322	0.0741
gender	m	0	.	.	.	.	.	.	.
age		0.1288	0.0113	62	11.43	<.0001	0.05	0.1063	0.1513
age*gender	f	-0.0043	0.0164	379	-0.26	0.7957	0.05	-0.0365	0.0280
age*gender	m	0	.	.	.	.	.	.	.

Note: DF=Degree of Freedom
**Males as the reference group

Subset Analysis

Comparisons of average crown heights of teeth #3 and #14 between females and males at ages 11, 20 and 40 were analyzed. No significant difference in the mean average crown heights of teeth #3 and #14 was found between males and females at age 11 (p=0.2266, a two-sample t-test). No significant difference in the mean average crown heights of teeth #3 and #14 was found between males and females at age 20 (p=0.0995, a two-sample t-test). Based on the two-sample t-test, there was a significant difference in mean average clinical crown heights of teeth #3 and #14 between males and females at age 40 (p=0.0353). The data indicated that mean average clinical crown height of teeth#3 and #14 for males was significantly greater than that observed for females (mean average crown height of teeth #3 and #14: 7.47 vs. 6.80mm, respectively) (Table 10-11).

Table 9 – Average Clinical Crown Height of Teeth #3 and #14 For All Subjects

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age11	28	4.74	0.62	3.52	5.80	4.79
Age20	27	6.48	0.84	5.23	8.14	6.41
Age40	27	7.15	0.84	5.84	8.75	6.98

Table 10 – Descriptive Statistics of Average Clinical Height of Teeth #3 and #14 for Females

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age11	14	4.59	0.64	3.52	5.70	4.69
Age20	13	6.20	0.83	5.23	8.14	6.36
Age40	13	6.80	0.60	6.23	8.34	6.67

Table 11 – Descriptive Statistics of Average Clinical Height of Teeth #3 and #14 for Males

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age11	14	4.88	0.59	3.92	5.80	4.92
Age20	14	6.74	0.79	5.46	7.70	6.94
Age40	14	7.47	0.92	5.84	8.75	7.45

Assessment of correlation between average crown heights of teeth #3 and #14 measured at ages 11 and 20 was performed using Pearson correlation test. The analysis indicated that there was a significantly increasing relationship between average crown heights of teeth #3 and #14 measured at ages 11 and 20 ($p<0.0001$), and a coefficient of 0.73 indicated there was a moderate association between the two measurements.

Assessment of correlation between average crown heights of teeth #3 and #14 measured at ages 11 and 40 was performed using Pearson correlation test. The analysis indicated that there was a significantly increasing relationship between average crown heights of teeth #3 and #14 measured at ages 11 and 40 ($p=0.0004$), and a coefficient of 0.64 indicated there was a moderate association between the two measurements.

Assessment of correlation between average crown heights of teeth #3 and #14 measured at ages 20 and 40 was performed using Pearson correlation test. The analysis indicated that there was a significantly increasing relationship between average crown heights of teeth #3 and #14 measured at ages 20 and 40 ($p<0.0001$), and a coefficient of 0.85 indicated there was a strong association between the two measurements.

Data were analyzed using a two-way ANOVA with repeated measures on one factor. The interaction between gender and time (age) was not significant ($F(2, 48)=2.13$; $p=0.1295$), nor was the main effect for gender ($F(1,24)=3.35$; $p=0.0797$).

However, this analysis did reveal a significant effect for time (age) ($F(2,48)=244.90$); $p<0.0001$). Post-hoc contrasts test found that the crown heights at ages 20 ($F(1,24)=222.73$; $p<0.0001$) and at age 40 ($F(1, 24)=360.91$; $p<0.0001$) were significantly higher that the crown heights observed at age 11, while the crown heights at age 40 ($F(1,24)=61.86$; $p<0.0001$) was significantly higher than the crown heights obtained at age 20.

