5-2008

Maxillary Incisor Crown Form and Crowding in Adolescent Orthodontic Patients

Kortne King Frederick
University of Tennessee Health Science Center

Maxillary Incisor Crown Form and Crowding in Adolescent Orthodontic Patients

Abstract

Dental crowding occurs when the mesiodistal tooth crown widths exceed the space available in the dental arch for proper alignment. Previous research dealing with this common orthodontic problem has measured mesiodistal (MD) tooth widths or *clinical* tooth height-to-width ratios from dental casts. The present study used full mouth periapical series of dental radiographs, which provided an opportunity to study *anatomical* crown form of the maxillary incisors, as measured from the cementoenamel junction (CEJ), in relation to crowding. The aim of this study was to evaluate the statistical association between maxillary incisor crown form and the extent of crowding in adolescent boys and girls who sought comprehensive orthodontic treatment. A recent suggestion is that incisor crown form (in contrast to size itself) affects the risk of anterior crowding. The sample consisted of 60 males and 91 females, with a mean age of 13.7 years and fully erupted maxillary central and lateral incisors. Periapical radiographs of the maxillary central (I1) and lateral (I2) incisors were scanned and digitized, and a computer program was used to measure linear dimensions and shape ratios for one maxillary central and one maxillary lateral incisor from each subject. Two complementary space analyses, Merrifield's anterior space analysis (TSASD) and Little's irregularity index, were performed on the dental casts to quantify crowding. In the present study, the average maxillary *central* incisor of males was an isometrically enlarged version of females. The average maxillary *lateral* incisor of females had a sexually dimorphic crown form characterized by a significantly smaller MD measurement at the level of the CEJ, which translated into more flared lateral incisor crowns. Analyzing the results by Angle classification, the maxillary lateral incisors in Class II division 2 subjects had a distinctive crown form characterized by shorter and narrower crowns. Overall, the maximum mesiodistal tooth width was the single significant predictor of TSASD and of incisor irregularity. The exception was the high predictive value of the width measurement at the level of the CEJ of the lateral incisor for predicting the irregularity index. Based on univariate and multivariate analyses, crown *size* of the maxillary incisors, rather than crown *form*, was most predictive of TSASD and of incisor irregularity. We found no suggestion that shape of the crowns were a governing factor of the predisposition to crowding. Larger teeth require more arch space to be well aligned, and in the absence of additional arch space, individuals with larger teeth display greater TSASD and incisor irregularity.

Document Type

Thesis

Degree Name

Master of Dental Science (MDS)

Program

Orthodontics

Research Advisor

Edward F. Harris, Ph.D.

Keywords

maxillary incisors, crown form, crowding

Subject Categories

Dentistry | Medicine and Health Sciences | Orthodontics and Orthodontology

MAXILLARY INCISOR CROWN FORM AND CROWDING IN ADOLESCENT ORTHODONTIC PATIENTS

A Thesis
Presented for
The Graduate Studies Council
The University of Tennessee
Health Science Center

In Partial Fulfillment
Of the Requirements for the Degree
Master of Dental Science
From The University of Tennessee

By
Kortne King Frederick
May 2008

DEDICATION

This thesis is dedicated to my parents, Dr. John Frederick and Valerie Frederick, who made the long educational journey toward a career in dentistry and further specialization in orthodontics exponentially more comfortable than I could have afforded myself. This thesis is also dedicated to my family: my sisters Dr. Kendra Frederick and Dennie Frederick, my brother, Gregory Frederick, my nieces, Jaana Jack and Riley "Bean," and finally, the neon, Penelope.

ACKNOWLEDGEMENTS

I would like to thank my thesis committee for their input and direction during my enrollment in the postdoctoral graduate program. Dr. Edward Harris, my committee chairman and research advisor, guided and instructed me throughout the research project. I would like to thank Dr. Russell Wicks and Dr. Richard Williams for attending meetings, providing feedback and making suggestions for improvement.

ABSTRACT

Dental crowding occurs when the mesiodistal tooth crown widths exceed the space available in the dental arch for proper alignment. Previous research dealing with this common orthodontic problem has measured mesiodistal (MD) tooth widths or *clinical* tooth height-to-width ratios from dental casts. The present study used full mouth periapical series of dental radiographs, which provided an opportunity to study *anatomical* crown form of the maxillary incisors, as measured from the cementoenamel junction (CEJ), in relation to crowding. The aim of this study was to evaluate the statistical association between maxillary incisor crown form and the extent of crowding in adolescent boys and girls who sought comprehensive orthodontic treatment. A recent suggestion is that incisor crown form (in contrast to size itself) affects the risk of anterior crowding. The sample consisted of 60 males and 91 females, with a mean age of 13.7 years and fully erupted maxillary central and lateral incisors. Periapical radiographs of the maxillary central (I1) and lateral (I2) incisors were scanned and digitized, and a computer program was used to measure linear dimensions and shape ratios for one maxillary central and one maxillary lateral incisor from each subject. Two complementary space analyses, Merrifield's anterior space analysis (TSASD) and Little's irregularity index, were performed on the dental casts to quantify crowding. In the present study, the average maxillary *central* incisor of males was an isometrically enlarged version of females. The average maxillary *lateral* incisor of females had a sexually dimorphic crown form characterized by a significantly smaller MD measurement at the level of the CEJ, which translated into more flared lateral incisor crowns. Analyzing the results by Angle classification, the maxillary lateral incisors in Class II division 2 subjects had a distinctive crown form characterized by shorter and narrower crowns. Overall, the maximum mesiodistal tooth width was the single significant predictor of TSASD and of incisor irregularity. The exception was the high predictive value of the width measurement at the level of the CEJ of the lateral incisor for predicting the irregularity index. Based on univariate and multivariate analyses, crown *size* of the maxillary incisors, rather than crown *form*, was most predictive of TSASD and of incisor irregularity. We found no suggestion that shape of the crowns were a governing factor of the predisposition to crowding. Larger teeth require more arch space to be well aligned, and in the absence of additional arch space, individuals with larger teeth display greater TSASD and incisor irregularity.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Anterior dental crowding is one of the most obvious and most common characteristics of malocclusion (Little 1975). Nearly 78% of the United States population has some degree of anterior dental crowding (Buschang and Shulman 2003). When judging the esthetics of a person's smile, the most easily recognized aspect of malocclusion typically is crowding in the anterior segment. Anterior crowding (incisor irregularity) is an orthodontic condition that the public considers to be a significant esthetic problem (*e.g.*, Shaw *et al*. 2007; Stenvik *et al*. 1997; Brook and Shaw 1989; Jenny 1975).

Size and shape of tooth crowns are morphogenetically pre-determined during embryogenesis by expression of growth factors from enamel knots (Smid *et al*. 2006). Growth hormone (GH) influences both tooth crown and root development prior to dentinogenesis as well as during appositional growth of dentin (Smid *et al*. 2006), and growth hormone receptors have been reported to be present on both odontoblasts and ameloblasts (Young 1995). Sexual dimorphism in tooth crown size has been reported in most human populations, with the average crown diameters of males being significantly larger than females. In a study of human twins, increased tooth crown size was found in females with twin brothers, most likely due to in utero hormonal diffusion (Dempsey *et al*. 1999).

The etiology of malocclusion is generally termed multifactorial (*e.g.*, Mossey 1999; Proffit 2000; Graber 2005) involving both genetic and environmental components (Hartsfield 2005). Some environmental factors that may affect the development of a malocclusion are airway obstruction, tongue posture, muscle tonicity, head posture, and oral habits such as digit sucking and tongue thrusting, variation in size and position of the bony bases, and variation in tooth size and shape (Proffit 2000; Hartsfield 2005).

Incisor crown form may also be a factor contributing to dental crowding. There is appreciable variation in incisor crown form. Variation in tooth dimensions, taper, contact size, and contact location may all contribute to differences in incisor alignment. According to House and Loop (Engelmeier 1996; Ibrahimagić *et al*. 2001) there are three typal forms of incisors (square, tapering, and ovoid), along with six combination forms (square-tapering, reverse-tapering, ovoid-square, ovoid-tapering, ovoid-reverse-tapering, and square-reverse tapering). House and Loop based their classification on the facial outline of crowns as well as their mesiodistal (MD) and gingivo-incisal contours

(Engelmeier 1996). Shape of an incisor crown influences the size and location of its contact points. Intuitively, a small, incisally positioned contact point is more likely to slip and produce incisor irregularity than a broad contact.

Research has documented a relationship between clinical crown width, arch length and incisor crowding. However, none of the studies have evaluated incisor crowding as it relates to the anatomical crown form. Rhee and Nahm (2000) looked at clinical crown form, described as the taper from the cervical fourth of the clinical crown to the incisal portion of the tooth, in relation to crowding. The present study had the opportunity to measure anatomical crown form from pretreatment periapical radiographs for the maxillary central (I1) and lateral (I2) incisors. Periapical radiographs allowed for measurements to be made at the cementoenamel junction (CEJ), as opposed to the measurement between dental papilla on orthodontic casts at a set distance from the cervical gingival margin (Rhee and Nahm 2000). The anatomical crown measurements from the pretreatment periapical radiographs were compared to measurements of incisor irregularity and tooth-size arch-size discrepancy (TSASD) made from pretreatment orthodontic casts. The objective of the present study was to evaluate statistical associations between maxillary incisor crown form and the extent of incisor irregularity in adolescent boys and girls who sought comprehensive orthodontic treatment.

CHAPTER II

REVIEW OF THE LITERATURE

Incidence of Incisor Irregularity

The majority of American youths develop some degree of dental crowding. Data from the Third National Health and Nutrition Examination Survey (1988-1994) estimated that only 22% of the United States population had no mandibular incisor irregularity (Buschang and Shulman 2003). This implies that 78% exhibited mandibular incisor crowding, ranging from mild to severe.

Esthetics

Dental esthetics affect a person's quality of life (Klages *et al*. 2004). Tedesco *et al*. (1983) found that when photographs were judged by dental professionals and by lay persons, children seeking orthodontic treatment were perceived as significantly less attractive than children not needing orthodontic correction. Lay persons rated children seeking orthodontic treatment as significantly less attractive than dental practitioners rated the same children.

Dentofacial attractiveness is important to a person's psychosocial well being. People with properly aligned teeth are judged to be more socially attractive over many personal characteristics than those with malocclusions (Anderson *et al*. 2005). During interpersonal interactions, the eyes usually scan another person's eyes first, then the mouth, spending little time on other facial features (Goldstein 1969). When considering features that are most influential to pleasing facial esthetics, the appearance of one's smile ranked second only to the eyes (Goldstein 1969). Anterior dental crowding is one of the most obvious characteristics of a dental malocclusion, and it is obvious to patients, parents, and the public, as well as to dental professionals (Little 1975; Destang and Kerr 2003).

Normal Incisor Crown Form

There is a wide range of incisor form, and several classification systems have been constructed. Most classification systems were devised to describe and categorize crown shapes for artificial teeth serving as dental replacements. According to a review article by Ibrahimagić *et al*. (2001), the oldest theory for the selection of anterior artificial teeth is the temperamental theory. The temperamental theory was not based upon scientific facts (as defined now), but rather on the 5th century B.C. belief of Hippocrates, in which each person can be allocated into one of four human temperaments—neurotic, sanguinic, biliar, and asthenic—and tooth shape was selected based upon the person's temperament.

According to Ibrahimagić *et al*. (2001) the temperamental theory was replaced by the geometrical theory of Leon Williams (1914a), which connects the shape of the tooth with the shape of the face. At the First District Dental Society meeting in December of 1913, Williams' aim was to destroy previous beliefs in temperamental forms of teeth (nervous, bilious, and sanguineous), stating that there was no scientific basis for selection. Williams performed an anthropometric study on more than 1,000 skulls at the University of the Royal College of Georgia. Williams did not find racially distinct forms of teeth (1914a). Rather, he described three distinct typal forms of teeth, regardless of race or Angle molar classification (1914b). Figure 1 illustrates the three Classes of teeth that Williams devised. Class I is characterized by the parallel or nearly parallel lines which represent the proximal surfaces for half or more than half of the length from the incisal edge (Figure 2). In Class II, the lines following the proximal surfaces converge so markedly that they often meet at a point near the root apex (Figure 3). The Class III crown form is characterized by a delicate double-curved line on its distal proximal surface and sometimes, though less frequently, on the mesial surface with all surfaces of this type being more rounded and graceful than the other two types (Figure 4) (Williams 1914b). The three Classes of tooth form described by Williams closely relate to the typal forms used today (Class I relates to square, Class II relates to tapering and Class III relates to ovoid).

In addition to the three forms of teeth described by Williams (1914b), he related the three Classes of teeth to four chief types of facial contours (Figure 5). The square face with parallel sides correlates well with his Class I tooth form. If the square face converges slightly at the forehead and the chin, then the teeth should also have lines that converge slightly toward the neck of the tooth (1914c). The oval face is a result of slightly rounding the angles of the square face and modifying the square tooth in this manner produces an oval tooth. The ovoid face is characterized by roundness, or heaviness in the lower part, which correlates with the special feature of the Class III tooth. The tapering face has a wider range of variation than the other types, the proximal surfaces of the tooth run in opposition to the proximal lines of the face. As the face tapers toward the chin, the central incisor tapers toward the neck of the tooth (Williams 1914c).

