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Passive eruption patterns in central incisors

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PASSIVE ERUPTION PATTERNS IN CENTRAL INCISORS

by

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A thesis submitted in partial fulfillment
of the requirements for the Master of
Science degree in Orthodontics
in the Graduate College of
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Thesis Supervisor: Professor Thomas E. Southard

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

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has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Orthodontics at the May 2010 graduation.

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To Katrina, my wonderful wife.
Thank you for all your hard work. I will
forever be grateful to you for allowing
me to chase my dreams.

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TABLE OF CONTENTS

LIST OF TABLES

Table

LIST OF FIGURES

Figure

INTRODUCTION

An esthetic smile is an important aspect of a person's beauty. As orthodontists treat patients one of the main goals is to achieve an esthetically pleasing smile. The relationship between teeth and gingival tissue is a major component of the esthetic smile. Tooth-gingiva relationships differ throughout one's lifetime. This study attempts to define the timeline of this relationship.

It is well known that a tooth erupts into the mouth from the underlying bone and soft tissue. What is routinely debated is the process and timing of the process. This process encompasses a number of dental specialties: pediatric dentistry, orthodontics, and periodontics. Two processes of eruption are commonly discussed: active eruption and passive eruption. The difficulty lies in determining when active eruption is complete and when passive eruption begins. If passive eruption is in any way disrupted a patient experiences altered passive eruption. This leaves a patient with the appearance of short teeth or an unaesthetic smile. This study focuses on the eruption of incisors, to help define eruption patterns and determine if there is a difference between male and female eruption patterns.

A similar study to this one was completed by Morrow et al. (2000). They investigated the relationship between age, gender and clinical crown length using a longitudinal study design. Their study included subjects 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 cross-sectional 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, Cleaton-Jones & Fatti 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 uses records taken in the subject's twenties, with some records continued into their forties. 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 maxillary and mandibular central incisors from the first occlusal contacts to adulthood. Previous studies have failed to obtain measurements into adulthood. We hope by using a final measurement during a subjects' adulthood we can better estimate final eruption times and measurements.

This study will compare the eruption of maxillary and mandibular central incisors while comparing the differences in male and female eruption patterns. Measurements will be made on models collected during the Meredith Facial Growth Study at the University of Iowa. Achieving experimental purpose will be done by measuring the teeth at timepoints to track incisal eruption over years of maturity. Statistical analysis will determine whether crown length differences are significantly different with time and between genders.

REVIEW OF THE LITERATURE

The review of literature will consist of an overview of ideal smile esthetics and definitions important to this study. The eruption process will be reviewed with emphasis on active eruption, passive eruption, and altered passive eruption. It will also include information on treatment options.

Ideal Esthetics

There is an increased desire for ideal esthetics in today's society. Recently there has been more attention dedicated in the orthodontic literature to achieving the perfect smile. Sarver (2001) proposed that orthodontists evaluate the posed smile on the basis of two major characteristics: the amount of incisor and gingival display, and the transverse dimension of the smile. Further breaking down smile esthetics was Garber and Salama (1996). The esthetic appearance of a smile has been suggested to have three components: the teeth, the lip framework, and the gingival scaffold.

Cosmetic dentistry literature contains many definitions on characteristics of tooth esthetics. Tooth heights, widths, proportions, connectors and even gingival contours on individual teeth have all been outlined. Townsend (1993) states that maxillary central incisors and canines should be at the same length and the lateral incisor should be 1 to 2 millimeters shorter. The author also mentioned that the maxillary central incisor crown height should be 13.5 millimeters and the maxillary lateral incisors should have a 12 millimeter crown height. Wheelers' (1974) textbook Dental Anatomy, Physiology and Occlusion suggest slightly different dimensions of individual teeth. The maxillary central incisor should be 10.5 millimeters from incisal edge to the cementoenamel junction and 8.5 millimeters from mesial contact to distal contact. The mandibular central incisor should be 9.0 millimeters from incisal edge to the cementoenamel junction and 5.0 millimeters from mesial contact to distal contact. The ideal maxillary incisor should be 80% width compared to height (Gurel 2003). Gillen et al. (1994) conducted a study to determine the average dimensions of the six anterior maxillary teeth. They measured casts from 54 patients ranging in age from 18 to 35. Using these measurements they calculated the following ratios: length to width, width to width, and length to length. Gillen concluded that central incisors and canines were equal in length and 20% longer that lateral incisors. Length-to-width ratio of canines and lateral incisors were similar (1:2.1), and the length-to-width ratio of central incisors was 1:1.1. There were gender-based differences in the length of the maxillary anterior teeth. The crown heights of males were significantly larger than those of females.

Connectors are a broad area where two adjacent teeth appear to touch. The esthetic relationship between anterior teeth is known as the 50-40-30 rule. This is defined by the connector between central maxillary incisors to be 50% of the length of the tooth. Maxillary central incisor’s connector with the maxillary lateral incisor should be 40% of the length of the central incisor. Optimum connector length between the maxillary lateral incisor and maxillary canine should be 30% of the length of the lateral incisor (Morley, Eubank 2001).

A smile is framed by the lips and therefore defines the esthetic smile zone. Goldstein (1976) defined the liplines as being high, medium, or low. A low lipline only shows a portion of the teeth below the lower border of the upper lip. A high lipline shows extra gingiva extending from the lower border of the upper lip to the free gingival margin. A medium lipline is deemed most attractive in western culture. During a smile, 1-3 millimeters of gingiva from the apical border of the free gingival margin to the lower border of the upper lip is displayed (Garber, Salama 1996). Sarver (2001) defined an ideal smile arc by having the maxillary incisal edge curvature parallel to the curvature of the lower lip upon smile.

Two important aspects of gingiva affect the final esthetic outcome: gingival shape and gingival contour. Gingival shape is the curvature of the gingival margin of the tooth, determined by the cementoenamel junction and the osseous crest (Sarver 2004).

Townsend (1993) reported that there should be an interdental papilla of 4.5 to 5 millimeters from the tip of the papilla to the depth of the marginal scallop, and the most apical part of the gingival scallop should reflect the angle of the long axis of the tooth.

According to the accreditation criteria for the American Academy of Cosmetic Dentistry, "The gingival shape of the mandibular incisors and the maxillary laterals should exhibit a symmetrical half-oval or half-circular shape. The maxillary centrals and canines should exhibit a gingival shape that is more elliptical. Thus, the gingival zenith is located distal to the longitudinal axis of the maxillary centrals and canines. The gingival zenith of the maxillary laterals and mandibular incisors should coincide with their longitudinal axis (Sarver 2004)."

Eruption

Eruption used to mean for many authors the very first appearance of the crown or part of it through the gingiva, others referred to it as the point when the crown of the tooth is halfway to its full projection into the mouth. Gron (1962) defined emergence for a tooth as that time when the tooth has just pierced the gingiva but is no more than 3 millimeters from the incisal edge. Garn et al. (1958) investigated associations among data for age of alveolar emergence of the mandibular premolar and molar teeth. Alveolar eruption was defined as the earliest time at which there is no longer apparent alveolar bone over the erupting tooth. Sturdivant et al. (1962) defined eruption as the age at which the alveolar mucosa is pierced and exposure of the crown of a tooth approximates one millimeter in diameter.

Fanning (1961) stated "that emergence is a fleeting moment in the continuous process of the tooth eruption; and the chance that the time of inspection coincides with the actual moment of emergence is a whole small." According to Tanner (1955) in longitudinal studies, the date of eruption of a tooth is at a time between two consecutive examinations. He said the best estimate of the age at eruption in such data, therefore, is the age at second examination less half the time elapsed since the first examination. Failure to make this correction, Tanner felt, has led much of the literature on tooth eruption derived from longitudinal studies to quote mean eruption figures which are typically six months too high. Savara (1978) agreed when he said that teeth unerupted at one visit but listed as present at the next visit, must be reported as erupting midway into the period.

The eruption of permanent dentition has been studied quite extensively and provides a criterion of physiological maturity covering the ages of six to thirteen. Cumulative incidence curves showing the percentage of children at each age with a given tooth erupted have been developed by various authors. Means and standard deviations of time of eruption of each tooth have been derived from these data.

Newman (1994) proposed 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.” This supported Barker’s (1975) statement 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.”

More recently there has been a turn in the trend of eruption from focusing on the actual time point of the moment of eruption to the process of erupting. An erupting tooth can be categorized as undergoing one of two phases of eruption: active eruption or passive eruption.

Active Eruption

Active eruption has been described as the eruption process of a tooth and their alveoli through the gingival tissues (Moshrefi 2000). This phase ends when the tooth makes contact with the opposing dentition but may continue with occlusal wear or loss of opposing teeth (Dolt 1997). Morrow et al. (2000) described active eruption as the maxillary central incisor erupting into the mouth at approximately six years of age and continue to erupt until it comes into contact with the opposing teeth. At this point approximately 50 % of the anatomic crown is covered with gingiva. Active eruption is divided into two types of eruption: pre-functional active eruption and functional active eruption (Weinberg 1996)(Weinberg 2000). Pre-functional 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 1996)(Weinberg 2000).

Passive Eruption

Passive eruption begins once active eruption has completed. This takes place as the dentogingival unit migrates in the apical direction until it is adjacent to the cementoenamel junction (CEJ) (Evian et al. 1993). 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).

Little to no literature is available explaining the reasons or actual histological process of passive eruption in permanent dentition. Soskolne and Bimstein (1989) summarized the apical migration of the junctional epithelium in primary dentition. They determined apical migration of the junctional epithelium in the human primary dentition appears to be related to a combination of the physiological and developmental processes of passive eruption and exfoliation, and the qualitative characteristics of the inflammatory cell infiltrate.

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 cementoenamel junction, 4) distance from the base of the sulcus to the cementoenamel junction, 5) distance of the cementoenamel 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."

Excessive Gingival Display

Excessive gingival display is a condition commonly called "gummy smile." It is characterized by excessive exposure of the maxillary gingiva during smiling. Foley et al. (2003) stated this condition is caused primarily by a skeletal deformity in which there is vertical excess of maxillary tissue, a soft-tissue deformity in which there is a short upper lip or a combination of the two. Another cause of excessive gingival display is insufficient clinical crown length.

Garber and Salama (1996) state the gummy smile can result from two problems: vertical maxillary excess and altered passive eruption. Vertical maxillary excess results from hyperplastic growth of the maxillary base. This causes the teeth to be further away from the maxillary base causing excess gingiva to be on display when smiling. Diagnosis involving vertical maxillary excess requires ruling altered passive eruption in combination with maxillary hyperplasia. These cases should be first treated for altered relationships between gingiva and the cementoenamel junction. The combined cases require for optimal treatment a multidisciplinary approach to treatment planning involving an orthodontist, a periodontist, an orthognathic surgeon and a restorative dentist.

Evaluation of short clinical crowns is also an important aspect of esthetics. This may be the primary cause of excessive gingival display. Common causes of short clinical crowns include coronal destruction resulting from traumatic injury, caries or incisal attrition, as well as coronally situated gingival complex resulting from tissue hypertrophy, or altered passive eruption (Levine, McGuire 1997).

Altered Passive Eruption

Altered passive eruption is the dentogingival relationship wherein the gingival margin is positioned coronally on the anatomic crown and does not approximate the cementoenamel junction due to the disruption in the development and eruptive patterns of the gingival unit (Rossi 2008).

Altered passive eruption has been labeled many different ways: retarded passive eruption, incomplete passive eruption, delayed passive eruption (Dolt 1997), (Coslet 1977). Regardless of name it occurs when the margin of gingiva is malpositioned incisally on the anatomic crown in adulthood and does not approximate the CEJ (Dolt 1997). Altered passive eruption has been divided into two types depending upon the relationship of the gingiva to the anatomic crown and then subdivided into those 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 incisal 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 or 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 to. 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 which age 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."