Comparisons of average crown heights of teeth #19 and #30 between females and males at ages 11, 20 and 40. No significant difference in the mean average crown heights of teeth #19 and #30 was found between males and females at age 11 ($p=0.1425$, a two-sample t-test). No significant difference in the mean average crown heights of teeth #19 and #30 was found between males and females at age 20 (p=0.8720, a two-sample t-test). No significant difference in the mean average crown heights of teeth #19 and #30 was found between males and females at age 40 (p=0.2424, a two-sample t-test) (Table 13-14).

Table 12 - Average Clinical Crown Height of Teeth #19 and #30 for all subjects

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age11	28	5.19	0.58	4.20	6.42	5.27
Age20	27	6.67	0.64	4.90	7.73	6.78
Age40	24	7.26	0.67	6.38	8.97	7.28

Table 13 – Descriptive Statistics of Average Clinical Crown Height of Teeth #19 and #30 for Females

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age11	14	5.03	0.45	4.20	5.66	5.04
Age20	13	6.65	0.51	5.96	7.73	6.72
Age40	13	7.11	0.54	6.38	7.86	6.98

Table 14 – Descriptive Statistics of Average Clinical Crown Height of Teeth #19 and #30 for Males

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age11	14	5.35	0.66	4.21	6.42	5.44
Age20	14	6.69	0.75	4.90	7.68	6.94
Age40	11	7.43	0.79	6.39	8.97	7.38

Assessment of correlation between average crown heights measured of teeth #19 and #30 at ages 11 and 20 was performed using Pearson correlation test. The analysis indicated that there was a significantly increasing relationship between average crown heights of teeth #19 and #30 measured at ages 11 and 20 ($p=0.0137$), and a coefficient of 0.48 indicated there was a moderate association between the two measurements.

Assessment of correlation between average crown heights of teeth #19 and #30 measured at ages 11 and 40 was performed using Pearson correlation test. The analysis indicated that there was a significantly increasing relationship between average crown heights of teeth #19 and #30 measured at ages 11 and 40 ($p=0.0091$), and a coefficient of 0.53 indicated there was a moderate association between the two measurements.

Assessment of correlation between average crown heights of teeth #19 and #30 measured at ages 20 and 40 was performed using Pearson correlation test. The analysis indicated that there was a significantly increasing relationship between average crown heights of teeth #19 and #30 measured at ages 20 and 40 ($p<0.0001$), and a coefficient of 0.79 indicated there was a moderate association between the two measurements.

Data were analyzed using a two-way ANOVA with repeated measures on one factor. The interaction between gender and time (age) was not significant ($F(2, 42)=0.41$; $p=0.6607$), nor was the main effect for gender ($F(1,21)=2.44$; $p=0.1336$).

However, this analysis did reveal a significant effect for time (age) ($F(2,42)=160.16$); $p<0.0001$). Post-hoc contrasts test found that the crown heights at age 20 ($F(1,21)=143.24$; $p<0.0001$) and at age 40 ($F(1, 21)=233.65$; $p<0.0001$) were significantly higher that the crown heights observed at age 11, while the crown heights at age 40 ($F(1,21)=35.52$; $p<0.0001$) was significantly higher than the crown heights obtained at age 20.

Change in Crown Height vs. Change in Cemento-enamel Junction to Alveolar Crest

Descriptive statistics were conducted for the average clinical crown measurement and average measurement of bone level from the cement-enamel-junction (CEJ) of two pairs of teeth (#3 and #14 or #19 and #30) at ages 12 and 20 as well as for the change from age 12 to 20 in the crown height vs. distance from CEJ to Alveolar Crest (AC) of two pairs of teeth.

A paired-sample t-test was used to detect a significant difference between cast and x-ray measurements for the change from age 12 to 20 in the average clinical crown measurements vs. CEJ to AC measurements of two pairs of teeth (#3 and #14 or #19 and #30).