Like Williams, House and Loop (Engelmeier 1996) classified incisor shape based on the facial outline of teeth focusing on the mesiodistal and the gingivo-incisal crown contours (Engelmeier 1996). The classification system of House

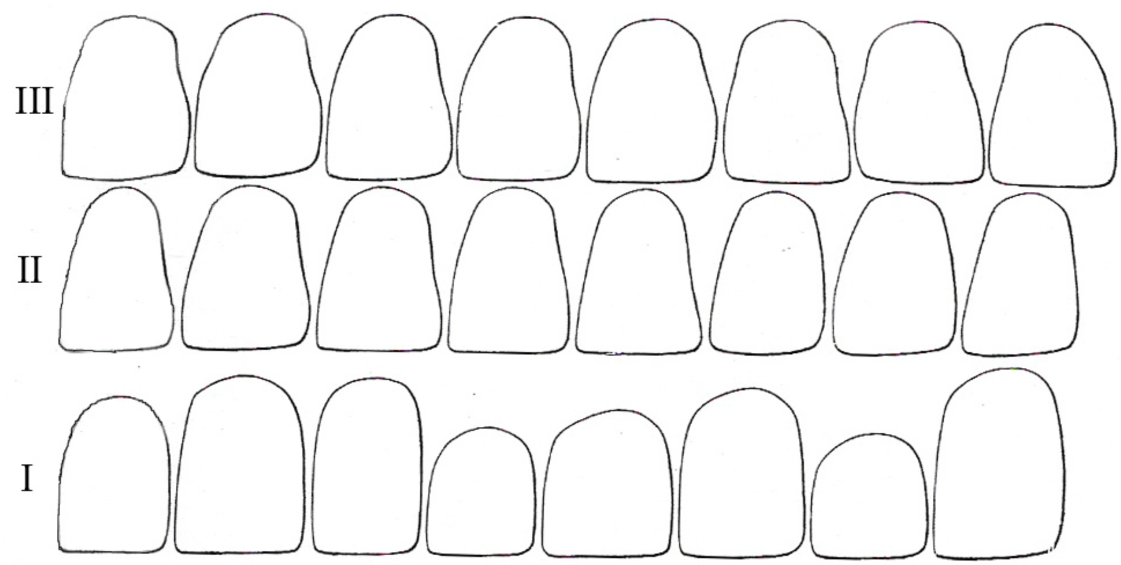


Figure 1. Illustration through outline drawings of the maxillary left central incisors of specimens of natural teeth, the three primary types of teeth as described by Leon Williams: Class III, Class II and Class I.

Adapted with permission from Williams JL. The tempermental selection of artificial teeth, a fallacy. Dent Digest 1914b;20:125-34.

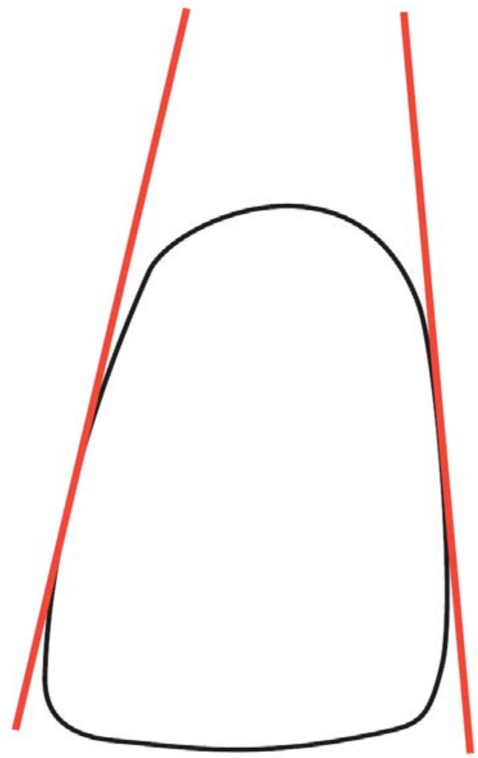


Figure 2: Illustration of the Class II crown form, as described by Leon Williams, of an upper left central incisor in which the lines following the proximal surfaces converge so markedly that they often meet at a point near the root apex.

Based on concepts from Williams JL. The tempermental selection of artificial teeth, a fallacy. Dent Digest 1914b;20:125-34.

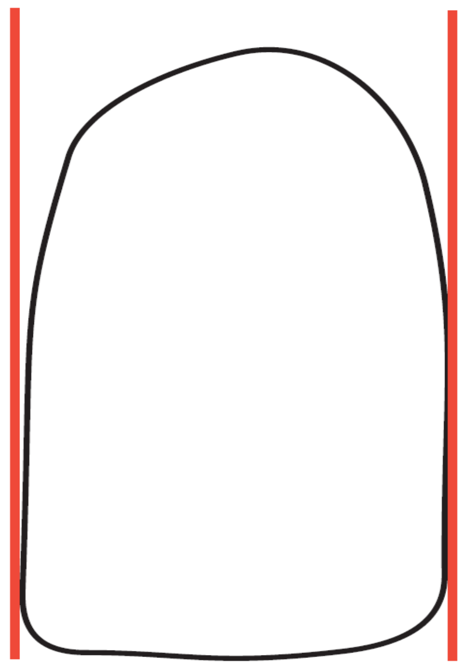


Figure 3. Illustration of the Class I crown form, as described by Leon Williams, of an upper left central incisor, characterized by the parallel or nearly parallel lines, which represent the proximal surfaces for at least half of the length from the incisal edge.

Based on concepts from Williams JL. The tempermental selection of artificial teeth, a fallacy. Dent Digest 1914b;20:125-34.

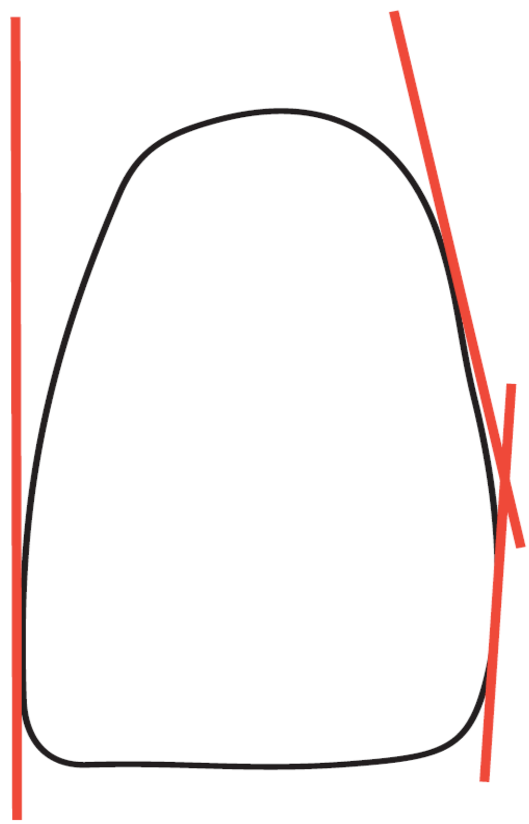


Figure 4. Illustration of the Class III crown form, as described by Leon Williams, which is characterized by a delicate double-curved line on its distal proximal surface and sometimes, though less frequently, on the mesial surface with all surfaces of this type being more rounded and graceful than the other two types.

Based on concepts from Williams JL. The tempermental selection of artificial teeth, a fallacy. Dent Digest 1914b;20:125-34.

Figure 5. This diagram shows the four chief types of faces, as described by Leon Williams. Williams added the ovoid face to the three basic forms, square, tapering, and oval, stating that the ovoid face is one that has a round and rather heavy lower face with a dome shaped forehead and a greater width below the eyes than above.

Adapted with permission from Williams JL. The tempermental selection of artificial teeth, a fallacy. Dent Digest 1914c;20:243-59.

and Loop (Figure 6) is based on three typal forms of incisors (square, tapering, and ovoid), along with six combination forms (square-tapering, reverse-tapering, ovoid-square, ovoid-tapering, ovoid-reverse-tapering, and square-reverse tapering). Incisor crown shape selection for an edentulous space using the modified Williams' classification system of House and Loop is done by relating the outline of the incisor crown to the outline of a person's face (Figure 6).

The makers of DENTSPLY Trubyte® IPN® denture teeth suggest that there are four basic face forms (square, square tapering, tapering, and ovoid) and for each there is a corresponding basic anterior tooth shape (Figure 7). Trubyte® IPN® further classifies the four face forms into seven categories (Figure 8) for finer patient facial definition in selection of anterior crown shape (square, square tapering, square ovoid, tapering, tapering ovoid, ovoid, and square tapering ovoid). DENTSPLY Trubyte® IPN®, as well as other dental supply companies, created indicators for determination of tooth form. The indicator is transparent plastic with a medial line and holes for the eyes and nose. By comparing angles between a patient's face and vertical lines on the indicator, the patient's face type can be determined and a corresponding tooth form can be selected.

Despite the numerous variations of tooth selection theories developed over the past century, there is not one that is completely reliable and accurate (Ibrahimagić *et al.* 2001). Though the facial outline suggestions of Williams and House and Loop are commonly used and have been adapted by dental supply companies, several studies have tried to associate central incisor shape with facial outline, but with little success.

Face Shape and Incisor Crown Form

The shape of a patient's face commonly is used to aid selection of maxillary central incisor crown shape (Williams 1914c; Engelmeier 1996; Ibrahimagić *et al*. 2001). Lindemann, Knauer and Pfeiffer (2004) assessed whether a significant relationship existed between maxillary central incisor shape and face shape. Models of the central incisors and facial photographs were scanned and digitized. The facial outline of the maxillary central incisor was inverted and superimposed over the facial outline. The similarity of contour shapes was determined using the Hausdorff distance, which measures how far two compact non-empty subsets of a metric space are from each other (Figure 9). The face shape outlines achieved by tracing to the level of the eyebrows were more closely related to maxillary central incisor shape than face shapes outlines traced to the hairline, and the maxillary central incisors of women had a smaller Hausdorff distance than men, but there was no statistically significant

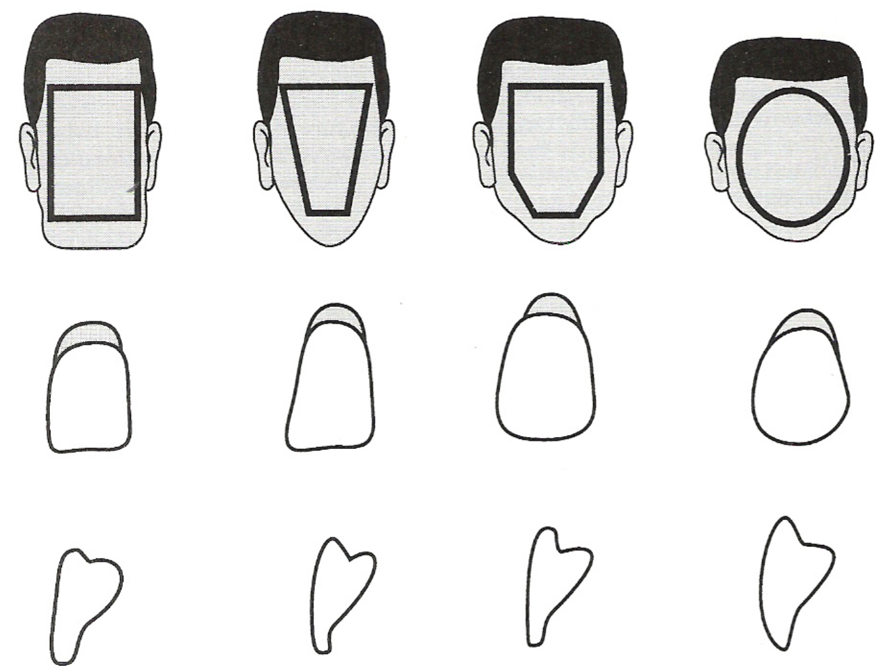


Figure 6. Illustration of House and Loop's classification of maxillary central incisor shape and the relation to facial forms described by Leon Williams. Facial forms and corresponding incisor forms from left to right: square, tapering, square tapering, and ovoid.

Adapted with permission from Engelmeier RL, ed. Complete dentures. Dent Clin No Am 40;1996:3,74.