Volchefsky 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 years 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). Volchefsky 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 nonpathologic, and has the appearance of short teeth. Evian (1993) described it as having the appearance of drug-induced gingival hyperplasia.

Diagnosis

The first step in diagnosis is to observe the patient in both smiling and repose. Further data is required if excess gingiva is displayed. First the maxillary lip needs to be evaluated for both length and activity. The average length of the maxillary lip in repose is 20 to 22 millimeters in females and 22 to 24 millimeters in males (Peck 1992). If the maxillary lip is the cause of a gummy smile, there is no treatment necessary.

Next, location of the cementoenamel junction needs to be identified with a probe subgingivally. If the cementoenamel junction is located in a normal position in the gingival sulcus, then the short clinical crown is probably due to incisal wear on abnormal tooth morphology. When the cementoenamel junction is not detected in the sulcus a diagnosis of altered passive eruption can be made.

The next step is bone sounding. A measurement from the gingival crest to the alveolar crest is taken. This should be approximately 3 millimeters. Usually the cementoenamel junction approximates the base of the sulcus; in altered passive eruption this measurement can be used to determine the relationship between the cementoenamel junction and the alveolar crest. Normal relationships require approximately 2 millimeters for both epithelial and connective tissue attachment between the cementoenamel junction and alveolar crest; therefore, a decision can be made which treatment is necessary (Moshrefi 2000) (Dolt 1997).

Radiographic viewing of the cementoenamel junction position can facilitate diagnosis of altered passive eruption. If the clinical crown length is less than the anatomical crown length measured on the radiograph, then altered passive eruption is present (Hempton, Esrason 1999).

Treatment Options

It has been proposed that treatment of altered passive eruption should be evaluated by the following criteria: periodontal involvements, restorative requirements, orthodontic requirements (Evian et al. 1993). Periodontal involvements can be treated one of two ways surgically. Performing a gingivectomy is the first option for periodontal correction. When it is determined that the osseous level is appropriate, that greater than 3 millimeters of tissue exists from bone to gingival crest, and that an adequate zone of attached gingiva will remain after surgery a gingivectomy is indicated (Dolt 1997). An apically positioned flap with ostectomy is required when the osseous levels are approximating the cementoenamel junction. Osseous recontouring is necessary when insufficient root is exposed to allow for a proper biologic width (Evian et al. 1993).

The timing of periodontal surgery is a source for debate. Orthodontic treatment typically precedes periodontal surgery, since movement of teeth may affect gingival harmony (Foley 2003). Dolt (1997) recommended that if clinical crowns are short due to altered passive eruption, crown lengthening should be performed prior to orthognathic surgery. Garber and Salama (1996) suggested a two-phase approach: initial periodontal surgery before orthognathic surgery with a second alteration following orthognathic surgery if necessary.

Restorative concerns of altered passive eruption come from difficulty of restoring a tooth with excess tissue. Also the appearance of short clinical crowns needs to be properly diagnosed. If incorrectly diagnosed, crown and bridgework performed to lengthen tooth appearance will leave patient with unaesthetic appearance and an extreme deep bite.

Orthodontic therapy can be affected by excess gingival tissue from altered passive eruption. Excess gingiva can make orthodontic treatment more difficult. From placing brackets and bands to oral hygiene a number of procedures are affected. Evian (1993) suggests removing tissue prior to orthodontic therapy. This allows the orthodontist to evaluate esthetic and functional needs more accurately because the entire crown is visible.

Similar Studies

Morrow et al. (2000) conducted a study named; "Clinical crown length changes from age 12-19 years: a longitudinal study." They investigated the relationship between age gender and clinical crown length 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 14-15 years old, 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 length according to age and gender for each of the three time periods were calculated. The 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 length for all 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 showed increases in clinical crown length between each time point.

The process of passive eruption resulting in increased clinical crown length 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. Incisor teeth were measured from the deepest curvature of the labial gingival margin to the middle of the incisal edge. Statistical analysis of the results consisted of an analysis of variance and Student's *t* test.

This cross-sectional study showed 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 cementoenamel 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 (1979) performed a longitudinal study. 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 $p < 0.01$. 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, suggestion that a continual passive eruption of the teeth was occurring.

They had a slightly different position from their first study by 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.”

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, 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 during the subjects twenties, anytime from years 20 to 29. A final set on a number of subjects was taken in their forties, anytime from years 40 to 49. 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-eight subjects had final records available in their forties (15 males and 13 females).

Measuring Device

All measurements were taken with a Cen-Tech digital caliper (China) which is a fine point caliper capable of measuring lengths to nearest one-hundredth of a millimeter.

Cast Measurements

Measurements were recorded for the maxillary central incisors (Teeth 8 and 9), and the mandibular central incisors (Teeth 24 and 25). Measurements points were the incisal edge of the tooth to the most apical (deepest) curvature of the gingival margin.

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-eight subjects contained measurements in their forties.

Some subjects measured did not have models in perfect measuring condition; therefore measurements at thirteen timepoints were not available for all subjects. Those teeth with visible coronal restorations, excessive incisal wear, impression inaccuracies, fractured models, or unreadable gingival margins were excluded from the study as these prevented an accurate measurement. No cementoenamel junctions were observed clinically.

Measurement Reliability

To evaluate measurement reliability, eight subjects (four male and four female) were re-measured at all timepoints. This represented 12.5% of the original casts measured. New measurements were taken at a separate time from the original measurements. Identical locations were used for measurement points. Intra-class correlation coefficients were computed as a measure of agreement between two measurements which were made on the same subject by a single observer. All tests employed a 0.05 level of statistical significance. SAS for Windows (v9.1, SAS Institute Inc, Cary, NC, USA) was used for the data analysis.

Statistical Analysis

Statistical analysis was performed looking at two different scenarios. The first was using all subjects to look at crown heights on teeth 8, 9, 24, and 25. All time points were considered. The second scenario uses longitudinal subsets of the first group to evaluate relationships of crown heights of teeth 8 and 9 and separately teeth 24 and 25. Time points (age) used were 11, 20, and 40.

For the first analysis there are a total of 64 subjects used. The data consist of the clinical crown height measurements for 29 females and 35 males yearly at ages 8 to 18, and once during their 20's and 40's. Crown heights were measured from the same four teeth for each subject. This study evaluated the effect of gender upon the growth of clinic crown heights.

Descriptive statistics for the clinical crown measurements were conducted. 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. 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 subset analysis for teeth 8 and 9 evaluated a total of 28 subjects selected in the data analysis, including 13 females and 15 males. Table 5A- 5C reports the descriptive statistics for the clinical crown heights at age 11, 20 and 40. The subset analysis for teeth 24 and 25 evaluated a total of 24 subjects selected in the data analysis, including 12 females and 12 males. Table 6A- 6C reports the descriptive statistics for the clinical crown heights at age 11, 20 and 40.

Pearson correlation test was used to evaluate whether there was an apparent increasing or decreasing relationship between crown heights 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.

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.

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

RESULTS

Measurement Reliability

Intra-class correlation coefficient was computed to assess intra-observer agreement in tracing of crown height measurements. Overall, there was very strong evidence that the intra-class 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. The data revealed that there was no statistically significant difference between two measurements ($p=0.1945$). The mean measurement difference between first and second measurements was 0.01mm (std =0.17).

Tooth 8

Figures 1 and 2 show the within-subject profile graphs according to gender by each age. Figure 3 illustrates mean clinical crown height over time for each gender.

Based on the two-sample t-test, there was a significant difference in mean clinical crown heights between males and females at ages 8, 9, 10, 11 and 12 ($p<0.05$ for each instance). The data indicated that mean clinical crown height for males was significantly greater than that observed for females at ages 8 to 12. However, no significant difference was found between males and females at ages 13 through 18, and at ages 20 and 40 (Table 1 through 3).

For tooth 8 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; an effect for time squared was included as well since the plots of the mean crown heights are curvilinear. Moreover, when assessing model fit, adding a cubic component did improve the fit of the model. The interest in this analysis is to test for difference in growth rates between the genders, and the parameter estimates for the crown height measurements.

The data showed there was a significant gender effect (p=0.0035), which revealed that there was a significant mean crown height difference between the genders over time. The age and age squared effects (p<0.0001 for each instance) were highly significant demonstrating that the crown height has a relationship which has a strong linear component with some curvature. The significant gender by age interaction (p=0.0078) demonstrated that the males and females differ in their linear component. The marginally significant (p=0.0604) gender by age squared interaction indicates that the males and females have slight differences in the degree of curvature in the crown height measure function.

Moreover, the results indicated that the estimate of males' intercept is 8.53, while for the females is 8.53-0.74=7.79. Similarly, the estimate for the males' slope is 0.14, while that for the females is 0.14+0.06=0.20. Thus estimated males' starting point is larger than that for the females, but their growth rate is lower than the females. Table 4 summarizes the results of this analysis.

<u>Tooth 9</u>

Figures 4 and 5 show 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, there was a significant difference in mean clinical crown heights between males and females at ages 10 and 11(p=0.0358 and p=0.0400, respectively). The data indicated that mean clinical crown heights for males were significantly greater than those observed for females at ages 10 and 11. However, no significant difference was found between males and females at ages 8 and 9, at ages 12 through 18, and at ages 20 and 40 (p>0.05 for each instance) (Table 5 through 7).

For tooth 9, 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; an effect for time squared was included as well since the plots of the mean crown height are curvilinear. Moreover, when assessing model fit, adding a cubic component did improve the fit of the model. The interest in this analysis is to test for difference in growth rates between the genders, and the parameter estimates for the crown height measurements.

The data showed a marginally significant gender effect ($p=0.0619$), which revealed that there was a marginally significant mean crown height difference between the genders over time. The age and age squared effects ($p<0.0001$ for each instance) were highly significantly demonstrating that crown height has a relationship which has a strong linear component with some curvature. The non-significant gender by age interaction ($p=0.2293$) demonstrates that the males and females do not differ in their growth rates across time. Non-significant gender by age squared interaction ($p=0.4757$) indicates that the males and females have no differences in the degree of curvature in the crown height measure function.

Moreover, the results indicated that the estimate of males' intercept is 8.38; while for the females is 8.38-0.49=7.89. Similarly, the estimate for the males' slope is 0.17, while that for the females is 0.17+0.04=0.21. Thus the estimated males' starting point is larger than that for the females, but their growth rate is lower than the females. Table 8 summarizes the results of this analysis.