Based on the paired-sample t-test, the results revealed that there was a significant difference between the cast and x-ray measurements for the mean change from age 12 to 20 in the average crown heights vs. CEJ to AC of teeth #3 and #14 ($p<0.0001$). The mean change from age 12 to 20 in average crown heights of teeth #3 and 14 from the cast measurements is significantly higher than that of the x-ray measurement from CEJ to AC (mean change: 1.51 vs. 0.36, respectively) (Table 7A and 7B). The mean difference in change between the two measurements is 1.13 (SD=0.68) (Table 7C).

Based on the paired-sample t-test, the results revealed that there was a significant difference between the cast and x-ray measurements for the mean change from age 12 to 20 in the average crown heights of teeth vs. CEJ to AC #19 and #30 ($p<0.0001$). The mean change in the average crown heights of teeth #19 and 30 is significantly higher than that of the x-ray measurement from CEJ to AC (mean change: 1.27 vs. 0.28, respectively) (Table 7A and 7B). The mean difference in change between the two measurements is 0.98 (SD=0.68) (Table 7C).

Table 15 – Descriptive Statistics of Cast Measurements for Crown Heights Ages 12 & 20

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age12_Cast_mean_Teeth3_14	60	5.05	0.63	3.67	6.99	5.04
Age20_Cast_mean_Teeth3_14	63	6.55	0.80	4.62	8.23	6.54
change_in_cast_mean_teeth3_14	59	1.51	0.53	0.22	3.08	1.53
Age12_Cast_mean_Teeth19_30	59	5.47	0.53	4.43	6.70	5.45
Age20_Cast_mean_Teeth19_30	63	6.74	0.69	4.90	8.71	6.75
change_in_cast_mean_teeth19_30	58	1.27	0.53	0.17	2.63	1.26

Note: change_in_cast_mean_teeth3_14=Age20_Cast_mean_Teeth3_14 minus Age12_Cast_mean_Teeth3_14
change_in_cast_mean_teeth19_30=Age20_Cast_mean_Teeth19_30 minus Age12_Cast_mean_Teeth19_30

Table 16 – Descriptive Statistics of X-ray Measurements from CEJ to AC Ages 12 & 20

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
Age12_Xray_mean_Teeth3_14	63	0.30	0.31	0.00	1.28	0.26
Age20_Xray_mean_Teeth3_14	56	0.67	0.42	0.00	2.24	0.58
change_in_Xray_mean_teeth3_14	55	0.36	0.43	-0.78	1.97	0.37
Age12_Xray_mean_Teeth19_30	63	0.23	0.20	0.00	0.74	0.22
Age20_Xray_mean_Teeth19_30	55	0.51	0.39	0.00	2.01	0.42
change_in_Xray_mean_teeth19_30	54	0.28	0.38	-0.23	2.01	0.18

Note: change_in_Xray_mean_teeth3_14=Age20_Xray_mean_Teeth3_14 minus Age12_Xray_mean_Teeth3_14
change_in_Xray_mean_teeth19_30=Age20_Xray_mean_Teeth19_30 minus Age12_Xray_mean_Teeth19_30

Table 17 – Descriptive Statistics of Mean Change Difference between Cast and X-ray Measurements Ages 12 & 20

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
diff_change_cast_Xray_teeth3_14	53	1.13	0.68	-0.78	2.57	1.07
diff_change_cast_Xray_teeth19_30	51	0.98	0.68	-1.01	2.13	1.15

Note: diff_change_cast_Xray_teeth3_14=change_in_cast_mean_teeth3_14 minus change_in_Xray_mean_teeth3_14
diff_change_cast_Xray_teeth19_30=change_in_cast_mean_teeth19_30 minus change_in_Xray_mean_teeth19_3

Descriptive statistics were conducted for the average clinical crown measurement and average measurement of bone level from the cement-enamel-junction (CEJ) of two pairs of teeth (#3 and #14 or #19 and #30) at ages 20 and 40 as well as for the change from age 20 to 40 in the crown height vs. distance from CEJ to Alveolar Crest (AC) of two pairs of teeth.