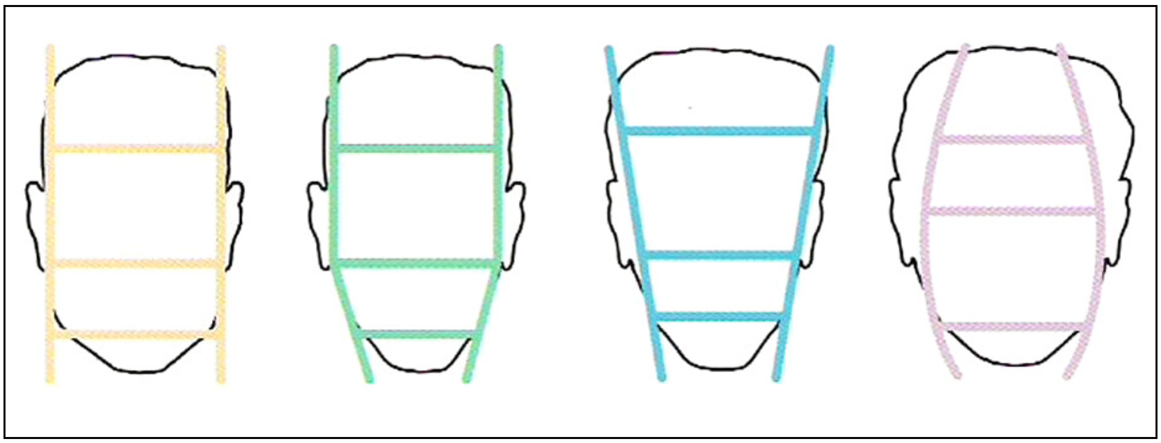


Figure 7. Four basic face form classifications as shown in the DENTSPLY Trubyte® IPN® Denture tooth anterior mould system: square, square tapering, tapering, and ovoid.

Adapted with permission from the DENTSPLY Trubyte® IPN® Mould Chart (Item 4343-A). Denstply International. York, PA.

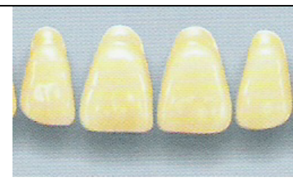
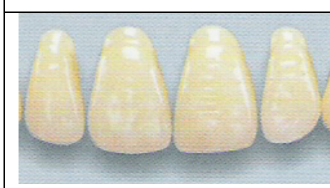
 (A) Ovoid	 (B) Square	 (C) Tapering
 (D) Tapering ovoid	 (E) Square ovoid	 (F) Square tapering
 (G) Square tapering ovoid		

Figure 8. Examples of House and Loop's (1996) classifications of incisor crown form from DENTSPLY Trubyte® IPN® denture tooth mould guide: (A) ovoid, (B) square, (C) tapering, (D) tapering ovoid, (E) square ovoid, (F) square tapering, and (G) square tapering ovoid.

Adapted with permission from the DENTSPLY Trubyte® IPN® Mould Chart (Item 4343-A). Denstply International. York, PA.

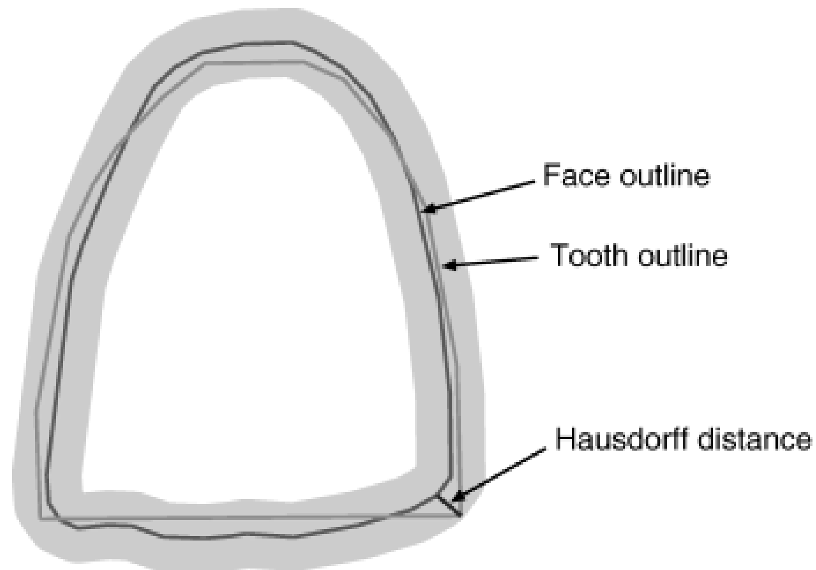


Figure 9. Illustration of the Hausdorff distance between the face (inverted and measured to the superior eyebrow line) and the tooth outlines of a maxillary central incisor. The similarity of contour shapes was determined using the Hausdorff distance, which measures how far two compact non-empty subsets of a metric space are from each other. The closer the Hausdorff distance is to zero, the more similar the two shapes are.

Adapted with permission from Lindemann HB, Knauer C, Pfeiffer P. Morphometric relationships between tooth and face shapes. J Oral Rehabil 2004;31:972-8.

association between face shape and maxillary central incisor shape (Lindemann, Knauer and Pfeiffer 2004).

An article by Wolfart *et al*. (2004) also challenged Leon Williams' (1914c) "law of harmony" concept that suggested an association existed between upside-down facial shape and the shape of the upper central incisor. This article also challenged the "dentogenic" theory proposed by Frush and Fisher (1956), who believed that gender was related to face or tooth shape. This study tested the null hypothesis that there is no gender dependent correlation between inverted face shape and central incisor crown shape. The secondary hypothesis was that dental practitioners and postgraduate students are not able to identify a subject's gender from photographs of anterior teeth without lips (Wolfart *et al*. 2004). Wolfart *et al*. (2004) took closed lip facial photographs and photographs of the anterior teeth without lips of 204 Caucasian dental students. Inverted facial outlines and dental outlines of the upper right central incisor were classified as either tapered, ovoid, or square and the facial form was compared to the incisor form for each subject. No significant correlation was found between tooth form and gender. There was a weak but statistically significant correlation between face shape and gender, tapered faces were more common in females (34%) than males (21%), and square faces were more common in males (38%) than females (26%). There was no statistically significant correlation between tooth shape and face shape, in only 35% of the cases tooth shape and face shape conformed. The participants were asked to determine the gender of each subject on the basis of tooth form from 204 black and white photographs. The accuracy of the decisions that the participants made predicting gender based solely on photographs of the anterior dentition was 55 (sd = 4%), which is similar to the rate that one would expect if the participants answered at random. This study concluded that neither the inverted facial shape nor the gender of a patient should be used as guidelines for anterior tooth selection, rather the opinion and desire of the patient should take precedence in anterior tooth selection (Wolfart *et al*. 2004).

Ibrahimagić *et al*. (2001b) re-examined Leon Williams' geometric theory to find the degree of correspondence between face and tooth form. The authors examined 2000 individuals between the age of 17 and 24 years. Three horizontal distances were measured on each face: temporal width (Ft-Ft), zygomatic width (Zyg-Zyg), and gonial width (Go-Go) as well as the length of the face (Tr-Gn). Three horizontal distances were measured on each maxillary central incisor: cervical width (CW), contact point width (CPW), and incisal width (IW) as well as the length of the central incisor. From these measurements, it was found that more than 98% of the examined population revealed three forms of the face—oval (83.3%), square-tapered (9.2%), and tapered (7%)—and three forms of the upper central incisor—tapered-square (53%), oval (30%), and tapered (16%)—similar to Leon Williams' postulation. However, the outline of the face matched the inverted outline of the central incisor in only 30% of the subjects. The most common combination in this study was the oval face shape with the tapered-square tooth form; this combination was found in 45% of the examined population. Additional findings included men having significantly larger dimensions for all face and tooth dimensions and left and right central incisors having identical dimensions and forms (Ibrahimagić *et al*. 2001b). Although still a commonly used method for selection of anterior tooth form, the postulation of Leon Williams (1914) that tooth shape related to a particular face form does not appear to hold true.

Methods of Measuring Incisor Crowding

One of the first steps in diagnosis and treatment planning of an orthodontic case is an assessment of the amount of spacing or crowding among the anterior teeth. The amount of anterior dental crowding often tips the balance for or against premolar extraction (Harris, Vaden and Williams 1987). Describing the degree of dental crowding or irregularity categorically as mild, moderate, or severe can be subjective and allows for a great deal of variation among dental professionals. In order to decrease subjectivity, various numerical indices have been developed to describe incisor irregularity quantitatively.

Little's Incisor Irregularity Index

Little (1975) developed an index of incisor irregularity that quantifies the degree of incisor crowding in numerical rather than qualitative terms. Little developed a scoring method that involved measuring the linear displacement between each of the anatomic contact points of the mandibular incisors from that of the adjacent anatomic contact point. The sum (from mesial of left canine to mesial of right canine) is the degree of anterior irregularity in millimeters (Figure 10). The larger the sum, the more severe the irregularity. One weakness of Little's incisor irregularity index is that it does not take into account instances of incisor irregularity in the vertical dimension or irregularities due to axial rotations when the contacts remain approximated.

Merrifield's Anterior Space Analysis

The Merrifield anterior space analysis (Graber 2005) measures tooth-arch discrepancy (TSASD) by first summing the mesiodistal widths of the six anterior teeth, canine to canine to determine the space required. Next, the space available is measured by assessing the millimetric assessment of the amount of bony

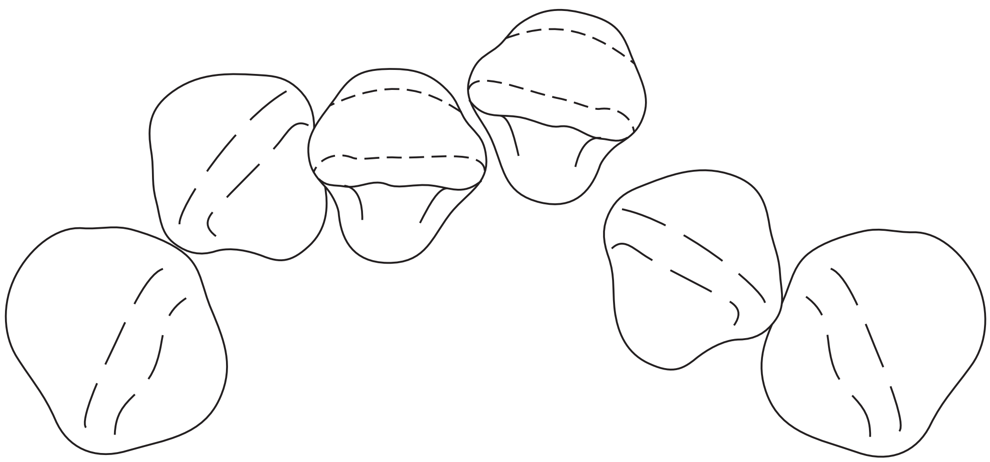


Figure 10. Displacement of proximal contact points as measured for Little's incisor irregularity index. The total irregularity is the sum of the five displacement measurements in millimeters.

support in the anterior segment, which requires clinical experience to determine whether the incisors need to be moved bodily during incisor alignment. The space available can be determined in a number of ways: (1) a malleable wire can be shaped to mimic the anticipated posttreatment incisal edge positions of the anterior teeth then straightened and its length measured; (2) a photocopy can be made of the occlusal aspect of the cast and measured with a planimeter; or (3) a pliable ruler can be held in the desired arch form to measure the space available. The required space is then subtracted from the available space to determine the discrepancy. A negative number signifies crowding and extraction may be necessary to align the dentition (Harris, Vaden and Williams 1987).

Incisor Crown Form

Size and shape of the maxillary anterior teeth are important in achieving pleasing dental and facial esthetics (Hasanreisoglu *et al*. 2005). There is an esthetically acceptable range of incisor crown shapes. Dentists need to select incisor shapes for a variety of reasons. In prosthodontics, crown form is an important esthetic consideration when selecting anterior denture teeth or replacing any other missing tooth. Denture tooth manufacturers, such as Trubyte®, have several incisor shapes to choose from, and some suppliers even have facial guides to associate a facial outline with a particular incisal form. In restorative dentistry, anterior dental restorations reshape and replace preexisting crown forms using crowns and veneers. In orthodontics, interproximal reduction and incisal enamelplasty are used to reshape teeth, because it is supposed that a flatter contact or a more rectangular incisal crown form is less likely to slip a contact and lead to crowding than a triangular or fan shaped incisor (Rhee and Nahm 2000).

A common assumption is that men should have incisor crowns that are more square and women should have more rounded crowns. Anderson *et al.* (2005) studied the contribution tooth shape has on the esthetics of the person's smile. Color photographs of the same female and male smiles were altered so that the only difference was in maxillary incisor or canine shape. The incisors were either square-round, square, or round, and the canines were either pointed, flat, or round (Figure 11). The photographs were judged by 120 restorative dentists, 113 orthodontists, and 120 lay people. Anderson *et al.* found that, for women, orthodontists preferred round and square-round incisors and restorative dentists preferred round incisors. Lay people did not have a discernible preference for incisor shape for women. For men, all three sets of judges preferred square-round incisors.