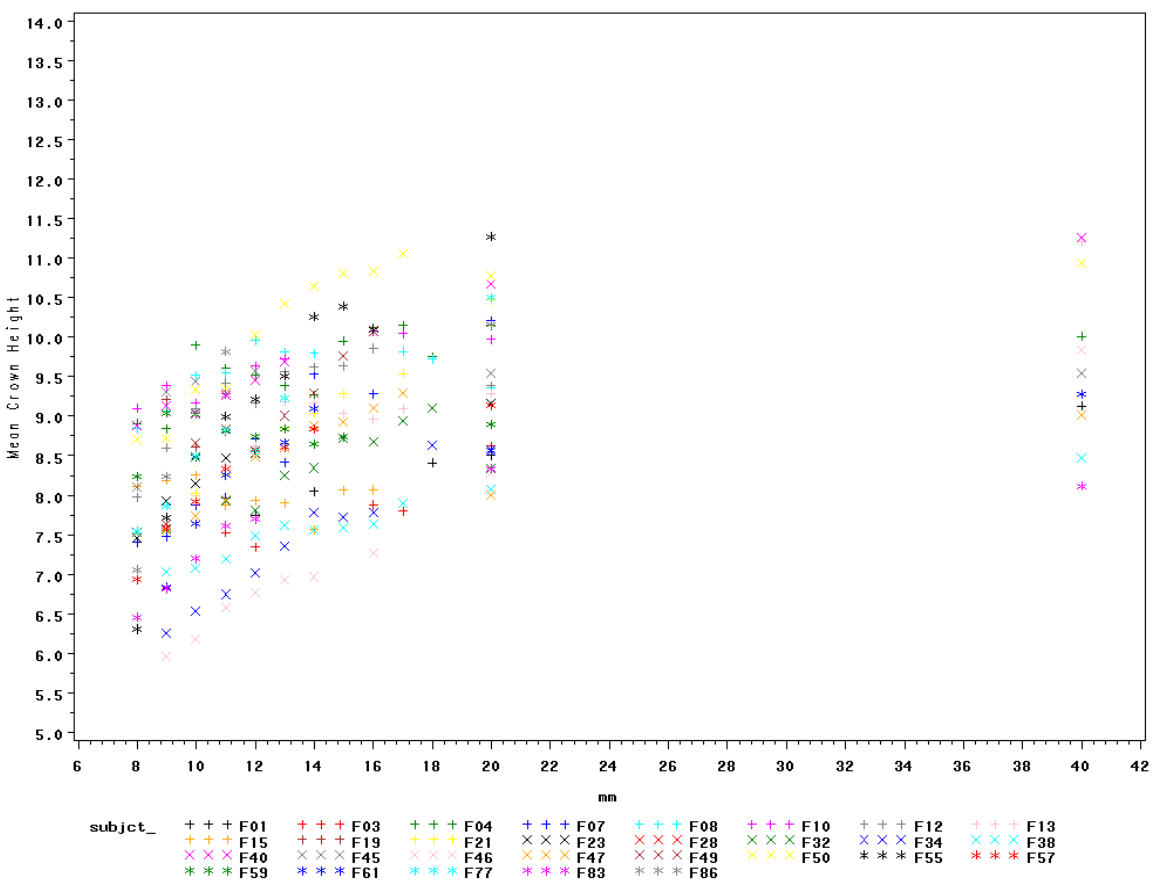

Figure 1 – Within female subjects profile graphs for tooth 8

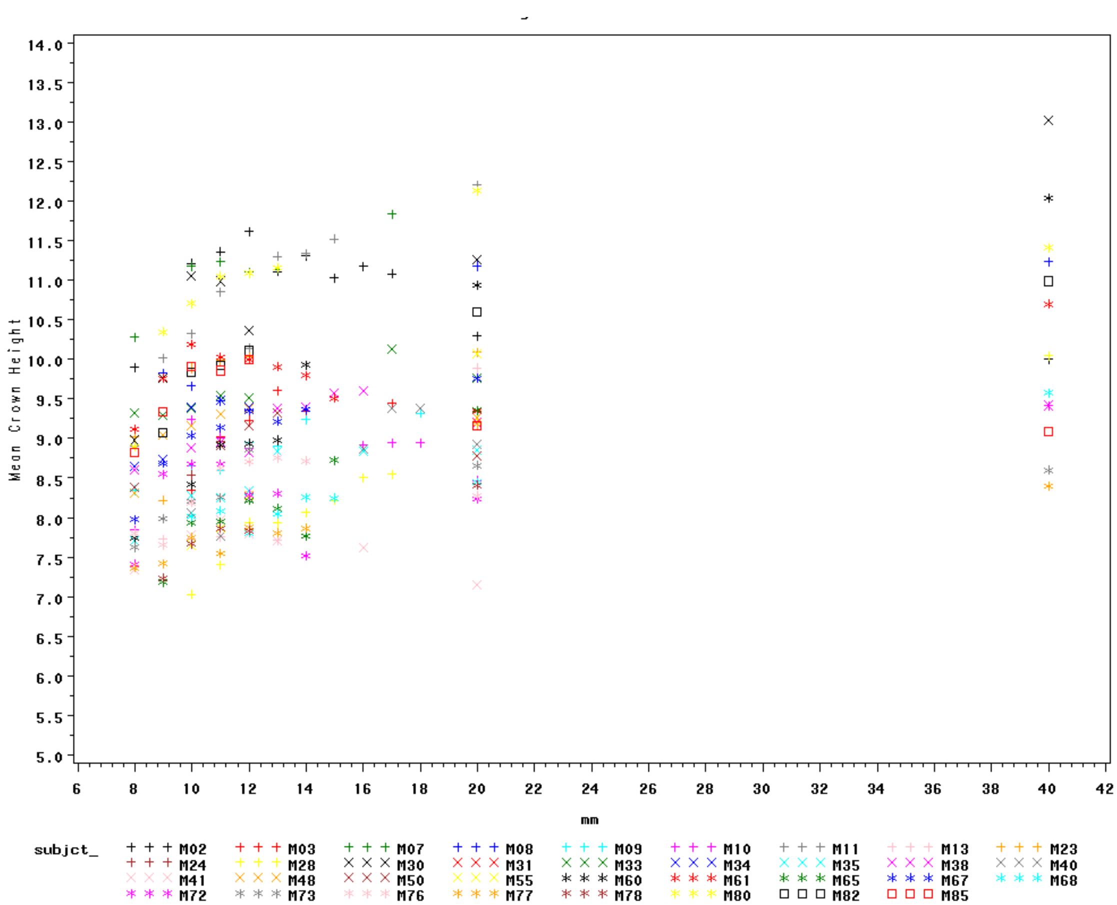

Figure 2 – Within male subjects profile graphs for tooth 8

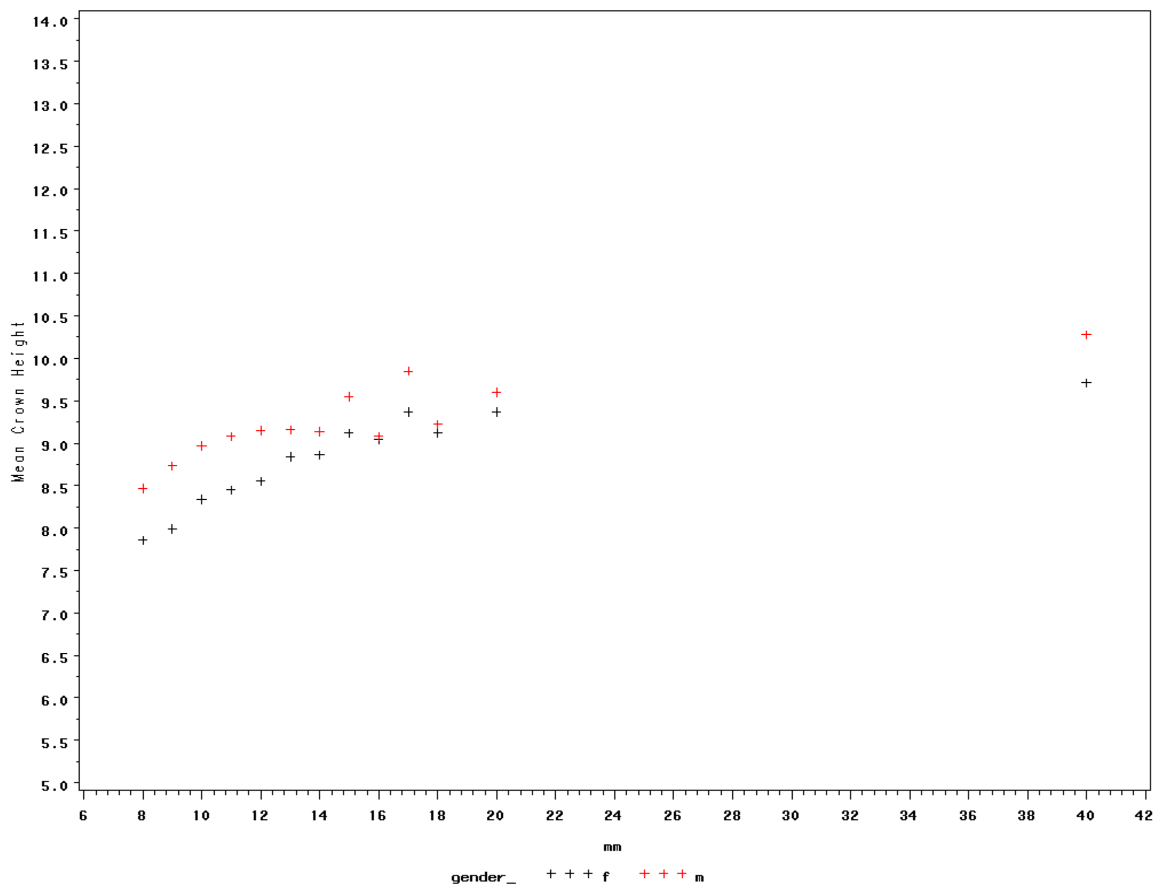

Figure 3 –Mean crown height by gender for tooth 8

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age_8	41	8.22	0.87	6.31	10.28	8.24
age_9	44	8.31	1.04	5.97	10.35	8.23
age_10	59	8.69	1.08	6.19	11.21	8.54
age_11	61	8.80	1.06	6.58	11.36	8.83
age_12	57	8.90	1.01	6.77	11.61	8.82
age_13	41	9.00	1.06	6.93	11.30	8.90
age_14	33	8.98	1.06	6.97	11.34	9.10
age_15	20	9.27	1.09	7.59	11.52	9.16
age_16	22	9.06	1.09	7.27	11.17	8.94
age_17	18	9.58	1.05	7.80	11.84	9.42
age_18	8	9.16	0.48	8.41	9.75	9.21
age_20	56	9.50	1.08	7.16	12.20	9.32
age_40	25	10.03	1.24	8.12	13.02	9.84

Table 1 –Descriptive Statistics of Tooth 8 Crown Heights for all subjects

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age_8	17	7.86	0.87	6.31	9.10	7.98
age_9	25	7.99	0.96	5.97	9.38	7.87
age_10	26	8.34	0.92	6.19	9.90	8.49
age_11	27	8.45	0.87	6.58	9.82	8.37
age_12	24	8.55	0.92	6.77	10.03	8.58
age_13	21	8.84	0.88	6.93	10.42	8.84
age_14	19	8.86	0.96	6.97	10.65	9.04
age_15	13	9.12	0.98	7.59	10.80	9.03
age_16	15	9.05	1.12	7.27	10.84	9.10
age_17	10	9.37	1.00	7.80	11.06	9.42
age_18	5	9.12	0.61	8.41	9.75	9.10
age_20	25	9.37	0.95	8.00	11.27	9.29
age_40	11	9.71	1.06	8.12	11.26	9.55

Table 2 –Descriptive Statistics of Tooth 8 Crown Heights for female subjects

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age_8	24	8.47	0.79	7.35	10.28	8.50
age_9	19	8.73	1.00	7.19	10.35	8.74
age_10	33	8.97	1.13	7.03	11.21	8.68
age_11	34	9.08	1.12	7.40	11.36	8.96
age_12	33	9.15	1.02	7.80	11.61	8.95
age_13	20	9.16	1.22	7.71	11.30	8.94
age_14	14	9.14	1.21	7.52	11.34	9.29
age_15	7	9.55	1.30	8.22	11.52	9.51
age_16	7	9.08	1.10	7.62	11.17	8.87
age_17	8	9.85	1.11	8.55	11.84	9.42
age_18	3	9.22	0.24	8.94	9.39	9.32
age_20	31	9.60	1.18	7.16	12.20	9.35
age_40	14	10.28	1.34	8.40	13.02	10.03

Table 3 –Descriptive Statistics of Tooth 8 Crown Heights for male subjects

Effect	Gender	Estimate	Std. Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Intercept		8.5333	0.1694	60	50.39	<.0001	0.05	8.1945	8.8721
gender	f	0.7397	0.2519	359	-2.94	0.0035	0.05	-1.2351	-0.2442
gender	m	0	.	.	.	.	.	.	.
age		0.1424	0.0152	60	9.36	<.0001	0.05	0.1120	0.1729
age*gender	f	0.0597	0.0223	359	2.68	0.0078	0.05	0.0158	0.1036
age*gender	m	0	.	.	.	.	.	.	.
age*age		-0.0031	0.0004	60	-7.56	<.0001	0.05	-0.0039	-0.0023
age*age*gender	f	-0.0011	0.0006	359	-1.88	0.0604	0.05	-0.00234	0.0001
age*age*gender	m	0	.	.	.	.	.	.	.