A paired-sample t-test was used to detect a significant difference between cast and x-ray measurements for the change from age 20 to 40 in the average clinical crown measurements vs. CEJ to AC measurements of two pairs of teeth (#3 and #14 or #19 and #30).

Based on the paired-sample t-test, the results revealed that there was no significant difference between the cast and x-ray measurements for the mean change from age 20 to 40 in the average crown heights vs. CEJ to AC of teeth #3 and #14 (p=.055). The mean change from age 20 to 40 in average crown heights of teeth #3 and #14 from the cast measurements is higher than that of the x-ray measurement from CEJ to AC (mean change: 0.64 vs. 0.33, respectively) (Table 8A and 8B). The mean difference in change between the two measurements is 0.28 (SD=0.55) (Table 8C). This mean difference trends in the same direction as the mean change from age 12 to 20, but was not significant for age 20 to 40.

Based on the paired-sample t-test, the results revealed that there was no significant difference between the cast and x-ray measurements for the mean change from age 20 to 40 in the average crown heights of teeth vs. CEJ to AC #19 and #30 (p=.27). The mean change in the average crown heights of teeth #19 and 30 is not significantly different than that of the x-ray measurement from CEJ to AC (mean change: 0.46 vs. 0.41, respectively) (Table 8A and 8B). The mean difference in change between the two measurements is 0.05 (SD=0.27) (Table 8C).

Table 18 – Descriptive Statistics of Cast Measurements for Crown Heights Ages 20 & 40

Variable	N	Mean	Std Dev	Minimum	Maximum
Age20_Cast_mean_Teeth3_14	18	6.36	0.77	5.23	7.70
Age40_Cast_mean_Teeth3_14	18	7.00	0.64	6.02	8.29
change_in_cast_mean_teeth3_14	18	0.64	0.44	0.09	1.36
Age20_Cast_mean_Teeth19_30	18	6.58	0.66	4.89	7.73
Age40_Cast_mean_Teeth19_30	15	7.14	0.56	6.38	7.86
change_in_cast_mean_teeth19_30	15	0.46	0.28	0.01	0.96

Note: change_in_cast_mean_teeth3_14= Age40_Cast_mean_Teeth3_14 minus Age20_Cast_mean_Teeth3_14
change_in_cast_mean_teeth19_30=Age40_Cast_mean_Teeth19_30 minus Age20_Cast_mean_Teeth19_30

Table 19 – Descriptive Statistics of X-ray Measurements from CEJ to AC Ages 20 & 40

Variable	N	Mean	Std Dev	Minimum	Maximum
Age20_Xray_mean_Teeth3_14	17	0.60	0.35	0.00	1.43
Age40_Xray_mean_Teeth3_14	18	0.92	0.48	0.00	2.18
change_in_Xray_mean_teeth3_14	17	0.33	0.49	-0.24	1.95
Age20_Xray_mean_Teeth19_30	17	0.45	0.30	0.00	0.98
Age40_Xray_mean_Teeth19_30	18	0.83	0.42	0.26	1.56
change_in_Xray_mean_teeth19_30	17	0.41	0.36	-0.07	1.40

Note: change_in_Xray_mean_teeth3_14= Age40_Xray_mean_Teeth3_14 minus Age20_Xray_mean_Teeth3_14
change_in_Xray_mean_teeth19_30=Age40_Xray_mean_Teeth19_30 minus Age20_Xray_mean_Teeth19_30

Table 20 – Descriptive Statistics of Mean Change Difference between Cast and X-ray Measurements Ages 20 & 40

Variable	N	Mean	Std Dev	Minimum	Maximum
diff_change_cast_Xray_teeth3_14	17	0.28	0.55	-0.80	1.09
diff_change_cast_Xray_teeth19_30	14	0.05	0.27	-0.44	0.49

Note: diff_change_cast_Xray_teeth3_14=change_in_cast_mean_teeth3_14 minus change_in_Xray_mean_teeth3_14
diff_change_cast_Xray_teeth19_30=change_in_cast_mean_teeth19_30 minus change_in_Xray_mean_teeth19_30

SUMMARY

Tooth 3

- Mean Crown Heights
    - No significant differences between genders at all ages
- Time Comparisons
    - No significant mean crown height difference between genders over time
    - The age effect ($p<0.0001$) was highly significantly demonstrating that there were significant changes in the crown height over time.