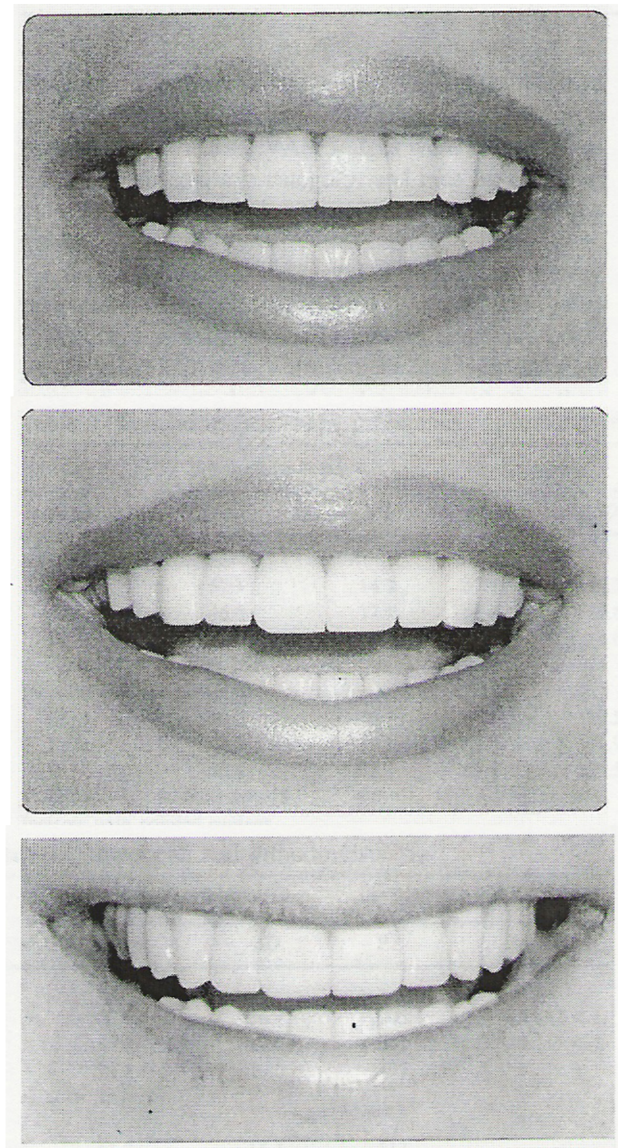


Figure 11. From top to bottom, the photos illustrate flat incisors with flat canines, square-round incisors with flat canines, and square-round incisors with pointed canines.

Adapted with permission from Anderson KM, Behrents RG, McKinney T, Buschang PH. Tooth shape preferences in an esthetic smile. Am J Orthod Dentofacial Orthop 2005;128:458-65.

In a study by Rhee and Nahm (2000), incisors were classified as square, ovoid, triangular, or a combination of two of the above (Figure 12). Rhee and Nahm hypothesized that the broader the contact, the more stable the position of the tooth and the less likely it would be to slip under pressure or tension. Triangular incisor forms have small anatomic contact areas and would have a less stable contact, which, they conjectured, would be reflected clinically as increased incisor irregularity. In their study measuring clinical crowns from dental casts, Rhee and Nahm found that patients with more incisor irregularity had greater maximum mesiodistal widths at the incisal-most aspect (IMD) relative to the maximum mesiodistal width at the cervical most measurement (CMD). In general, larger width ratios (IMD/CMD) were found in the crowded group (Figure 12). Crowding, measured as incisor irregularity, was more common in individuals with triangularly shaped incisors (*i.e.*, those with a larger IMD:CMD ratio). The coefficients of determination (r^2) between the incisor width ratio and the irregularity index were fairly high, ranging from 55% to 65%. This implies that the incisor width ratio is one feature of crowding and can be useful following orthodontic treatment during the retention phase and can be adjusted during orthodontic treatment by means of interproximal reduction to increase stability.

Interproximal Reduction

The size, shape and location of contact points can be altered during orthodontic treatment. The judicious reshaping of contacts, particularly in the mandible, can enhance postorthodontic retention by providing larger contact areas and lessening crown widths. The aim is to reduce the continued anterior crowding caused naturally by the anterior component of force of occlusion (Watson 1979; Boese 1980; Destang and Kerr 2003). The improved retention found by Boese (1980) following interproximal reduction may imply that if the alteration of crown form can improve stability, there may be certain crown forms that are more prone to irregularity prior to orthodontic treatment.

Crown Dimensions and Incisor Crowding

Peck and Peck (1972) stated that orthodontic diagnostic analyses using tooth size data had looked only at mesiodistal tooth widths to assess (1) prediction of unerupted teeth, (2) tooth-size arch-size discrepancy within an arch, or (3) tooth size harmony between arches. In their study, Peck and Peck (1972) looked at mandibular incisor crown shapes assessed as the ratio of mesiodistal width to faciolingual breadth (MD/FL) to determine a relationship between mandibular incisor shape and an absence of crowding (naturally well-

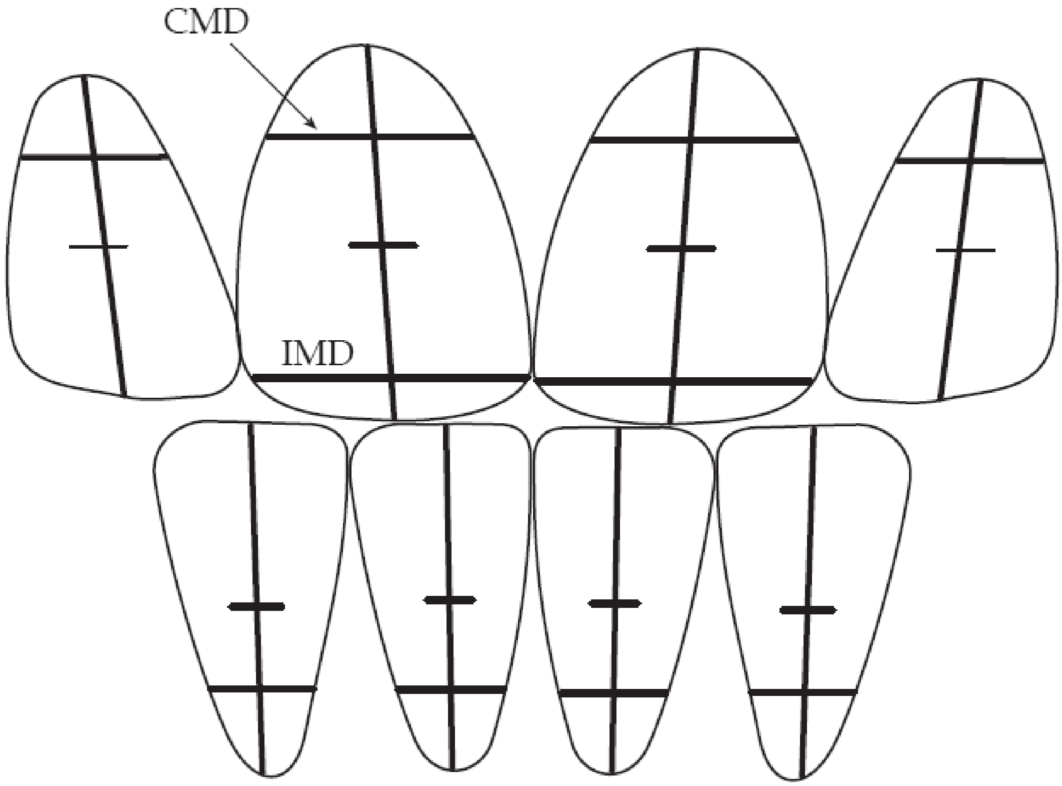


Figure 12. Diagram of measurements made by Rhee and Nahm (2000). CMD refers to cervical mesiodistal width. In their study the clinical crown was divided into fourths along the long axis and the mesiodistal width (CMD) was measured at the cervical portion of the clinical crown at a distance, one fourth of the labial crown length from the gingival margin. IMD refers to the maximum mesiodistal measurement at near the incisal edge. Measurements were taken from dental casts and therefore represent measurements of the clinical crown.

aligned incisors). Women (n = 45) were selected as having naturally occurring "perfect mandibular incisor alignment" and a second set of 70 subjects served as the control sample. These controls were of similar age and European stock, but not otherwise selected for. The unselected control subjects consequently had on average more incisor crowding than the subjects selected for perfect occlusion. Peck and Peck measured the maximum mesiodistal and faciolingual dimensions intraorally for the mandibular incisors and found that well-aligned mandibular incisors exhibited lower MD/FL ratios. The mean value of the MD/FL index showed a highly significant difference with a mean value of 88.4 and 90.4 for the group with perfectly aligned central and lateral incisors, respectively, versus mean indexes of 94.4 and 96.8 for the crowded central and lateral incisors. These comparisons suggest that well-aligned mandibular incisors do possess distinctive crown shapes. Patients with well-aligned incisors often had smaller MD widths, most likely because narrower incisors require less mandibular arch length. Additionally, narrower incisors mesiodistally, tend to have "flatter," less acute mesial and distal surfaces that are less susceptible mechanically to contact slippage that may account in part for the incisor shape—alignment relationship. When the MD/FL ratio exceeds 88 to 92 for a mandibular central incisor or 90 to 95 for a mandibular lateral incisor, Peck and Peck recommended reapproximation (IPR) to reduce the mesiodistal dimension and alter the ratio so that it is in a favorable range for postretention stability.

Smith *et al*. (1982) challenged the study by Peck and Peck (1972) for leaving at least two important questions unanswered. First, the study by Peck and Peck was based solely on crowding in untreated cases and reasons for pretreatment crowding may differ from those for posttreatment relapse. Secondly, Peck and Peck did not explain the biological significance for the labiolingual measurement, thus failing to explain why (interpret) their ratios were more useful than simply measuring mesiodistal tooth lengths. Smith *et al*. (1982) addressed the latter question by measuring lower incisors from 200 dental casts, 100 pretreatment casts from the University of Maryland Orthodontic Clinic and 100 casts from an untreated Hutterite population in Canada. In contrast to Peck and Peck, Smith *et al*. measured Little's irregularity index, and the mesiodistal and labiolingual tooth widths from dental casts, rather than making the measurements intraorally. Smith *et al*. found that males had slightly larger average tooth dimensions than females and that lower lateral incisors had higher MD/FL ratios than lower central incisors. When the two geographic groups were compared, the pretreatment casts of the orthodontic patients had higher MD/FL ratios than the Hutterite population; however, the orthodontic population also had greater mesiodistal lengths for the four mandibular incisors than the Hutterites by an average of 1.6 mm for males and 1.4 mm for females. In both samples, mesiodistal tooth length had the highest correlation with the crowding index, tooth shape (MD/FL) was slightly less correlated with crowding, and the correlation of labiolingual width with crowding was close to zero. After running multiple regression analyses for each population, mesiodistal length entered the equation first, indicating that it was more important that the shape ratio in predicting crowding. The results of this study indicated that there was virtually no relationship between labiolingual width and incisor irregularity, and that tooth shape ratios were related to crowding because they included the measurement of mesiodistal tooth width.

Bernabé and Flores-Mir (2006) noted that tooth size was not the only factor in dental crowding, but that one should also consider crown proportion. The authors felt that a multivariate approach (MANOVA) should be used to determine if the observed differences for tooth sizes or crown proportions between arches for different crowding degrees (moderate, mild, or none) were statistically significant. This study took measurements from 200 casts of Peruvian high school students having full permanent dentitions and no orthodontic treatment. Mesiodistal and buccolingual tooth diameters were taken for each tooth from first molar to first molar in both dental arches. The tooth-size arch-length discrepancy (TSALD) was calculated by subtracting the sum of the mesiodistal (MD) tooth widths from the arch perimeter. Those subjects with a discrepancy of at least -5.1 mm were considered to have moderate crowding (18% of maxillary arches and 17% of mandibular arches); those with a discrepancy between -0.1 mm and -5.0 mm were considered to have mild crowding (43% of maxillary arches and 41% of mandibular arches); and those with zero or positive discrepancy were considered to have no crowding (39% of maxillary arches and 42% of mandibular arches). When all upper mesiodistal tooth sizes were grouped together, the results of a MANOVA yielded a statistically significant average difference between moderate, mild and no crowding and the same was found when the mandibular MD tooth widths were summed, meaning that at least one tooth size varied among the groups. Each MD tooth size was then compared among groups through a one-way ANOVA, which showed statistical significance for all maxillary teeth. A one-way ANOVA was also applied to the MD tooth sizes of the mandibular teeth, and a statistically significant difference was found for all teeth except the lower lateral and canine. A MANOVA and one-way ANOVA for buccolingual tooth widths yielded no statistically significant difference. And, when looking at the ratio of MD/BL tooth widths, ANOVA showed statistically significant differences in upper second premolars, canines and central incisors and lower first premolars, canines and central incisors. In accordance with Peck and Peck (1972), the authors found larger MD/BL ratios in arches with moderate crowding as compared to mild crowding, and the lowest ratios in those arches without crowding. The authors conclude that malocclusions with moderate, mild, and no crowding tend to differ significantly in their mesiodistal tooth sizes and crown proportions, individually or combined, but do not differ significantly in their buccolingual tooth sizes.