Note: DF=Degree of Freedom

**Males as the reference group

Table 4---Summary of the Full Model Used in the Random Coefficient Regression Analysis of Tooth 8

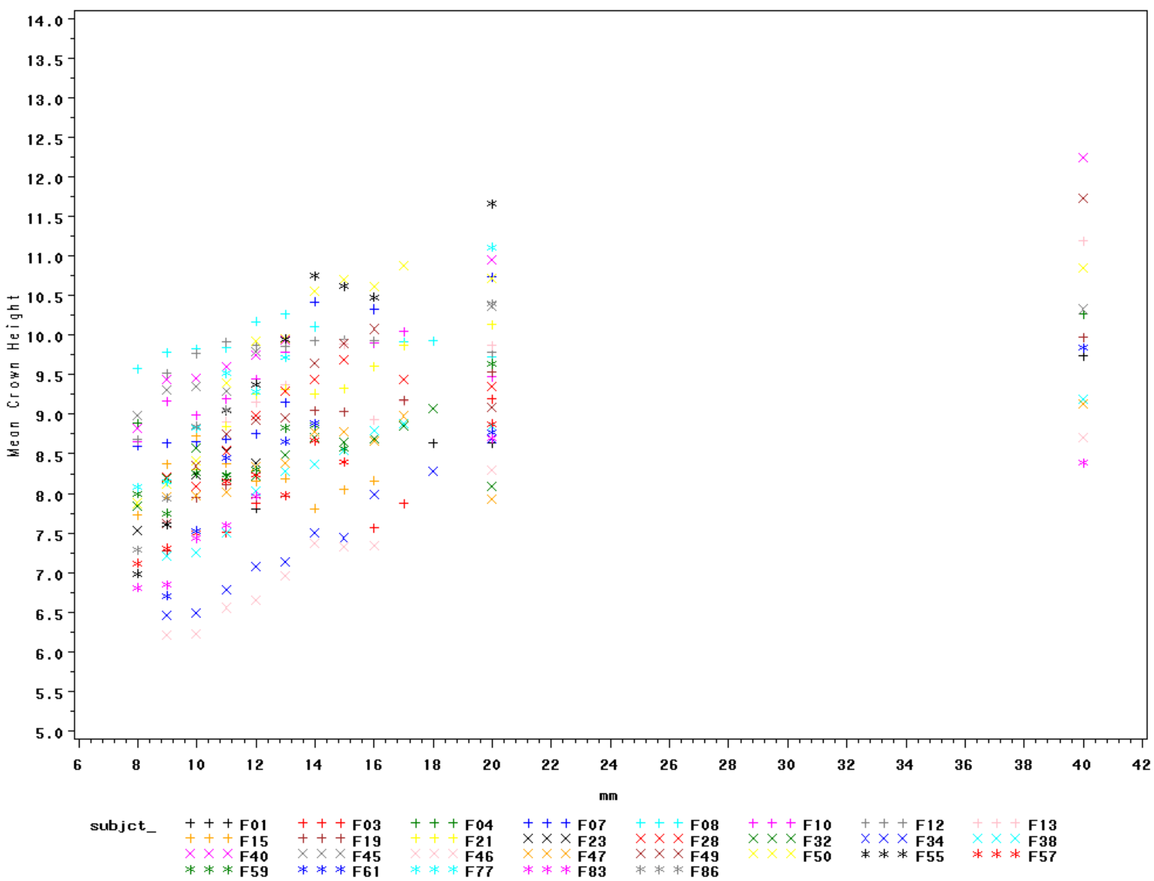

Figure 4 – Within female subjects profile graphs for tooth 9

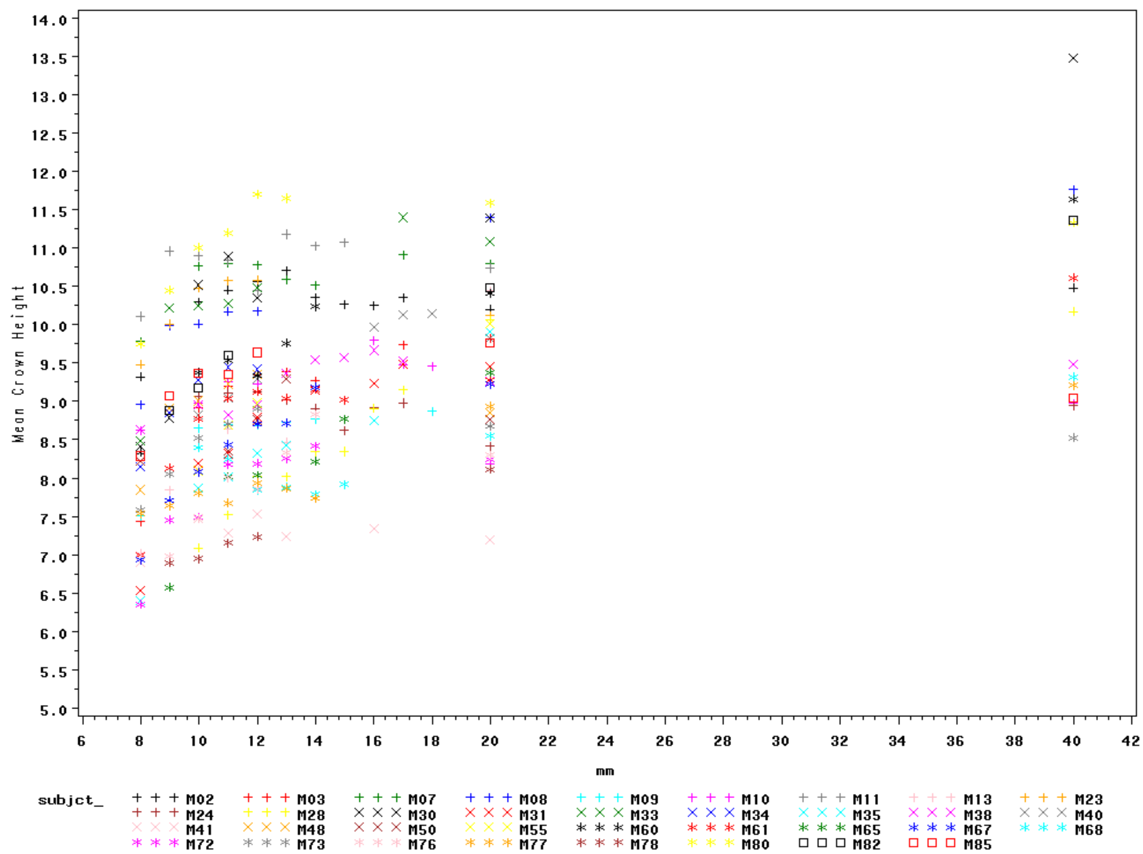

Figure 5 – Within male subjects profile graphs for tooth 9

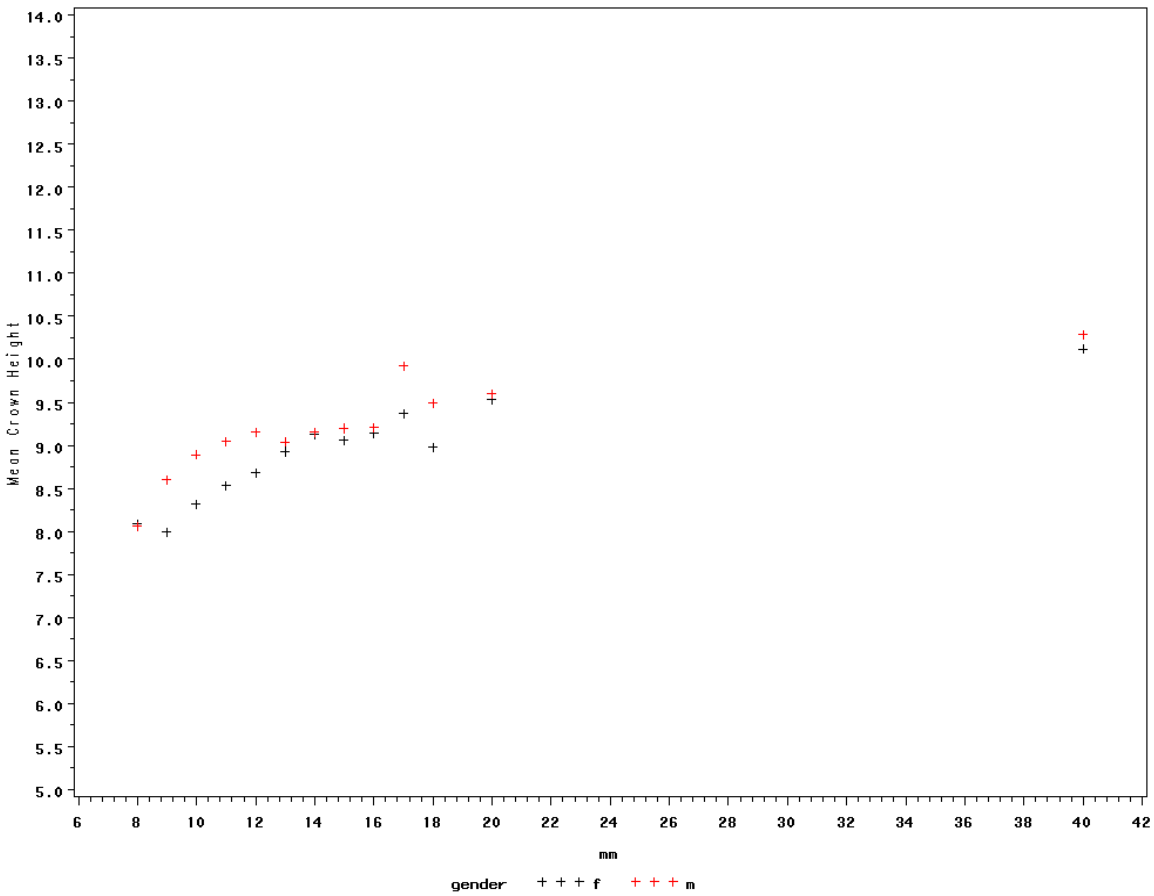

Figure 6 –Mean crown height by gender for tooth 8

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age_8	43	8.07	0.97	6.36	10.11	8.08
age_9	44	8.25	1.14	6.21	10.96	8.13
age_10	60	8.64	1.06	6.23	11.01	8.62
age_11	63	8.82	1.01	6.56	11.20	8.71
age_12	61	8.95	1.00	6.65	11.70	8.96
age_13	43	8.98	1.05	6.96	11.65	8.96
age_14	36	9.14	0.95	7.38	11.03	9.10
age_15	24	9.10	1.01	7.33	11.07	8.90
age_16	24	9.16	0.99	7.34	10.62	9.09
age_17	21	9.63	0.81	7.87	11.40	9.49
age_18	7	9.20	0.68	8.28	10.15	9.08
age_20	60	9.57	1.03	7.20	11.66	9.50
age_40	28	10.21	1.27	8.39	13.47	10.07