Tooth 14

- Mean Crown Heights
    - Significant differences in mean crown heights at age 40 (Males larger $p<0.05$)
    - No significant difference at all other ages
- Time Comparisons
    - No significant mean crown height difference between genders over time
    - The age effect ($p<0.0001$) was highly significantly demonstrating that there were significant changes in the crown height over time.

Tooth 19

- Mean Crown Heights
    - Significant difference at age 9 (Males larger $p<0.05$)
    - No significant differences between genders at all other ages
- Time Comparisons
    - No significant mean crown height difference between genders over time
    - The age effect ($p<0.0001$) was highly significantly demonstrating that there were significant changes in the crown height over time.

Tooth 30

- Mean Crown Heights
    - Significant difference at age 9 (Males larger $p<0.05$)
    - No significant differences between genders at all other ages
- Time Comparisons
    - No significant mean crown height difference between genders over time
    - The age effect ($p<0.0001$) was highly significantly demonstrating that there were significant changes in the crown height over time.

Longitudinal subset analysis

- 11&20—Significant increasing relationship between mean crown heights
- 11&40—Significant increasing relationship between mean crown heights
- 20&40—Significant increasing relationship between mean crown heights
- Interaction between gender and age were not significant.
- Significant effect for time
    - Crown heights at ages 20 and 40 were significantly greater than at 11
    - Crown heights at age 40 were significantly greater than at age 20

Change in Crown Height vs. Change in Cemento-enamel Junction to Alveolar Crest

- The mean change from age 12 to 20 in average crown heights of teeth #3 and 14 from the cast measurements is significantly higher than that of the x-ray measurement from CEJ to AC (mean change: 1.51 vs. 0.36, respectively)
- The mean change from age 12 to 20 in the average crown heights of teeth #19 and 30 is significantly higher than that of the x-ray measurement from CEJ to AC (mean change: 1.27 vs. 0.28, respectively)
- The mean change from age 20 to 40 in average crown heights of teeth #3 and 14 from the cast measurements is not significantly different than that of the x-ray measurement from CEJ to AC (mean change: 0.64 vs. 0.33, respectively) though the trend is similar to the data from 12 & 20
- The mean change from age 20 to 40 in the average crown heights of teeth #19 and 30 is not significantly different than that of the x-ray measurement from CEJ to AC (mean change: 0.46 vs. 0.41, respectively)

DISCUSSION

The principal findings of this study center around three main areas of interest. The first is the relationship between gender and clinical crown height. Gender does not have a significant effect on clinical crown height of first molars over time. This was found for all four teeth measured. While males had a larger starting point than females and had a greater rate of increase, the effects were not significant over time. There were time points in which crown heights differed by gender, but taken as a whole, the difference does not seem to be of consequence. In the subset analysis males had significantly greater mean crown heights in the subjects' 40s. This was found when both #3 and #14 were taken together.

These findings agree with those of Bassey (1991) in which he found no significant difference in the crown heights of any tooth at any age between genders. Bassey continued his study by pooling the data and looking at changes among the whole. Morrow (2000) found significant gender effects for three of the four teeth measured including the Maxillary right central incisor, right canine, and left lateral incisor. There was no gender effect found for the Mandibular left central incisor. Morrow did not measure the molars hence there could be variation in different areas of the mouth.