Shah, Elcock and Brook (2003) took a different approach to investigating associations between the shape of mandibular incisors and anterior crowding by sectioning casts at the contact points and the occlusogingival midpoint. Study casts of untreated subjects were marked with pencil dots at the proximal contact points (CP) and at the midpoint (MP) of the mandibular incisors and horizontal lines were drawn on the casts to connect the mesial and distal points (Figure 13). The casts were sectioned first at the contact point level (CP) and scanned (Figure 14), then sectioned again at the midpoint level (MP) and scanned (Figure 15). Mandibular incisor crowding was quantified using Little's irregularity index and tooth size arch length discrepancy were measured using a digital caliper. Shah, Elcock and Brook (2003) found that no predictor of lower incisor crowding could be established from mandibular incisor crown shape in their study.

Dental crowding has also been studied by relating the sum of mesiodistal crown widths to arch dimensions (Howe *et al.* 1983). Howe *et al.* found no significant difference in tooth size, measured as the sum of mesiodistal crown widths, between crowded and non-crowded groups. However, the dental arch dimensions in the crowded group were found to be smaller than in the non-crowded group, so they concluded that tooth-size arch-size discrepancies are primarily the fault of inadequate bony development.

Poosti and Jalali (2007) stated that malocclusion is the result of either a skeletal or a dental discrepancy, but crowding is a consequence of a tooth-size arch-length discrepancy. The purpose of this study was to examine the extent to which tooth sizes or arch dimensions contributed to dental crowding. The study sample consisted of 60 pretreatment orthodontic casts. Thirty subjects, 15 male and 15 female, had straight profiles, normal overjet, normal overbite, and an Angle's Class I molar and canine relationship. The other 30 subjects, 15 male and 15 female, were also Class I, but had greater than 5 mm of crowding. From the casts, the following five measurements were made: largest mesiodistal tooth widths, arch perimeter, arch length, intercanine distance, and intermolar width. The authors found that, for both males and females, when the maximum mesiodistal tooth widths were summed, the crowded group presented larger tooth widths for both the maxilla and the mandible when compared to the uncrowded group. The greatest difference in tooth width was seen in the maxillary lateral incisors. Intercanine and intermolar widths were found to be greater in the maxillas of the uncrowded group. In this study the arch length and arch perimeter showed no significant difference between groups, however the uncrowded group had wider, not longer, maxillary dental arches than the crowded group. The authors concluded that tooth size (mesiodistal width) had the greatest contribution to crowding, and the maxillary arch width was the skeletal feature that exhibited the greatest difference between the crowded and uncrowded groups.

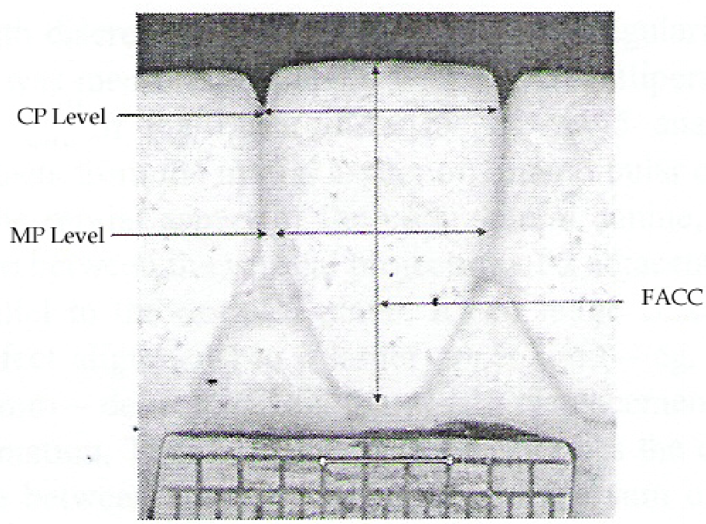


Figure 13. Labial view of lower central incisor showing lines at contact point (CP) and midpoint (MP) levels as well as the facial axis of the clinical crown (FACC).

Adapted with permission from Shah AA, Elcock C, Brook AH. Incisor crown shape and crowding. Am J Orthod Dentofacial Orthop 2003;123:562-7.

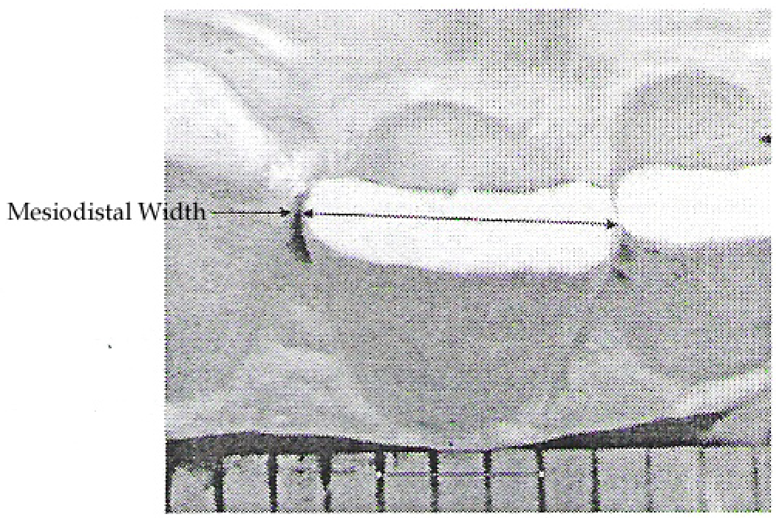


Figure 14. Measurement of mesiodistal (MD) width on lower central incisor sectioned at the contact point level.

Adapted with permission from Shah AA, Elcock C, Brook AH. Incisor crown shape and crowding. Am J Orthod Dentofacial Orthop 2003;123:562-7.

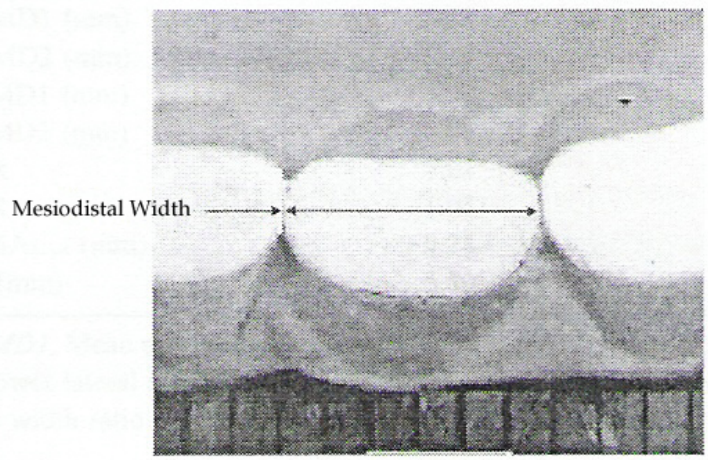


Figure 15. Measurement of mesiodistal (MD) width on lower central incisor sectioned at midpoint level.

Adapted with permission from Shah AA, Elcock C, Brook AH. Incisor crown shape and crowding. Am J Orthod Dentofacial Orthop 2003;123:562-7.

Fastlicht (1970) compared anterior crowding in untreated patients to patients that had been treated orthodontically several years previously to see if (1) orthodontic treatment had an influence through time on the crowding of incisors and (2) to clarify the causes of mandibular crowding. The sample studied consisted of 28 subjects that had Class II, division 1 malocclusions converted to normal occlusions and had records taken between 1.5 to 10 years postretention, the other 28 subjects did not receive any orthodontic treatment and were judged to have balanced upper dental arches with overjet within normal limits and were therefore assumed to have neutrocclusions. Cast measurements of the mesiodistal tooth widths of incisors, intercanine widths, overjet and overbite were recorded for each subject. With sexes pooled, Fastlicht found mesiodistal widths to be nearly the same between the treatment and untreated group, but larger mesiodistal widths were associated with increased crowding. Maxillary crowding was more frequent in females than in males, and there was more crowding in the untreated group when compared to the group that had received orthodontic treatment. Mandibular crowding however occurred more frequently in males than females, but again was present to a larger degree in the group that had not had orthodontic treatment. A smaller intercanine width was found in subjects with more crowding. Overbite was greater in the group that had received orthodontic treatment. The author notes that as overbite increases, mandibular crowding also increases, most likely due to the lower incisors hitting the cingulum of the upper incisors. There was no statistically significant difference in overjet between treated and untreated subjects, however overjet tended to be larger in males when compared to females.

Several other studies have looked for associations between mesiodistal crown widths and dental crowding. For example, Sterrett *et al.* (1999) measured mesiodistal crown widths in male and female orthodontic patients as well as clinical crown lengths (measured as the greatest distance from incisal edge to the most apical gingival margin) from dental casts. They obtained the width/length ratios for the maxillary sextant. The mean width/length ratio of the maxillary three anterior teeth was 0.81. The authors were not able to find a significant correlation was between any of the tooth dimensions measured in relation to subject height.

McCann and Burden (1996) wanted to relate crown size within a particular malocclusion, namely bimaxillary protrusion. The authors cited previous studies that average mesiodistal tooth diameters are larger in males than females and larger in blacks than whites. McCann and Burden speculated that the high frequency of bimaxillary protrusion seen in blacks, although also found in whites, may be associated with larger mesiodistal tooth widths, which contribute to the malocclusion. The study looked at children from Northern

Ireland. One group of 30 children consisted of 14 males and 16 females presenting with Class I bimaxillary protrusion (determined cephalometrically by an U1/L1 < 125º, Ul/SN > 115º, IMPA > 99º), and a control group of 30 children, 14 males and 16 females randomly selected with a variety of malocclusions, excluding bimaxillary protrusion. Maximum mesiodistal tooth measurements were taken from unsoaped dental casts. For every tooth type, the mean mesiodistal tooth diameters were larger in the bimaxillary protrusive subjects, and the sum of the overall dentitions (maxillary and mandibular) were larger by 5.7% in the bimaxillary protrusive cases compared to the controls. The authors acknowledged that the etiology of bimaxillary protrusion is multifactorial, and that environment, soft tissue, and skeletal factors likely play an important role, but that their study showed that tooth size (mesiodistal tooth width) might also play a part in the etiology of bimaxillary protrusion in that larger teeth may contribute to the proclination.

Gingival Tissue and Clinical Crown Form

The anatomical crown of the average maxillary central incisor as examined from the facial of extracted human teeth is on average 10 to 11 mm long, 8 to 9 mm wide at the contact areas, and the mesiodistal measurement where the root joins the crown will be on average 1.5 to 2.0 mm narrower than the measurement taken between contact points (Ash 1993). The anatomical crown of the average maxillary lateral incisor is about 2 mm narrower mesiodistally between contact points and 2 to 3 mm shorter incisocervically than the central incisor (Ash 1993).

The clinical crown typically differs from the anatomical crown. In most cases, the crown portion of the tooth is not covered by bone when it is fully erupted in the oral cavity. In young patients with a healthy periodontium, the interdental papilla fills the interdental spaces and covers part of the cervical third of the crown (Ash 1993). The gingival line follows the curvature, but not necessarily the level of the cervical line, also known as the cementoenamel junction (Figure 16). The crown as defined by the cervical line (CL) is considered the anatomical crown; the portion of the crown that is defined by the gingival line (GL) is the clinical crown (Ash 1993). In most patients with a healthy periodontium, the clinical crown displays a smaller surface area than the anatomical crown since a portion of the gingiva covers some of the anatomic crown.

The gingival sulcus varies from 0.5 to 3 mm with an average depth of 1.8 mm. When a tooth first becomes functional, the bottom of the sulcus is usually found on the cervical half of the anatomic crown; with age, the sulcus bottom

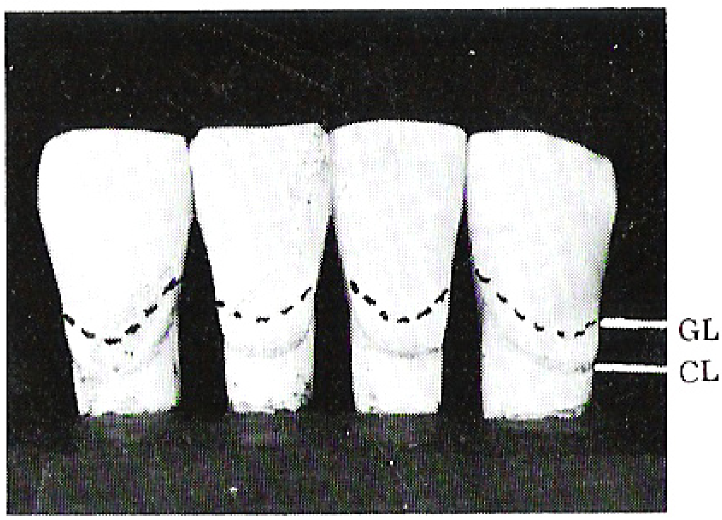


Figure 16. The crown as defined by the cervical line (CL) is considered the anatomical crown, the portion of the crown that is defined by the gingival line (GL) is the clinical crown (Ash 1993). In most patients with a healthy periodontium, the clinical crown displays a smaller surface area than the anatomical crown since a portion of the gingiva covers some of the anatomic crown.