Table 5 –Descriptive Statistics of Tooth 9 Crown Heights for all subjects

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age_8	17	8.09	0.80	6.81	9.58	8.00
age_9	25	7.99	0.96	6.21	9.78	7.96
age_10	26	8.32	0.88	6.23	9.83	8.33
age_11	28	8.53	0.84	6.56	9.91	8.54
age_12	26	8.68	0.90	6.65	10.17	8.57
age_13	22	8.93	0.93	6.96	10.27	9.06
age_14	19	9.13	0.97	7.38	10.75	9.05
age_15	16	9.06	1.02	7.33	10.71	8.91
age_16	15	9.14	1.08	7.34	10.62	8.93
age_17	11	9.37	0.79	7.87	10.88	9.18
age_18	4	8.98	0.71	8.28	9.93	8.86
age_20	27	9.53	0.97	7.93	11.66	9.47
age_40	13	10.12	1.15	8.39	12.24	9.97

Table 6 –Descriptive Statistics of Tooth 9 Crown Heights for female subjects

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age_8	26	8.06	1.09	6.36	10.11	8.19
age_9	19	8.60	1.29	6.58	10.96	8.79
age_10	34	8.89	1.12	6.95	11.01	8.88
age_11	35	9.05	1.08	7.16	11.20	9.04
age_12	35	9.15	1.03	7.24	11.70	9.13
age_13	21	9.04	1.18	7.24	11.65	8.72
age_14	17	9.15	0.95	7.74	11.03	9.15
age_15	8	9.20	1.05	7.92	11.07	8.90
age_16	9	9.21	0.87	7.34	10.25	9.24
age_17	10	9.92	0.78	8.98	11.40	9.64
age_18	3	9.49	0.64	8.87	10.15	9.46
age_20	33	9.60	1.08	7.20	11.59	9.76
age_40	15	10.29	1.40	8.53	13.47	10.17

Table 7 –Descriptive Statistics of Tooth 9 Crown Heights for male subjects

Effect	Gender	Estimate	Std. Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Intercept		8.3790	0.1754	62	47.76	<.0001	0.05	8.0283	8.7296
gender	f	-0.4888	0.2608	323	-1.87	0.0619	0.05	-1.0019	0.0244
gender	m	0	.	.	.	.	.	.	.
age		0.1695	0.0197	62	8.62	<.0001	0.05	0.1302	0.2088
age*gender	f	0.0351	0.0291	323	1.20	0.2293	0.05	-0.0222	0.0924
age*gender	m	0	.	.	.	.	.	.	.
age*age		-0.0037	0.0005	61	-7.09	<.0001	0.05	-0.0048	-0.0027
age*age*gender	f	-0.0006	0.0008	33	-0.71	0.4757	0.05	-0.0021	0.0008
age*age*gender	m	0	.	.	.	.	.	.	.

Note: DF=Degree of Freedom

**Males as the reference group

Table 8---Summary of the Full Model Used in the Random Coefficient Regression Analysis of Tooth 9

Tooth 24

Figures 7 and 8 show the within-subject profile graphs according to gender by each age. Figure 9 illustrates mean clinical crown height over time for each gender.

Based on the two-sample t-test, no significant difference was found between males and females at ages 8 through 18, and at ages 20 and 40 ($p>0.05$ for each instance) (Table 9 through 11).

For tooth 24, 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. No effect for time squared was included for tooth 24 since it didn't significantly improve the fit of the model. The interest in this analysis is to test for difference in growth rates between the genders, and the parameter estimates for the crown height measurements.

There was no significant mean crown height difference between the genders over time ($p=0.7007$). The non- significant gender by age interaction ($p=0.5325$) which demonstrates that the males and females do not differ in their growth rates across time. The age effect ($p=0.0009$) was highly significant in demonstrating the significant changes in the crown heights over time.

Moreover, the results indicated that the estimate of males' intercept is 7.42; while for the females is 7.42-0.09=7.33. Similarly, the estimate for the males' slope is 0.04, while that for the females is 0.04+0.01=0.05. Thus the estimated males' starting point is larger than that for the females, but their growth rate is lower than the females. Table 12 summarizes the results of this analysis.

Tooth 25

Figures 10 and 11 show the within-subject profile graphs according to gender by each age. Figure 12 illustrates mean clinical crown height over time for each gender.

Based on the two-sample t-test, no significant difference was found between males and females at ages 8 through 18, and at ages 20 and 40 ($p>0.05$ for each instance) (Table 13 through 15).

For tooth 25, 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. No effect for time squared was included for tooth 25 since it didn't significantly improve the fit of the model. The interest in this analysis is to test for difference in growth rates between the genders, and the parameter estimates for the crown height measurements.

There was no significant mean crown height difference between the genders over time ($p=0.8834$). The non- significant gender by age interaction ($p=0.3359$) which demonstrates that the males and females do not differ in their growth rates across time. The age effect ($p<0.0001$) was highly significant in demonstrating the significant changes in the crown heights over time.

Moreover, the results indicated that the estimate of males' intercept is 7.43; while for the females is 7.43+0.03=7.46. Similarly, the estimate for the males' slope is 0.05, while that for the females is 0.05-0.02=0.03. Thus females' starting point is larger than that for the males, but their growth rate is lower than the males. Table 16 summarizes the results of this analysis.