The change of clinical crown height in adulthood among the population was a second focus of this study. The subset analysis consisted of all subjects with measurements available at 11, 20, and 40 years. As expected there was a significant increase in mean clinical crown height from age 11-20 and 11-40. Growth of the jaws and eruption of the teeth is a normal growth process during these periods of time. The more important and more interesting finding was a significant increasing relationship in mean clinical crown height measured from 20-40. A strong association was found for maxillary molars while a moderate association was found for mandibular molars. The mean crown heights at 40 were significantly higher than those at age 20 indicating a continued eruption of the teeth or an apical migration of the gingiva after age 20. Generally, growth is completed in a subject's 20s yet the teeth show changes into the 40s. Teeth continue to erupt into adulthood and the gingival margin does not move with the erupting tooth.

Volchansky and Cleaton-Jones (1976) measured incisors, canines, premolars, and molars and found that by age 12 the measurements had leveled off for most teeth. They found increasing measurements in upper and lower lateral incisors, upper first premolars, and second molars until the age of 16 which was the limit of the study. The first molars were measured from the deepest point of the gingival margin to the point between the mesial and distal buccal cusps. This measurement technique differed from that employed in this study. They admit that a longitudinal study would be more appropriate for the determination of changing clinical crown height over time than the cross-sectional study they performed. This study used a longitudinal design and addresses this concern.

Volchansky and Cleaton-Jones followed this with another study on the gingival margin in 1979. This study utilized standardized photography to measure the changes over time. The study looked at dental students, all over 18 years of age, during a three year period. They only measured incisors and canine teeth, but did find a significant increase in crown height over the three year period indicating a continued passive eruption of the gingival margin. The study ended in the subjects' 20s and did not follow them later into adulthood as the present study has. The strength of the study was the ability to track the subjects in a longitudinal design and a sample of dental students should help control for periodontal pathology. Their study agrees with this one in the continual passive eruption of the gingival margin into the 20s.

A study by Bassey in 1991 looked at the change in clinical crown height among a Nigerian population. Cross-sectional in design, the study found significant increases in all teeth over time from 21-45 years of age. Bassey found that the measurement of teeth of Nigerian people was somewhat shorter than the measurements for Caucasian teeth found in Volchansky's study. It is an interesting finding as Bassey notes that periodontal disease is considered more widespread among the Nigerian population.

In 2000, Morrow published a longitudinal report on the clinical crown height changes from 12-19 years. Three maxillary anterior teeth and one mandibular anterior tooth were measured. A significant age effect was found for all teeth throughout the period studied, yet the study ended at 19 years. The current study finds a similar trend in the continued eruption of teeth but extends the period studied well into adulthood. Morrow recognizes a potential conflict with the early placement of restorations such as veneers, crowns or implants and the continued passive eruption of the gingival margin. Like this study, there is evidence that continued passive eruption is the norm and should not be overlooked in treatment planning for the younger patient.

The current study aimed to complete a longitudinal study that focused on the eruption of the first molars over time yet attempted to determine whether the eruption into adulthood is due to the normal aging process or a pathologic one. Through comparison of radiographic measurements from CEJ to AC at 12 years and in the subjects' 20s with measurements of the change in crown height from 12 and 20s one can look at the difference in bone level vs. eruption. The study finds that the mean change in clinical crown height was greater than the change in measurement from CEJ to AC for both maxillary and mandibular first molars. This differential change could indicate that the gingival margin migrates apically without an equal loss of bone height. When viewed in context of an established biologic width of approximately 2mm this finding is perplexing. The distance from CEJ to AC should follow the change in crown height if the biologic width is maintained. There could be many reasons for this discrepancy. One is that the measured distance is from the interproximal alveolar bone whereas the crown is measured on the buccal surface. The alveolar bone is often highest in the interproximal and tends to be positioned more apically on the buccal.

From the 20 and 40 time points the discrepancy between the two measurements becomes insignificant. For #3 and #14 the trend still exists for a greater change in crown height vs change in CEJ to AC but the findings weren't statistically significant. The results of the radiographic measurements are in agreement with Boyle et al. (1973) in their study of alveolar crest height and age in which they found measurements between 0.2 and 2.15mm with a mean of 1.24mm. From 10 – 20 years of age the measurement was less than 1.0mm and increased to 1.5mm as the patient aged.