Adapted with permission from page 87. Ash M. Wheeler's dental anatomy, physiology and occlusion, 7th ed. Philadelphia: WB Saunders; 1993.

may gradually migrate to the cementum (Ten Cate 1998). Smith *et al*. (1996) measured clinical probing depths of sulci every four weeks for a period of 20 weeks in 44 young adult subjects displaying good oral hygiene. The average probing depth taken at the buccocervical site of a maxillary lateral incisor was 1.45 mm (sd = 0.49) and the average probing depth at the mesiobuccal of the same tooth was 2.11 ± 0.53 mm.

Altered (retarted) passive eruption is a condition that occurs following tooth eruption where the free gingival margin comes to rest "at" or "coronal to" the cervical bulge of the tooth. This can lead to a square and squatty appearing clinical crown; one that can be perceived as unesthetic. When present in the maxillary anterior sextant, it may give the appearance of a gummy smile (Sterrett *et al*. 1999).

Miller *et al*. (2000) examined 40 healthy young adult males and females measuring masticatory mucosa by means of an ultrasonic measurement device SDM® at a maximum of 149 sites in each volunteer. The thickness of the buccal gingiva was measured midbuccally with the edge of the probe at the level of the bottom of the gingival sulcus (*i.e.*, about one to two millimeters apical to the gingival margin) as well as at the base of the interdental papilla. The average thicknesses of the buccal masticatory mucosa for the maxillary central and lateral incisors were 1.00 (sd = 0.30 mm) and 0.86 (sd = 0.33 mm) for the midbuccal and 1.86 (sd = 0.45 mm) and 1.32 (sd = 0.38 mm) for the interdental papilla.

CHAPTER III

MATERIALS AND METHODS

The purpose of the present study is to evaluate the statistical associations between maxillary incisor crown form and the extent of incisor irregularity in adolescent boys and girls who sought comprehensive orthodontic treatment.

Dental crowding occurs when the sum of the mesiodistal widths of the teeth exceeds the space available in the dental arch. Previous research aimed at tooth width versus arch length discrepancies have measured mesiodistal tooth widths from dental casts or measured *clinical* tooth height-to-width ratios from casts. The present study has access to full mouth periapical series of dental radiographs taken at the same pretreatment time point as orthodontic dental casts. The periapical radiographs used in this study provide an opportunity to study *anatomical* crown form of the maxillary incisors, as measured from the CEJ, in relation to maxillary crowding, as measured from the dental casts using Little's irregularity index and Merrifield's space analysis. The aim of this study is to evaluate the statistical association between maxillary incisor crown form and the extent of incisor irregularity and tooth-size arch-size discrepancy in adolescent boys and girls who sought comprehensive orthodontic treatment.

Sample Composition

The sample was one of convenience. Subjects were selected without regard to Angle molar classification, though the data was later divided and analyzed based on Angle molar classifications and by sex.

The sample consisted of 151 American white adolescents of western European descent living in or near Jonesboro, Arkansas. The sample consisted of 60 males and 91 females, with orthodontic records taken prior to treatment. At the time of initial records the patients' ages ranged from 7 to 37 years, with a mean age of 13.7 years and a standard deviation of 4.45 years. All subjects had fully erupted maxillary central and lateral incisors with completed root apexification. In instances where incisal wear was notable from the dental casts (*i.e.*, wear facets), the worn teeth were not included in the study as wear affects the measurement of crown height.

The data were collected from pretreatment orthodontic cases from a single private practice orthodontist. Each patient record included a full mouth series of periapical radiographs and pretreatment orthodontic casts from the same examination. Cases with distorted or poor radiographic quality were discarded. The maxillary pretreatment dental cast was used to measure crowding—assessed as both incisor irregularity (Little 1975) and tooth width arch length discrepancy (Merrifield 1978)—and to relate mesiodistal widths on dental casts to corresponding tooth crown widths on the scanned radiographs in order to adjust for magnification on the dental radiographic images in the mediolateral plane. There were four main criteria for inclusion in this study:

1. Patient records were taken prior to orthodontic treatment.
2. Patients were American whites as determined from the pretreatment extraoral photographs. The intent was to remove the effects of racial variation that are known to affect tooth size and dental arch dimensions (*e.g.*, Chung and Niswander 1975; Kieser 1990).
3. Dental casts and a full-mouth radiographic series were available from the same pretreatment time point.
4. Incisors were excluded on a tooth-by-tooth basis if, from inspection of the cast or radiograph, a tooth was too deviated to provide a reasonably oriented periapical film image.

The study focused on the crown dimensions as measured from nine landmarks on the periapical radiographs of one of the maxillary central incisors and one of the maxillary lateral incisors from each subject. Assuming right and left side symmetry (Khalaf *et al*. 2005), the least rotated central and lateral incisor was chosen and measured for each subject.

Methods

Periapical radiographs of the four maxillary central and lateral incisors were placed next to a transparent millimetric ruler on a flatbed scanner. Scans of the periapical radiographs were saved as 16-bit graphical TIFF images. Each TIFF file was opened in Adobe® Photoshop® 6.0 (Adobe, San Jose, CA) where the one or two images (left and right quadrants) of the desired maxillary incisors were cropped, converted to 8-bit grayscale, adjusted to best brightness and contrast, and saved as a Photoshop® 6.0 file. The maxillary central and lateral incisor with the most clearly identifiable landmarks (right or left) was selected for each subject. The selected central and lateral incisor was then magnified as much as possible with all of the landmarks still visible on the computer screen. The straight-line measurement tool in Photoshop® was used to make millimetric measurements between the landmarks, with a readout accuracy of 0.1 mm. A data collection sheet was printed out for each subject (Figure 17), the patient number, film width, the right or left was marked for each central and lateral measured and all of the millimetric measurements obtained with the straight-line

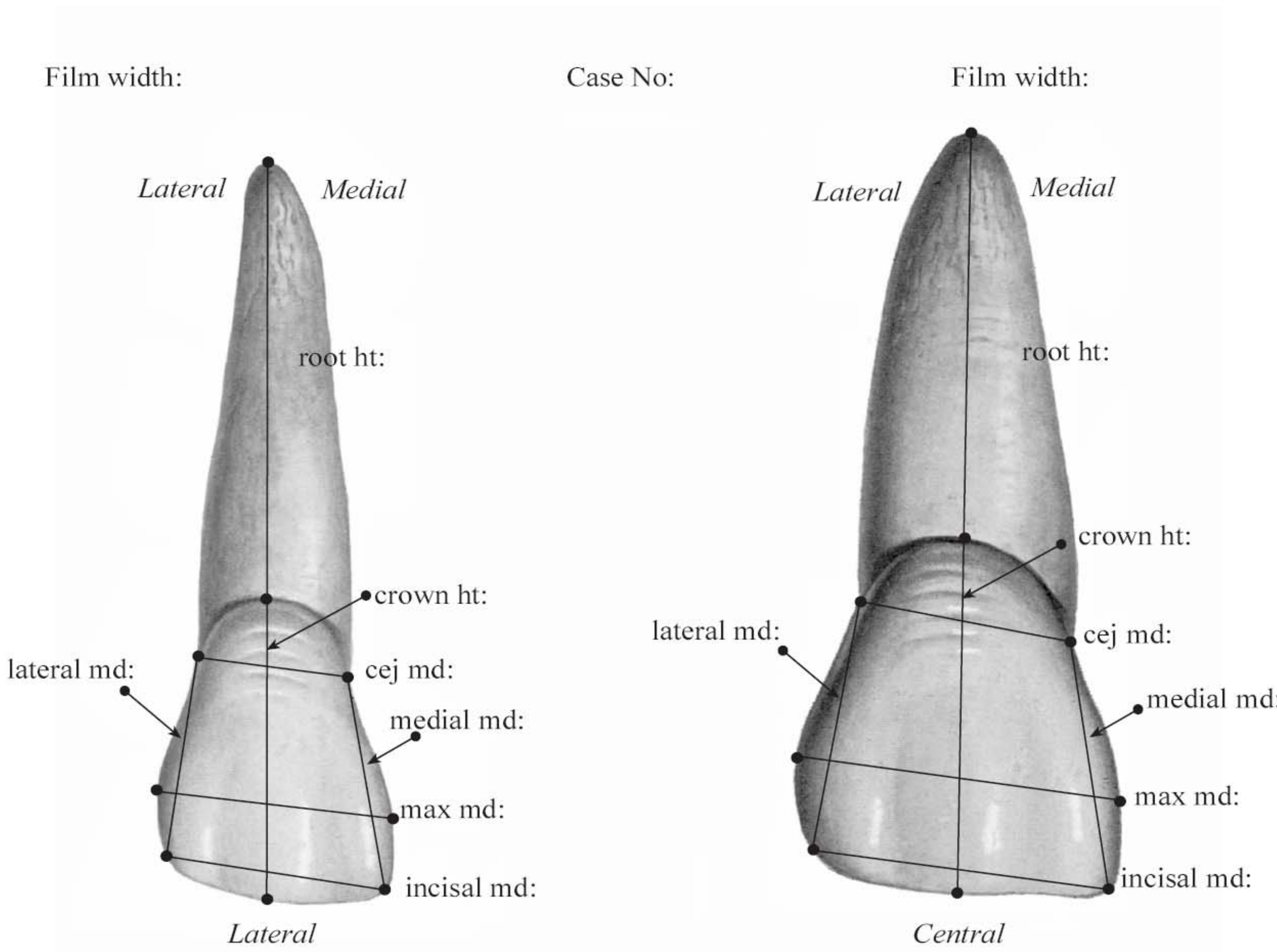


Figure 17. Illustration of the data sheet used to record measurements from the radiographic images.

measurement tool were recorded. These data were later transferred to a Microsoft® Excel® spreadsheet (Microsoft, Seattle, WA) with the patient demographic data and dental cast measurements.

Landmarks

Tooth measurements relied on nine landmarks (Figure 18):

1. Root apex: The most apical point on the median convexity of the root.
2. Crown convexity: The most apical aspect of the cementoenamel junction in the medial aspect.
3. Medial Incisal point: The incisal-most aspect of the crown in the mediolateral middle of the crown
4. Medial CEJ: The junction between the crown and root at the tooth's medial aspect viewing the labial aspect of the tooth.
5. Lateral CEJ: The junction between the crown and root at the tooth's lateral aspect viewing the labial aspect of the tooth.
6. Occlusomedial angle: The point on the medial-occlusal angle of the crown most distant from the lateral cementoenamel junction point.
7. Occlusolateral angle: The point on the lateral-occlusal angle of the crown most distant from the medial cementoenamel junction point.
8. Medial crown tangent: Viewing the labial aspect of the crown, this is the medial marginal point at the maximum mesiodistal crown width.
9. Lateral crown tangent: Viewing the labial aspect of the crown, this is the lateral marginal point at the maximum mesiodistal crown width.

Distances

These landmarks were used to define eight distances (Figure 19):

1. Root length: The distance from the root apex to the medial margin of the CEJ.
2. Crown height: The distance from the medial margin of the CEJ to the medial incisal point.
3. Cervical width: The distance between the medial and lateral CEJ landmarks
4. Maximum mesiodistal width: Empirically, the broadest crown width at right angle to the crown's long axis
5. Incisal width: Distance between the medial-occlusal and lateral-occlusal landmarks
6. Medial crown height: Crown height measured between the medial CEJ and medial-occlusal point.