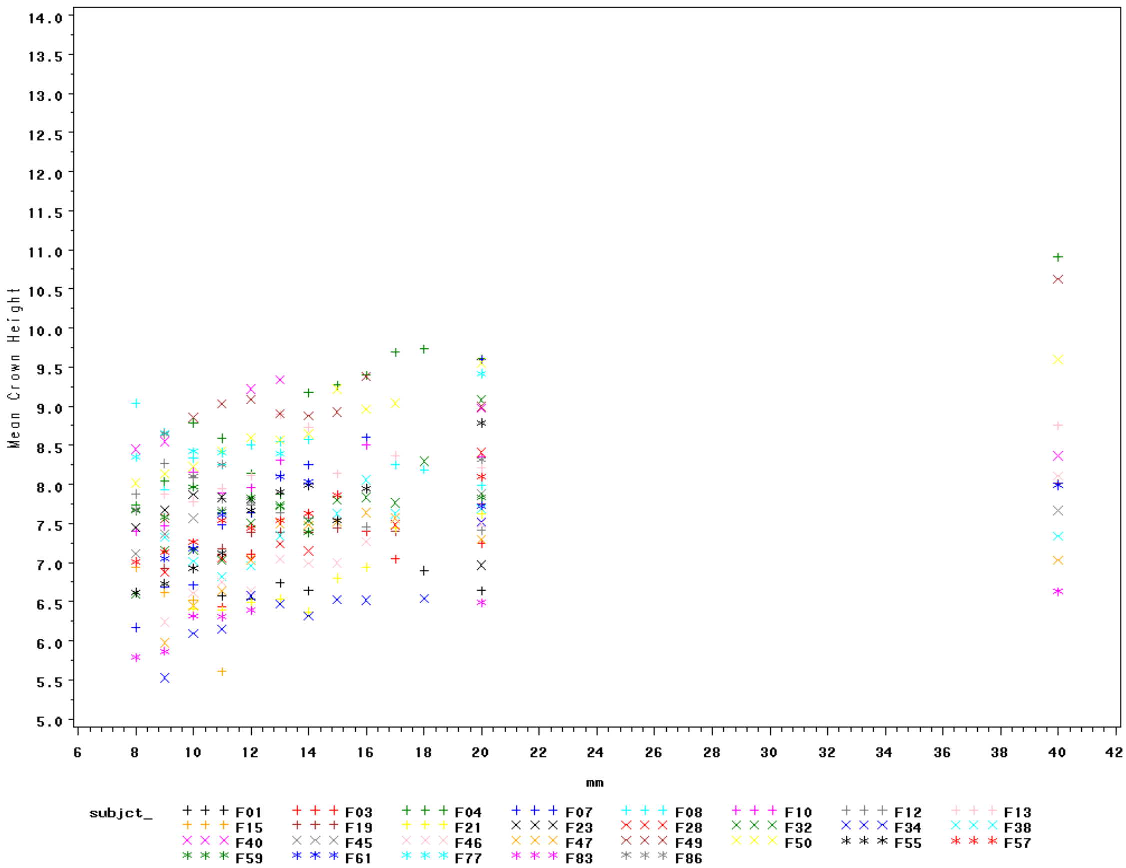

Figure 7 – Within female subjects profile graphs for tooth 24

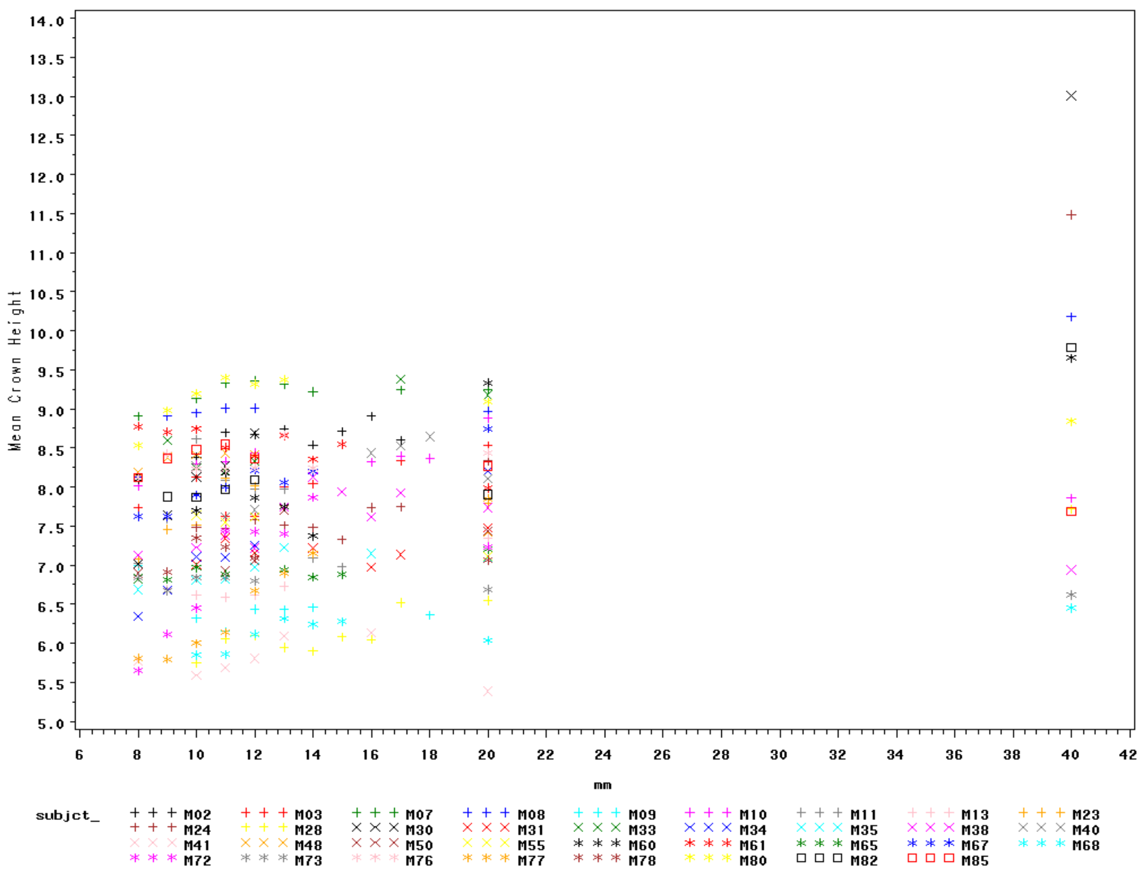

Figure 8 – Within male subjects profile graphs for tooth 24

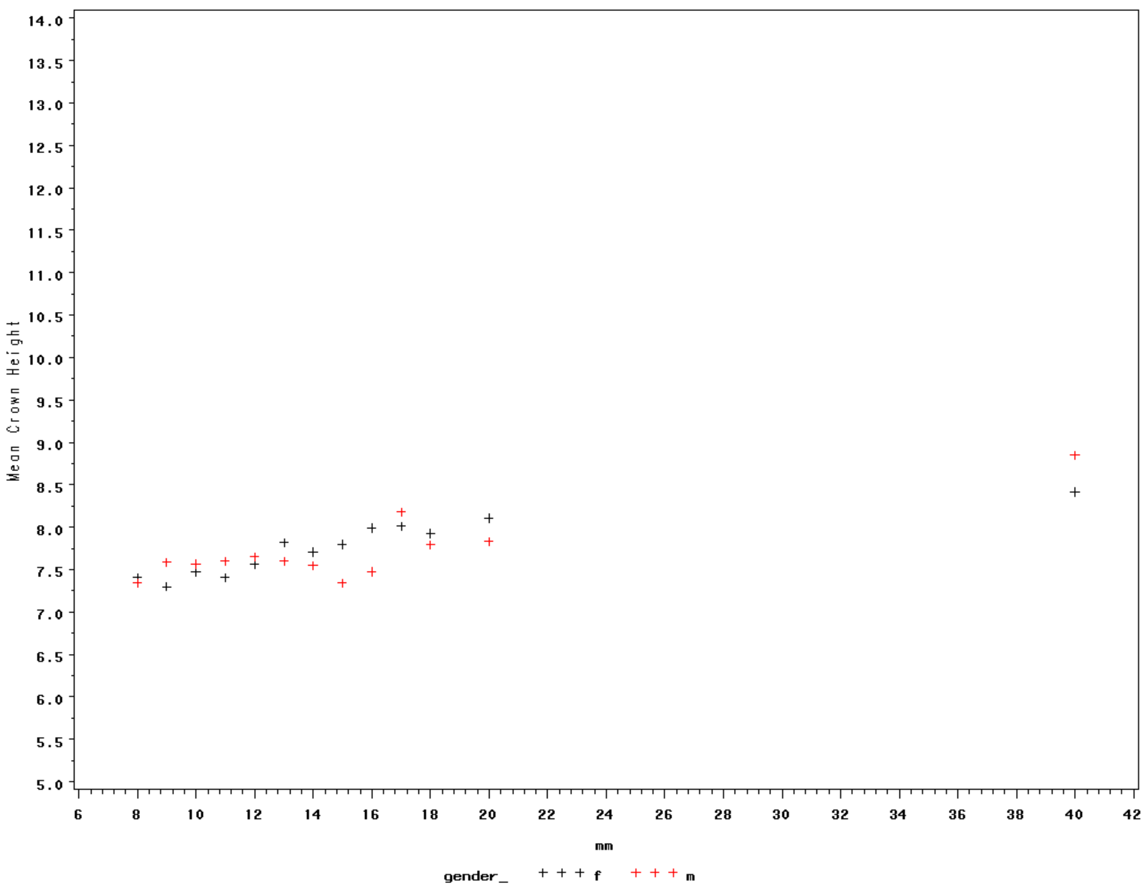

Figure 9 –Mean crown height by gender for tooth 24

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age_8	43	7.37	0.89	5.65	9.04	7.40
age_9	45	7.43	0.90	5.53	8.98	7.47
age_10	61	7.53	0.92	5.59	9.20	7.57
age_11	64	7.52	0.91	5.61	9.40	7.59
age_12	60	7.62	0.85	5.81	9.36	7.63
age_13	44	7.71	0.88	5.95	9.38	7.73
age_14	37	7.64	0.84	5.90	9.22	7.54
age_15	22	7.64	0.90	6.08	9.27	7.55
age_16	23	7.79	0.94	6.05	9.40	7.74
age_17	22	8.09	0.81	6.52	9.69	8.09
age_18	8	7.88	1.17	6.36	9.73	8.25
age_20	59	7.96	0.93	5.39	9.61	7.89
age_40	24	8.64	1.70	6.45	13.01	8.06

Table 9 –Descriptive Statistics of Tooth 24 Crown Heights for all subjects

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age_8	17	7.41	0.84	5.79	9.04	7.45
age_9	26	7.30	0.85	5.53	8.66	7.35
age_10	27	7.48	0.84	6.10	8.86	7.26
age_11	29	7.41	0.85	5.61	9.03	7.55
age_12	25	7.57	0.78	6.39	9.22	7.64
age_13	23	7.82	0.76	6.47	9.34	7.73
age_14	20	7.71	0.82	6.32	9.17	7.56
age_15	14	7.80	0.84	6.53	9.27	7.60
age_16	14	7.99	0.88	6.52	9.40	7.90
age_17	12	8.01	0.77	7.05	9.69	7.70
age_18	5	7.93	1.27	6.54	9.73	8.19
age_20	28	8.11	0.88	6.49	9.61	7.94
age_40	12	8.42	1.35	6.63	10.91	8.06

Table 10 –Descriptive Statistics of Tooth 24 Crown Heights for female subjects

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age_8	26	7.34	0.93	5.65	8.91	7.11
age_9	19	7.59	0.97	5.80	8.98	7.63
age_10	34	7.57	1.00	5.59	9.20	7.67
age_11	35	7.60	0.97	5.69	9.40	7.62
age_12	35	7.65	0.91	5.81	9.36	7.62
age_13	21	7.60	1.00	5.95	9.38	7.71
age_14	17	7.55	0.89	5.90	9.22	7.48
age_15	8	7.34	0.98	6.08	8.71	7.16
age_16	9	7.48	1.00	6.05	8.91	7.62
age_17	10	8.18	0.88	6.52	9.38	8.37
age_18	3	7.79	1.25	6.36	8.65	8.37
age_20	31	7.83	0.96	5.39	9.34	7.85
age_40	12	8.85	2.03	6.45	13.01	8.35

Table 11 –Descriptive Statistics of Tooth 24 Crown Heights for male subjects

Effect	Gender	Estimate	Std. Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Intercept		7.4186	0.1539	62	48.21	<.0001	0.05	7.1111	7.7262
gender	f	-0.0879	0.2285	384	-0.38	0.7007	0.05	-0.5371	0.3613
gender	m	0	.	.	.	.	.	.	.
age		0.0413	0.0118	62	3.49	0.0009	0.05	0.0176	0.0649
age*gender	f	0.0109	0.0175	384	0.62	0.5325	0.05	-0.0235	0.0454
age*gender	m	0	.	.	.	.	.	.	.

Note: DF=Degree of Freedom

**Males as the reference group

Table 12---Summary of the Full Model Used in the Random Coefficient Regression Analysis of Tooth 24