The radiographic measurements also provide some insight into the overall periodontal health of the subjects. The mean measurement from CEJ to AC in the 20s for teeth #3 and #14 was 0.67mm and for #19 and #30 it was 0.52mm. In the 40s the measurement from CEJ to AC for #3 and #14 was 0.92mm and for #19 and #30 was 0.83mm. These mean distances are below what has been established as normal (2mm) and associated with a healthy periodontium (Newman et al. 2002). The difference between radiographic appearance and true alveolar crest height ranges from 0 – 1.6mm (Newman et al. 2002). Even with the extreme, the subjects are close to a normal crest height. None of the other studies that looked at passive eruption over time collected data regarding the crest height.

This study has its limitations. Static plaster casts provide little information regarding the periodontal status of the patient. It would be informative to have periodontal probing for the patients throughout adulthood to determine the true nature of the apical migration of the gingival margin. Radiographic measurement of the alveolar crest from the CEJ is an inexact measurement. The angulation of the x-ray beam as well as the distance from the film was not standardized among the bitewing radiographs used for this study. This can create distortion in measured distances due to magnification, foreshortening and elongation.

In this study the measurement of the molar was from the mesio-buccal cusp tip to the greatest depth of the mesial gingival margin. Other studies (Volchansky 1976, Bassey 1991) have used the midpoint between the mesial and distal cusps. That method tries to eliminate the effect of attrition associated with the cusp tip on the measurement while this study's method is an attempt to measure the tooth regardless of attrition so any gain in crown height would not be attributed to wear. Many published studies have made the claim that the change in eruption over time equaled the attritional wear and therefore the overall crown height relative to the gingival margin should remain somewhat constant.

Some patients in the study had orthodontic treatment and it is still unclear what effect orthodontic treatment and tooth size has on the position of the gingival margin. A recent article by Richman (2011) discussed the position of the teeth bucco-lingually, as well as their size, in relation to the presence of gingival recession on the facial contours. He concludes that there is strong correlation between the two and that there is a need among the orthodontic community to recognize the potential for gingival recession if the teeth are improperly positioned. This study does not account for tooth mass or position in the measurement of clinical crown height.

The sample size of this study was limited by a number of factors. The models were not all in perfect condition. Some of the gingival margins were difficult to distinguish. Some subjects had missing teeth and the cause of the missing teeth was unknown. Some subjects had large restorations, crowns, or obvious gingival recession which excluded them from measurement. As the subjects aged, the availability of casts decreased, making the sample size the smallest at the most significant age groups.

CONCLUSION

The purpose of the study was to determine the eruption patterns of maxillary and mandibular first molars using a longitudinal sample collected from the Meredith Growth Study at the University of Iowa. Particular attention was paid to the continuous eruption of the first molars throughout adulthood and the dynamic changes occurring between the tooth and the gingival margin. An attempt was made to separate pathologic change and change associated with passive eruption by measuring radiographic alveolar bone height compared with the radiographic position of the cement-enamel-junction. Statistical analysis determined whether first molar crown height changed significantly with time and whether differences in heights existed between genders. Achieving experimental purpose was accomplished through measurement of crown height from age 8 until a subject’s 40s to track the continuous changes that occur throughout life. The following conclusions can be drawn from this study.

- First molar crown heights do not significantly differ between gender over time and the rates of increase are similar.
- Mean crown heights of teeth #3 and #14 are significantly greater at subjects’ 40s compared with the subjects’ 20s. Likewise, the crown heights are greater in the subjects’ 20s than age 11.
- Mean crown heights of teeth #19 and #30 are significantly greater at subjects’ 40s compared with the subjects’ 20s. Likewise, the crown heights are greater in the subjects’ 20s than age 11.
- The age effect ($p<0.0001$) was highly significantly demonstrating that there were significant changes in the crown heights of #3, #14, #19 and #30 over time.

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