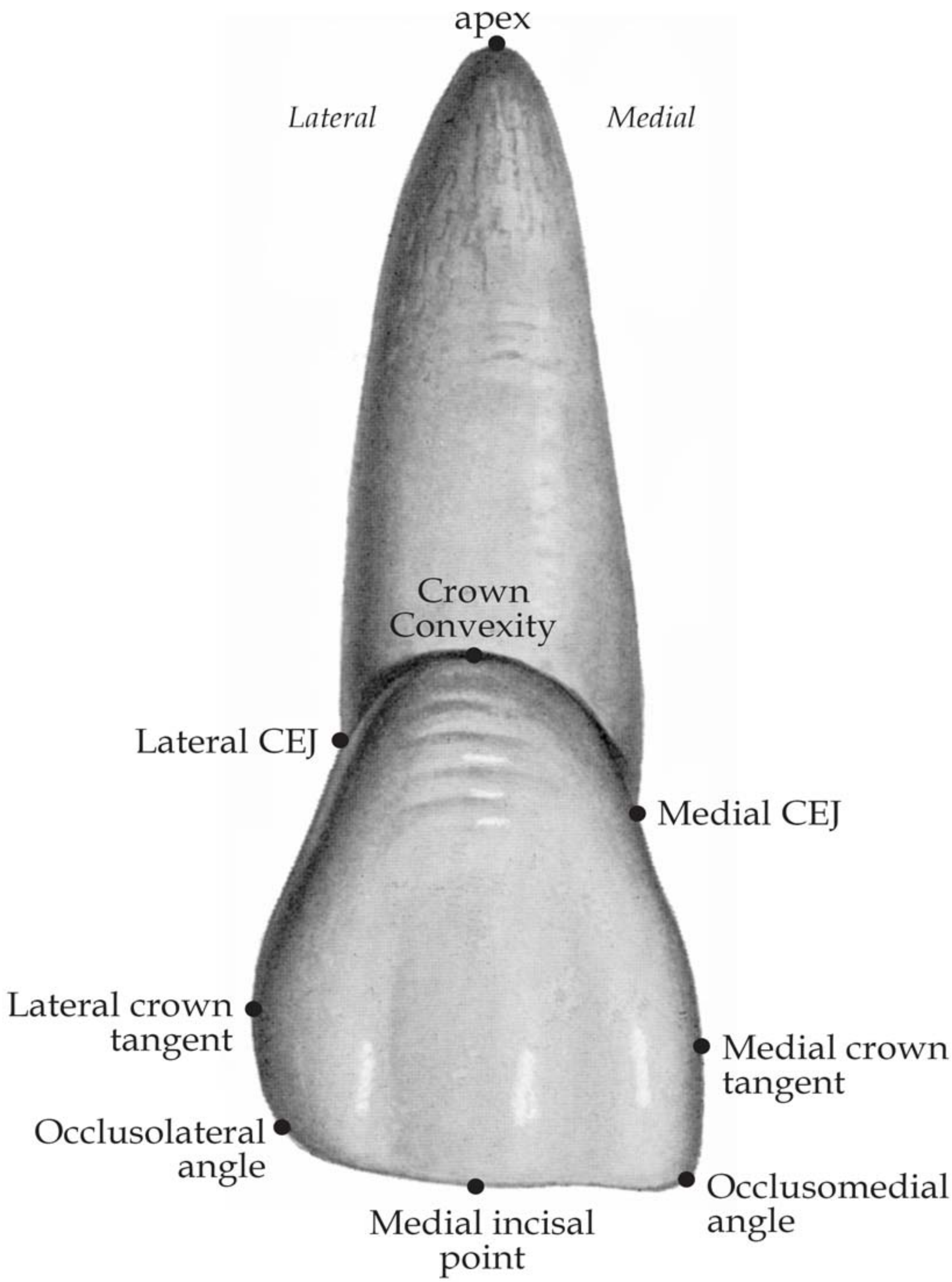


Figure 18. Labial view of a right maxillary central incisor showing the nine landmarks located on each tooth. See text for details. Comparable landmarks were located on the lateral incisor.

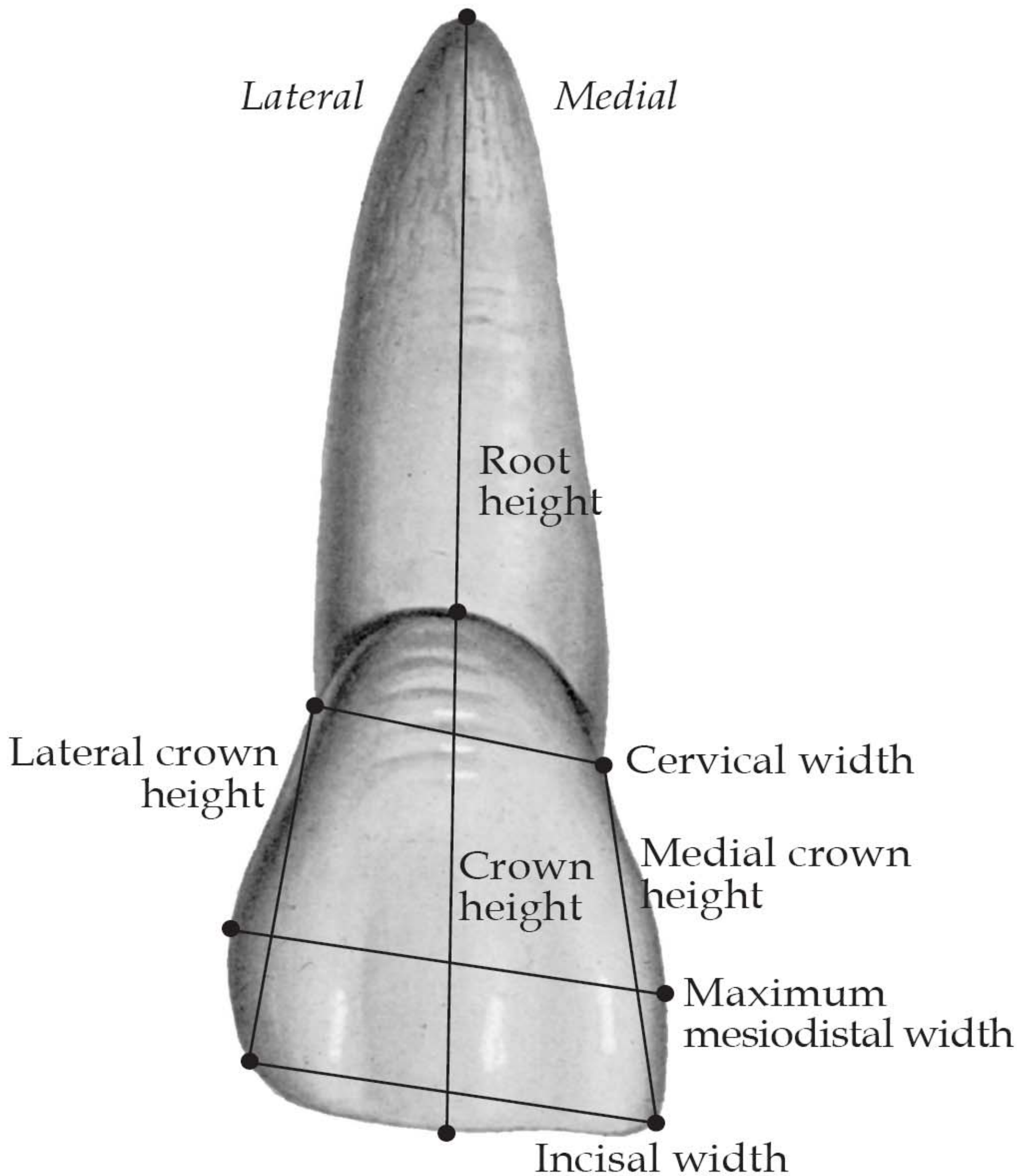


Figure 19. Labial view of a right maxillary central incisor showing the linear distances measured on each tooth. See text for details. Comparable measurements were made on the lateral incisor.

7. Lateral crown height: Crown height measured between the lateral CEJ and the lateral-occlusal point.
8. Tooth length: The overall length is the sum of root length plus crown height.

Derived Variables

A series of ratios was calculated as measures of crown and tooth form. These are calculated for each individual and separately for the maxillary central and lateral incisor. The following calculations were made:

$$\text{Tooth Length} = \text{Root Length} + \text{Crown Height}$$

$$\text{Crown-Root Ratio} = \frac{\text{Crown Height}}{(\text{Crown Height} + \text{Root Length})}$$

$$\text{Length–Width Ratio} = \frac{\text{Maximum MD Width}}{(\text{Crown Height} + \text{Root Length})}$$

$$\text{Width–Height Ratio} = \frac{\text{Maximum MD Width}}{\text{Crown Height}}$$

$$\text{Crown Flare 1} = \frac{\text{Maximum MD Width}}{\text{CEJ Width}}$$

$$\text{Crown Flare 2} = \frac{\text{Maximum MD Width}}{\text{Incisal MD Width}}$$

$$\text{Crown Flare 3} = \frac{\text{Incisal MD Width}}{\text{CEJ Width}}$$

$$\text{Eccentricity} = \frac{\text{Medial Height}}{\text{Lateral Height}}$$

Data Collection

Distances calculated in Photoshop® 6.0 were transcribed onto data forms and then entered into a Microsoft® Excel® spreadsheet (Microsoft, Seattle, WA), where the ratios were calculated. The Excel® document was then loaded into JMP (SAS Corporation, Cary, NC) where statistical analysis was performed.

The study corrected for magnification mediolaterally between the periapical radiographs and the dental casts from the same pretreatment appointment by relating the greatest mesiodistal crown width from the dental casts to the maximum mesiodistal crown width at a right angle to the tooth's long axis on the periapical radiograph.

The primary research question was whether there was a significant statistical association between arch size tooth size discrepancy—quantified as Little's incisor irregularity index or as Merrifield's tooth size arch size discrepancy—and incisor crown form measured as any of the indices listed above. The hypothesis was tested using linear regression analysis (*e.g.*, Freund and Littell 1991). The crown dimensions and ratios were the independent (predictive) variables, and incisor irregularity was the dependent (outcome) variable.

Intrinsic Error in Periapical Radiographs

In periapical radiographs, image shape distortion can result from unequal magnification of different parts of the same object when not all parts of the object are in the same focal spot-to-object distance (White and Pharoah 2000). The paralleling technique is the preferred method for making intraoral radiographs and is best achieved in the maxilla by positioning the film toward the middle of the oral cavity with a film holder, away from the teeth, so the film is parallel to the long axis of the tooth. The paralleling technique produces some magnification of the image since the image must project across the distance between the object and the film, but when used with a long open-ended cone, the focal spot-to-object distance is also increased, directing only the most central and parallel rays of the beam to the film, thereby increasing the image sharpness and resolution (White and Pharoah 2000).

Common problems of distortion associated with periapical radiographs are foreshortening and elongation. Foreshortening (image is shorter than the actual object) occurs when the x-ray beam is perpendicular to the film, but the object is not parallel to the film. Elongation (image is longer than the object) occurs when the x-ray beam is oriented at right angles to the object, but not the film. If, in the present study, the radiographic image of the crown appeared elongated, foreshortened, or distorted due to rotation of the tooth, as compared to the crown on the dental cast, the antimeric maxillary central or lateral incisor was measured, if neither was accurate, the patient was excluded from the study.

Statistical Analysis

Data were collated into an Excel spreadsheet (Microsoft® Corporation, Redmond, WA) then transferred to the JMP statistical package (SAS Institute Inc., Cary, NC). Exploratory data analysis (Tukey 1977) was performed, searching for outliers; those due to technical errors were corrected. Conventional descriptive statistics (*e.g.*, Sokal and Rohlf 1995) were calculated; these (and their abbreviations) are sample size (n, taken as counts of individuals, not sides), the arithmetic mean ($\bar{x}$), the standard deviation (sd), and the standard error of the mean (sem, calculated as sd/$\sqrt{n}$). The conventional alpha level of 0.05 was used throughout, and all of the tests were two-tail. No correction was made for multiple comparisons. Salient results of the analysis were graphed using Delta Graph® 4.0.5 (Rockware, Inc., Golden, CO) for Windows.

Analysis of covariance (ANCOVA) models were useful in the present study because they can be used to test for an association between two variables, while controlling for extraneous variables (*e.g.*, patient's sex, measurements of homologous left-right traits), thus (1) greatly reducing the number of tests that have to be performed (and interpreted), (2) preserving degrees of freedom, and (3) testing for statistical interactions among the variables evaluated in combination. Tests were run using the JMP statistical package, which uses a generalized linear model approach for calculation. The predominant model uses patient's sex as the covariate, so (1) males and females can be combined in the same test while (2) testing for heterogeneity of slopes—whether the association is significantly different in the two sexes. The form of the table is this:

Intercept
Tooth size
Sex
Tooth size-by-Sex Interaction

where Intercept is the Y-intercept, Tooth size is one of the measures of crown size, Sex is whether the patient is male or female, and the Interaction term tests whether the association (the slope of the regression line) is statistically different between the two sexes. If the interaction term is significant, then the main effects of the model are biased, and the analysis should be run on a sex-specific basis.

CHAPTER IV

RESULTS

Sexual Dimorphism

It is well documented for both the primary and permanent dentitions that males have statistically larger teeth than females (*e.g.*, Kieser 1990). These intragroup trends for larger crown and root lengths in males have been exploited by forensic anthropologists, human biologists, and others to determine the sex of unknown skeletal specimens (*e.g.*, Ditch and Rose 1972). Clinically, statistical differences in tooth size are of little interest because one is treating an individual, not a statistical average, and there is considerable overlap in tooth size distributions of the two sexes. From the present research perspective, sexual dimorphism is primarily a "nuisance variable" in that the subject's sex needs to be accounted for in the statistical tests so that this source of variation (*i.e.*, sexual dimorphism) does not confound the tests that are looking for associations among other variables.

In this preliminary section, the variables were tested for sexual dimorphism in order to describe its prevalence and extent. Tables 1 (central incisor) and 2 (lateral incisor) list the results of one-way analysis of variance testing whether the male and female means differ significantly.