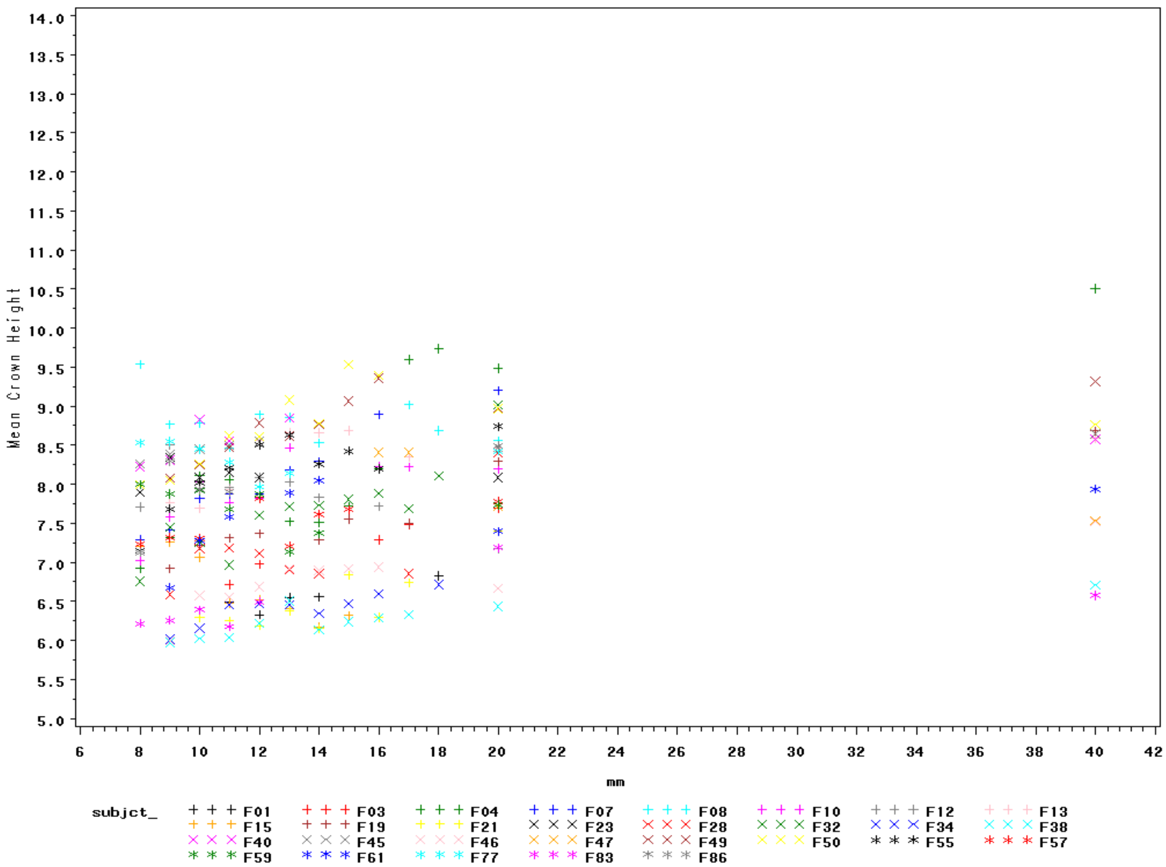

Figure 10 – Within female subjects profile graphs for tooth 25

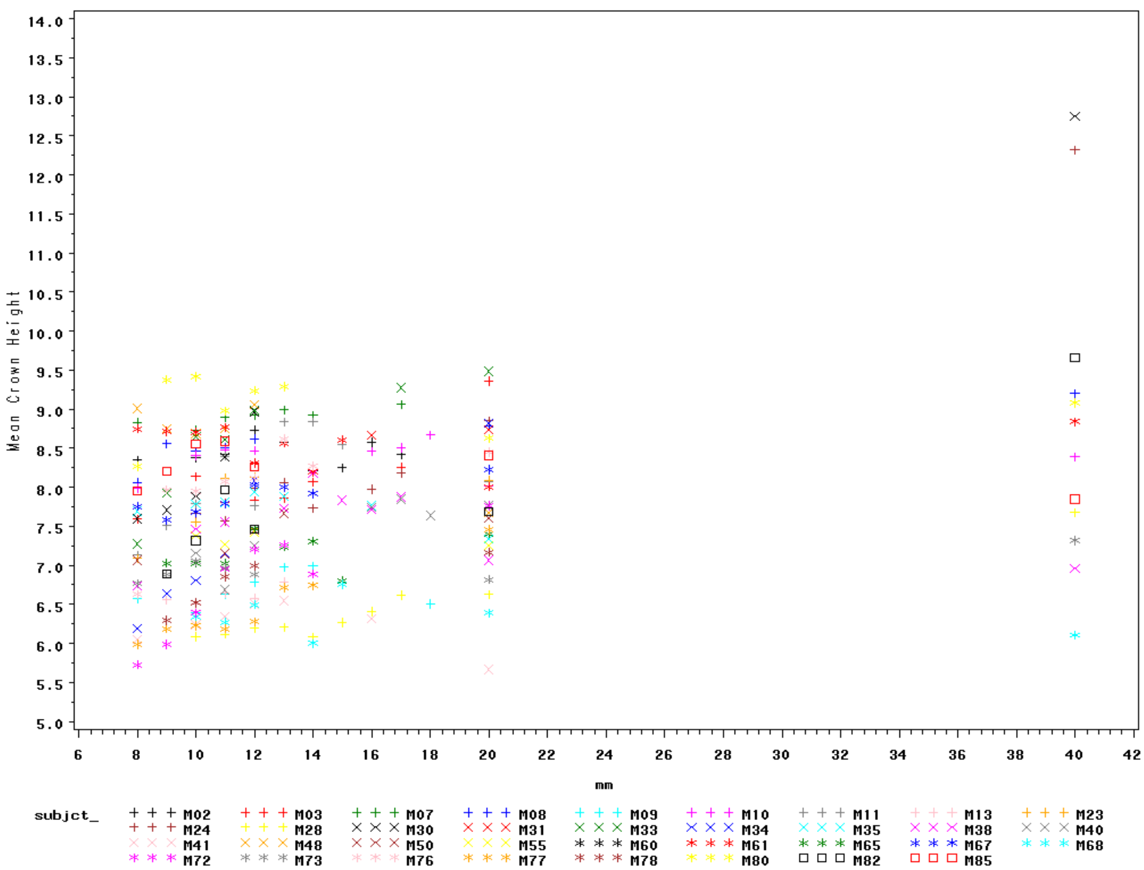

Figure 11 – Within male subjects profile graphs for tooth 25

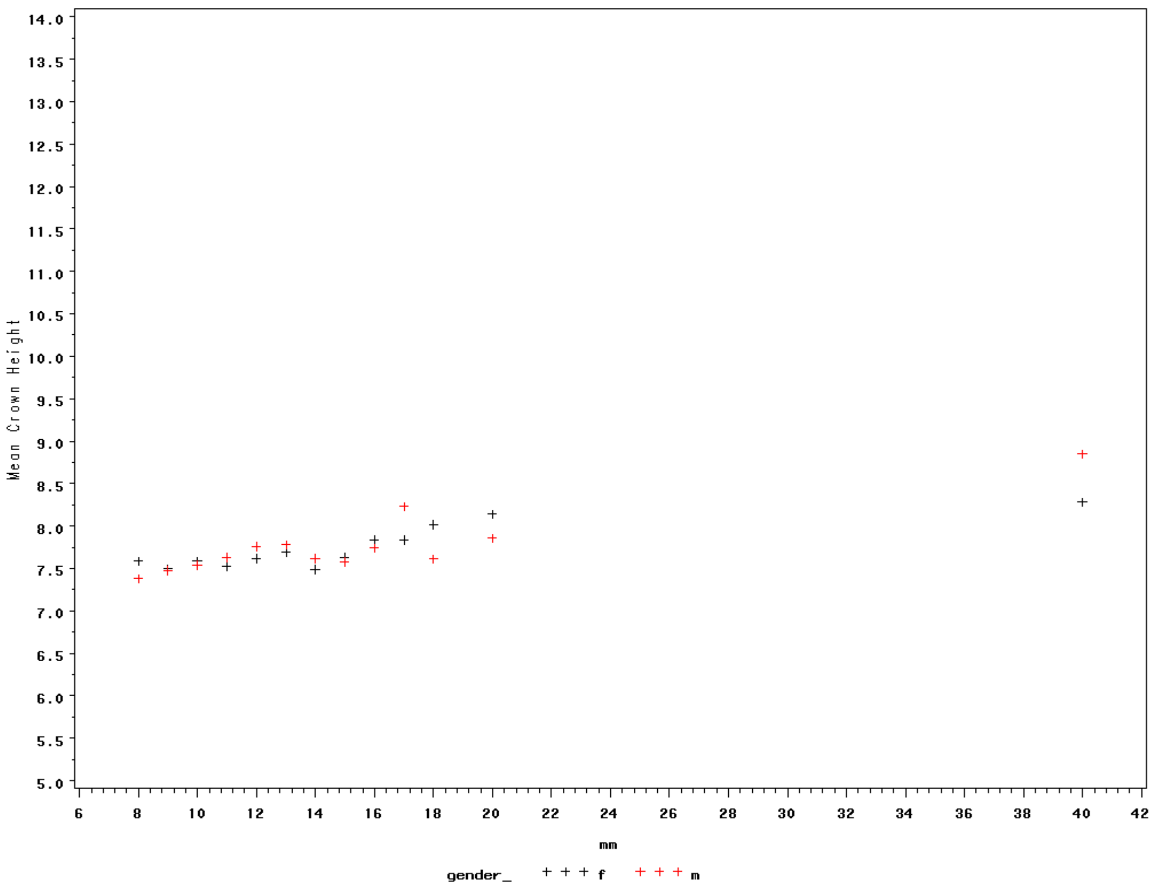

Figure 12 –Mean crown height by gender for tooth 25

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age_8	41	7.47	0.87	5.73	9.54	7.29
age_9	43	7.49	0.90	5.98	9.38	7.58
age_10	58	7.57	0.86	6.03	9.42	7.69
age_11	61	7.58	0.85	6.04	8.98	7.79
age_12	59	7.70	0.87	6.19	9.24	7.83
age_13	41	7.73	0.90	6.21	9.29	7.86
age_14	35	7.55	0.90	6.00	8.92	7.73
age_15	21	7.62	0.98	6.24	9.54	7.68
age_16	23	7.80	0.95	6.29	9.40	7.89
age_17	20	8.01	0.90	6.33	9.60	8.20
age_18	8	7.86	1.14	6.51	9.74	7.88
age_20	57	7.99	0.83	5.67	9.49	8.07
age_40	24	8.56	1.61	6.11	12.75	8.59

Table 13 –Descriptive Statistics of Tooth 25 Crown Heights for all subjects

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age_8	17	7.59	0.79	6.22	9.54	7.29
age_9	25	7.50	0.86	5.98	8.77	7.58
age_10	26	7.59	0.81	6.03	8.83	7.87
age_11	28	7.52	0.83	6.04	8.62	7.82
age_12	26	7.62	0.89	6.19	8.89	7.83
age_13	22	7.69	0.92	6.38	9.08	7.81
age_14	20	7.49	0.91	6.14	8.78	7.57
age_15	14	7.63	1.03	6.24	9.54	7.62
age_16	14	7.84	1.04	6.29	9.40	8.05
age_17	11	7.84	1.00	6.33	9.60	7.69
age_18	5	8.02	1.28	6.72	9.74	8.11
age_20	27	8.14	0.78	6.44	9.49	8.29
age_40	12	8.28	1.10	6.58	10.51	8.59

Table 14 –Descriptive Statistics of Tooth 25 Crown Heights for female subjects

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age_8	24	7.38	0.93	5.73	9.01	7.44
age_9	18	7.49	0.99	5.99	9.38	7.55
age_10	32	7.54	0.92	6.09	9.42	7.62
age_11	33	7.63	0.88	6.12	8.98	7.79
age_12	33	7.76	0.87	6.20	9.24	7.83
age_13	19	7.78	0.89	6.21	9.29	7.86
age_14	15	7.62	0.91	6.00	8.92	7.92
age_15	7	7.58	0.96	6.27	8.61	7.84
age_16	9	7.74	0.86	6.32	8.67	7.77
age_17	9	8.23	0.77	6.62	9.28	8.26
age_18	3	7.61	1.08	6.51	8.67	7.64
age_20	30	7.86	0.87	5.67	9.49	7.89
age_40	12	8.85	2.00	6.11	12.75	8.62

Table 15 –Descriptive Statistics of Tooth 25 Crown Heights for male subjects

Effect	Gender	Estimate	Std. Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Intercept		7.4256	0.1553	61	47.80	<.0001	0.05	7.1150	7.7363
gender	f	0.03350	0.2283	365	0.15	0.8834	0.05	-0.4155	0.4824
gender	m	0	.	.	.	.	.	.	.
age		0.05313	0.01160	61	4.58	<.0001	0.05	0.0299	0.0763
age*gender	f	-0.01631	0.01693	365	-0.96	0.3359	0.05	-0.04961	0.0169
age*gender	m	0	.	.	.	.	.	.	.

Note: DF=Degree of Freedom

**Males as the reference group

Table 16---Summary of the Full Model Used in the Random Coefficient Regression Analysis of Tooth 25

SUBSET ANALYSIS

Teeth 8 and 9

The following are comparisons of average crown heights between females and males at ages 11, 20 and 40:

At age 11--Based on the two-sample t-test, there was a significant difference in mean clinical crown heights between males and females at age 11 (p=0.0180). The data indicated that mean clinical crown height for males was significantly greater than that observed for females (mean crown height difference between males and females= -0.964; std=1.01) (Table 17 through 19).

At age 20--No significant difference was found between males and females at age 20 (p=0.2107, a two-sample t-test).

At age 40--No significant difference was found between males and females at age 40 (p=0.5557, a two-sample t-test).

The following are assessments of correlation between average crown heights measured at ages 11 and 20; 11 and 40; 20 and 40:

Ages 11 and 20--Assessment of correlation between average crown heights 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 height measured at ages 11 and 20 (p<0.0001), and a coefficient of 0.77 indicated there was a moderate association between the two measurements.

Ages 11 and 40--Assessment of correlation between average crown heights 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 height measured at ages 11 and 40 (p=0.0002), and a coefficient of 0.65 indicated there was a moderate association between the two measurements.

Ages 20 and 40--Assessment of correlation between average crown heights 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 height measured at ages 20 and 40 (<0.0001), and a coefficient of 0.85 indicated there was a strong association between the two measurements.

Data was analyzed using a two-way ANOVA with repeated measures on one factor. The interaction between gender and time (age) was not significant (F(2, 52)=2.94; p=0.0674), nor was the main effect for gender (F(1,26)=2.37; p=0.1357).

However, this analysis did reveal a significant effect for time (age) (F(2,52)=40.92); p<0.0001). Post-hoc contrasts test found that the crown heights at ages 20 (F(1,26)=30.95; p<0.0001) and at age 40 (F(1, 26)=56.06; p<0.0001) were significantly higher that the crown heights observed at age 11, while the crown heights at age 40 (F(1,26)=21.50; p<0.0001) was significantly higher than the crown heights obtained at age 20.

<u>Teeth 24 and 25</u>

The following are comparisons of average crown heights of teeth 24 and 25 between females and males at ages 11, 20 and 40:

At age 11--Based on the two-sample t-test, there was no significant difference in mean clinical crown heights between males and females at age 11 (p=0.7464) (Table 20 through 22).

At age 20**--**No significant difference was found between males and females at age 20 (p=0.5148, a two-sample t-test).

At age 40**--**No significant difference was found between males and females at age 40 (p=0.9009, a two-sample t-test).

The following are assessments of correlation between average crown heights of teeth 24 and 25 measured at ages 11 and 20; 11 and 40; 20 and 40:

Ages 11 and 20--Assessment of correlation between average crown heights 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 24 and 25 measured at ages 11 and 20 ($p<0.0001$), and a coefficient of 0.87 indicated there was a strong association between the two measurements.

Ages 11 and 40--Assessment of correlation between average crown heights of teeth24 and 25 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 24 and 25 measured at ages 11 and 40 ($p=0.0087$), and a coefficient of 0.52 indicated there was a moderate association between the two measurements.

Ages 20 and 40--Assessment of correlation between average crown heights of teeth24 and 25 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 24 and 25 measured at ages 20 and 40 ($p<0.0001$), and a coefficient of 0.76 indicated there was a moderate association between the two measurements..

Data were then analyzed using a two-way ANOVA with repeated measures on one factor. The interaction between gender and time (age) was not significant ($F(2, 44)=0.60$; $p=0.5556$), nor was the main effect for gender ($F(1,22)=0.00$; $p=0.9664$).

However, this analysis did reveal a significant effect for time (age) ($F(2,44)=6.57$); $p=0.0032$). Post-hoc contrasts test found that the mean average crown heights of teeth24 and 25 at ages 20 ($F(1,22)=9.85$; $p=0.0048$) and at age 40 ($F(1, 22)=7.28$; $p=0.0132$) were significantly higher that the mean average of crown heights of teeth24 and 25 observed at age 11, while the mean average of crown heights of teeth 24 and 25 at age 40 ($F(1,22)=4.57$; $p=0.0439$) was significantly higher than the crown heights obtained at age 20.

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age11	28	8.87	1.10	6.57	11.13	8.92
age20	28	9.60	1.05	7.97	11.86	9.52
age40	28	10.15	1.20	8.26	13.25	10.03

Table 17 –Descriptive Statistics of Teeth 8 and 9 Crown Heights for all subset subjects

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age11	13	8.35	0.85	6.57	9.44	8.36
age20	13	9.33	0.96	7.97	10.82	9.58
age40	13	10.00	1.06	8.26	11.75	9.94

Table 18–Descriptive Statistics of Teeth 8 and 9 Crown Heights of female subset subjects

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age11	15	9.31	1.12	7.46	11.13	9.23
age20	15	9.83	1.10	8.33	11.86	9.47
age40	15	10.28	1.33	8.57	13.25	10.11

Table 19 –Descriptive Statistics of Teeth 8 and 9 Crown Heights of male subset subjects

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age11	24	7.72	0.92	6.07	9.19	7.85
age20	24	7.99	0.91	6.22	9.55	8.10
age40	24	8.39	1.38	6.28	11.91	8.14

Table 20–Descriptive Statistics of Teeth 24 and 25 Crown Heights for all subset subjects

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age11	12	7.65	0.86	6.25	8.75	7.77
age20	12	8.12	0.93	6.84	9.55	8.10
age40	12	8.35	1.18	6.61	10.71	8.25

Table 21–Descriptive Statistics of Teeth 24 and 25 Crown Heights for female subset subjects

Variable	N	Mean	Std Dev	Minimum	Maximum	Median
age11	12	7.78	1.02	6.07	9.19	7.87
age20	12	7.87	0.92	6.22	8.88	8.17
age40	12	8.42	1.60	6.28	11.91	7.95

Table 22–Descriptive Statistics of Teeth 24 and 25 Crown Heights for male subset subjects

SUMMARY

Tooth 8

- Mean Crown Heights
  - Significant differences in mean clinical heights at ages 8-12 (Males larger $p<0.05$)
  - No significant differences at ages 13-18, 20, 40
- Crown Height trends over time
  - Significant mean crown height difference between genders over time
  - Males and females differ in their eruption rates over time
  - Females growth is faster during span of measurements
  - Males growth starting point at age eight is larger

Tooth 9

- Mean Crown Heights
  - Significant differences in mean clinical heights at ages 10-11 (Males larger $p<0.05$)
  - No significant differences at ages 8, 9, 12-18, 20, 40
- Crown Height trends over time
  - Marginally significant mean crown height difference between genders over time
  - Males and females do not significantly differ in eruption rates over time
  - Females growth is faster during span of measurements
  - Males growth starting point at age eight is larger

Tooth 24

- Mean Crown Heights
  - No significant differences at ages 8-18, 20, 40
- Crown Height trends over time
  - No significant mean crown height difference between genders over time
  - High significance in changes in crown heights over time
  - Males and females do not significantly differ in eruption rates over time
  - Males starting points is larger, however their growth rate is lower

Tooth 25

- Mean Crown Heights
  - No significant differences at ages 8-18, 20, 40
- Crown Height trends over time
  - No significant mean crown height difference between genders over time
  - High significance in changes in crown heights over time
  - Males and females do not significantly differ in eruption rates over time
  - Females starting points is larger, however their growth rate is lower

Longitudinal Subset Analysis Teeth 8 & 9

- Age 11—Significant difference at age 11 (Males larger)
- Age 20—No difference
- Age 40—No difference
- 11&20—Significant increasing mean crown heights
- 11&40—Significant increasing mean crown heights
- 20&40—Significant increasing 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

Longitudinal Subset Analysis Teeth 24 & 25

- Age 11—No significant difference
- Age 20—No significant difference
- Age 40—No significant difference
- 11&20— Significant increasing mean crown heights
- 11&40— Significant increasing mean crown heights
- 20&40— Significant increasing 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

DISCUSSION

The principle findings of this study focused on three points: mean crown heights between males and females, eruption rates between males and females, and age effect of a subject on eruption. First the differences between male and female mean crown heights were only present on maxillary incisors at early ages. Tooth 8 at ages 8 to 12 and for tooth 9 at ages 10 to 11. All other ages and all other teeth showed no gender differences for mean crown height. Second, eruption rates differ for males and female for tooth 8 only. Teeth 9, 24, 25 all showed no differences in their rate of increasing crown height over time. Finally, a significant age effect for teeth 8 and 9 and also for teeth 24 and 25 in the subset studies was found. There was no significant factor between age and gender. Teeth heights at age 20 and 40 were significantly greater than age 11. At age 40 heights were significantly greater than age 20. Teeth continue to erupt until a patient's forties.

In comparing this study with previous studies I would like to focus on the three studies that were presented in the similar studies section of the literature review. Comparisons will be made between Volchansky and Cleaton-Jones' studies from 1976 and 1979. Then I will compare this study with Morrow's study of 2000.

Volchansky and Cleaton-Jones' cross-sectional study from 1976 used two hundred and thirty-seven pre-treatment orthodontic study models of male and female Caucasian children between ages 6 and 16. Clinical crowns of all the permanent teeth that had erupted were measured. Incisor teeth were measured from the deepest curvature of the labial gingival margin to the middle of the incisal edge. Our study used sixty-four subjects ages 8-18, 20 and 40. Four teeth were measured in this study. Both studies used the same measurement points. The sample was much larger in their study; however this study was able to measure more timepoints with a much older final measurement.

The results differed greatly between the two studies. Volchansky and Cleaton-Jones reported that 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. Our study found that clinical crown height continued to increase through patients' forties.

Our study was able to address their statement: "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." The longitudinal subset of our sample provided the ultimate proof of changing clinical crown height with age by producing results showing increased crown height until a patient's final measurements in their forties. However, our sample size was much smaller in comparison to their two hundred and thirty-seven models.

The longitudinal study published by Volchansky and Cleaton-Jones in 1979 has different materials and methods than the present study. Their results and conclusion are more comparable to the results of this study. 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. 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. The use of a photographic technique is different than all other studies looking at gingival heights. Both studies used the same measurement points. Our sample was larger than their study and this study was able to measure more timepoints with a much older final measurement.

They reported 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. As with their study, we report that there is continual passive eruption of teeth beyond twenty years of age. In our study maxillary central incisors showed significant effects for time through age forty.

They had a slightly different position from their first study by 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.” Our study agrees with this statement and would add, “Eruption has not ceased after 40 years of age, further studies are needed to determine whether passive eruption or functional active eruption is taking place.”

Finally, in comparing our study with Morrow et al. more similarities were found. They used four hundred and fifty-six sets of study models. 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 14-15 years old, 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. Morrow et al used a significantly larger number of subjects than our study. We were able to use ten more timepoints, with a much older final measurement.

Morrow et al. showed a significant age effect on crown length for all teeth. 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 showed increases in clinical crown length between each timepoint. Our results agree with their results. A significant gender effect was found for the maxillary right central incisor, with no gender effect for the mandibular central incisors. Our comparisons also showed there was an increase in clinical crown height between each timepoint, continuing until forty years of age.

Our study agrees and disagrees with their statement, “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.” Our data also does not show whether or not gingival levels are stable at age 18. We also report that we cannot determine whether gingival levels are stable at 40 years of age. Our data does not agree with the statement that “females’ eruption is essentially complete by age 18-19 years.” Once again our data shows continued eruption to age 40.

We have addressed a couple of the key missing elements of the previous studies. Those missing elements in review were age of final measurement and a longitudinal sample. A cross-sectional study by Volchansky and Cleaton-Jones (1976) used measurements which were concluded at 16 years old. Morrow et al. completed a longitudinal study with final measurements at 19 years. A three year longitudinal study by Volchansky and Cleaton-Jones (1979) started with patients at age 18 and finished at age 21.

The sample used for this study addressed the age requirement by ensuring that each subject had a measurement during their twenties. Forty-four percent of subjects had a final measurement in their forties. The longitudinal element was satisfied by the subset analysis using these before mentioned forty-four percent and measuring three timepoints for all subjects at ages 11, 20’s and 40’s.

This study is not without limitations. The sample size of this study was on the smaller size of comparable studies. Also the number of missing measurements due to fractured models, undetectable gingival measurement locations, and tooth restorations prevented a longitudinal study for the complete sample. There were also a number of missing models from the complete sample thus making measurements for each subject at each timepoint impossible.

Clinically the results of this study will allow orthodontist to recognize that teeth continue to erupt into adulthood. When looking at gingival relationships and clinical crown heights it is important to use the results of this study in finishing cases. Display of clinical crowns will continue after treatment.

There are a couple of questions that continue to be unanswered following this study. Is continued passive eruption or is functional active eruption the reason for increased crown length over time? Also is bone recession and therefore passive eruption the cause of increased crown length? We have determined that eruption continues now we must determine the cause of it. Future studies to address this question might add a radiographic component to the study. If periapical radiographs could be used to measure the anatomic crown height and the bone to cementoenamel junction distance, they can be compared to the clinical crown height on the study models. This would allow the researcher to determine whether the increased clinical crown was due to active eruption or passive eruption or even bone recession.

CONCLUSIONS

The purpose of this study was to determine the eruption patterns of central incisors from the first occlusal contacts to adulthood. This study compared the eruption of maxillary and mandibular central incisors. Statistical analysis determined whether crown length differences are significantly different with time.

We hoped by using a final measurement during a subjects' adulthood we can better estimate final eruption times and measurements. Achieving experimental purpose was done by measuring the teeth over timepoints to track incisal eruption through years of maturity into adulthood. The following conclusions can be made from this study:

- Differences between male and female mean crown heights were only present on maxillary incisors at early ages. Tooth 8 at ages 8 to 12 and for tooth 9 at ages 10 to 11. All other ages and all other teeth showed no gender differences.
- Eruption rates differ for males and female for tooth 8 only. Teeth 9, 24, 25 all showed no differences in their rate of increasing crown height over time.
- A significant age effect for teeth 8 and 9 and also teeth 24 and 25 in the subset studies was found. There was no significant factor between age and gender. Teeth heights at age 20 and 40 were significantly greater than age 11. At age 40 heights were significantly greater than age 20. Teeth continue to erupt unto a patient's forties.

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