Percentage sexual dimorphism is also listed in these two tables. The formula is:

$$\text{Percentage sexual dimorphism} = \left(\frac{\bar{x}_{\mathrm{M}} - \bar{x}_{\mathrm{F}}}{\bar{x}_{\mathrm{F}}}\right) \times 100$$

This is the extent that the mean for males exceeds that for females, and, for the central incisor (Table 1), all of these percentages are positive. Most of the eight linear dimensions are significantly larger in males for the central incisor (I1). This is true for root height (Figure 20), crown height (Figure 21), mesiodistal crown width at the CEJ, at the midcrown, and at the incisal edge (Figures 22-24). Crown heights at the lateral and the medial aspects are not particularly dimorphic (Figures 25-26). Tooth length (root plus crown height) is quite dimorphic statistically (Figure 27), with males being about 8% larger on the average.

Table 1. Analysis of variance testing for sexual dimorphism in variables measured on the maxillary central incisor.[1]

	Male	Female	Percent	Analysis of Variance		
Variable	mean	mean	Dimorphism	MS	F Ratio	P Value
Root Height	14.518	13.723	5.79	22.843	5.84	0.0169
Crown Height	12.002	11.594	3.52	6.015	5.19	0.0241
MD Width at CEJ	6.589	6.303	4.55	2.967	11.69	0.0008
Maximum MD Width	8.801	8.574	2.64	1.859	6.12	0.0145
Incisal MD Width	7.618	7.371	3.36	2.212	6.37	0.0127
Lateral Crown Height	8.676	8.360	3.78	3.620	3.43	0.0658
Medial Crown Height	8.974	8.607	4.27	4.880	4.30	0.0398
Tooth Length	26.520	25.317	4.75	52.302	8.16	0.0049
Crown-Root Ratio	0.454	0.459	-1.09	0.001	0.70	0.4044
Length-Width Ratio	0.334	0.341	-2.02	0.002	1.48	0.2259
Width-Height Ratio	0.737	0.744	-0.94	0.002	0.45	0.5025
Flare 1	1.340	1.365	-1.84	0.023	3.10	0.0805
Flare 2	1.158	1.165	-0.63	0.002	0.68	0.4100
Flare 3	1.159	1.174	-1.23	0.008	0.85	0.3570
Crown Eccentricity	0.969	0.976	-0.77	0.002	0.27	0.6063

[1]There are 60 males and 91 females for each test: df for the F ratios are 1 and 149.

Table 2. Analysis of variance testing for sexual dimorphism in variables measured on the maxillary lateral incisor.

	Male	Female	Percent	Analysis of Variance		
Variable	mean	mean	Dimorphism	MS	F Ratio	P Value
Root Height	14.174	13.775	2.89	5.738	1.69	0.1953
Crown Height	10.276	9.756	5.33	9.774	7.01	0.0090
MD Width at CEJ	5.049	4.843	4.25	1.533	5.96	0.0158
Maximum MD Width	6.751	6.684	0.99	0.159	0.38	0.5377
Incisal MD Width	5.532	5.524	0.14	0.002	0.01	0.9400
Lateral Crown Height	7.341	6.895	6.46	7.171	7.09	0.0086
Medial Crown Height	7.743	7.320	5.78	6.482	5.49	0.0205
Tooth Length	24.449	23.531	3.90	30.490	4.26	0.0407
Crown-Root Ratio	0.421	0.415	1.52	0.001	1.65	0.2003
Length-Width Ratio	0.278	0.286	-2.70	0.002	2.96	0.0874
Width-Height Ratio	0.661	0.689	-4.05	0.028	8.04	0.0052
Flare 1	1.342	1.383	-2.93	0.059	7.69	0.0063
Flare 2	1.223	1.215	0.62	0.002	0.37	0.5460
Flare 3	1.101	1.142	-3.60	0.061	7.22	0.0080
Crown Eccentricity	1.062	1.067	-0.45	0.001	0.05	0.8179

[1]There are 60 males and 91 females for each test: df for the F ratios are 1 and 149.

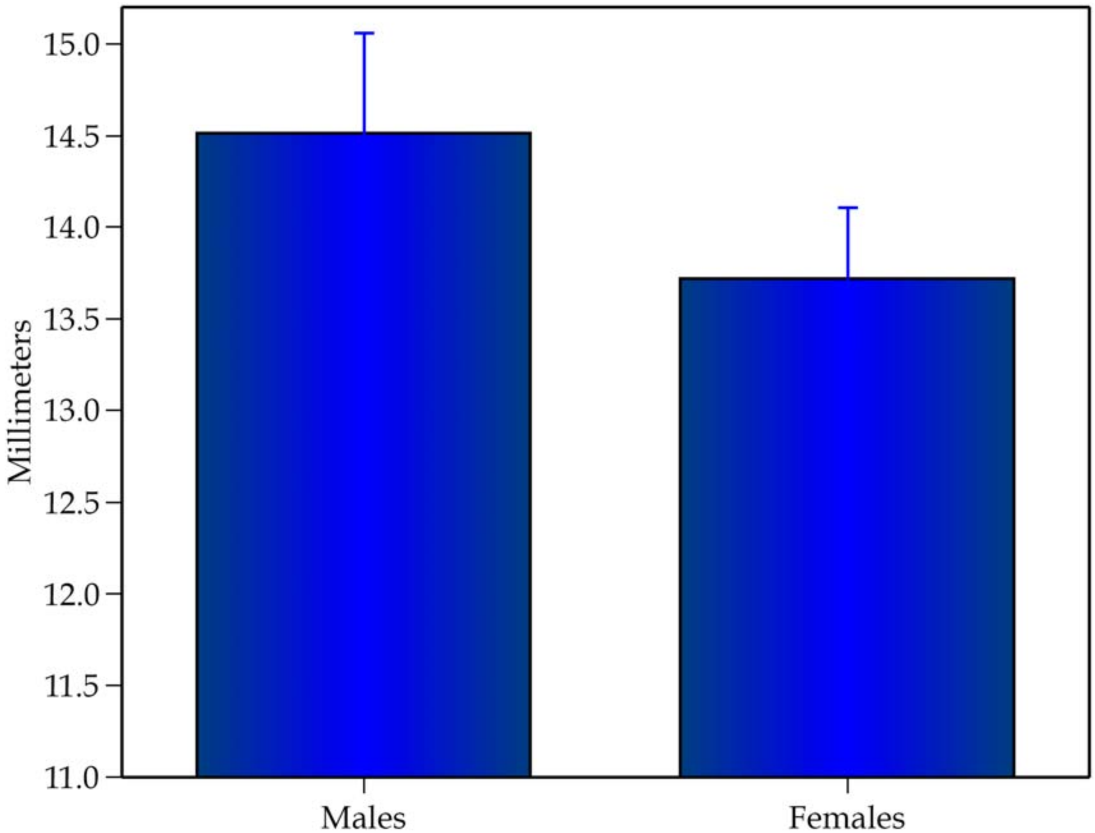


Figure 20. Mean dimension, by sex, for root height of the maxillary central incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

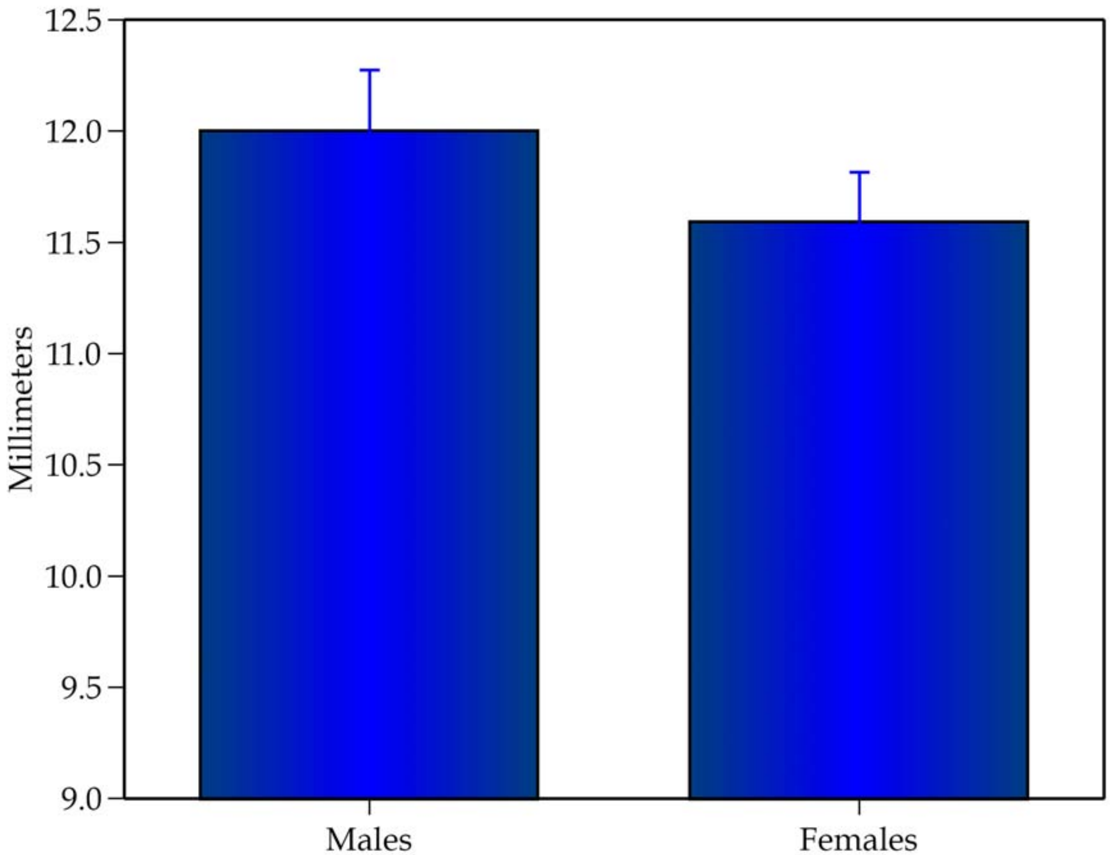


Figure 21. Mean dimension, by sex, for crown height of the maxillary central incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

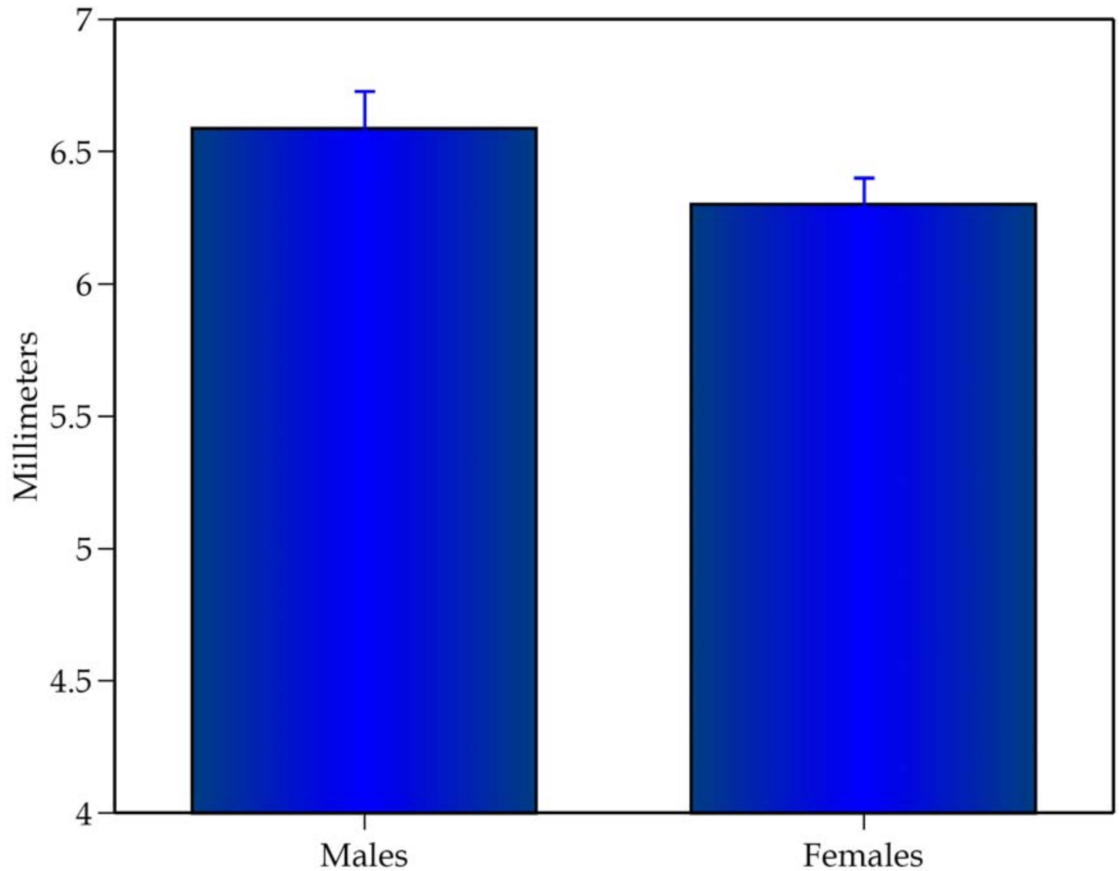


Figure 22. Mean dimension, by sex, for mesiodistal crown width at the level of the CEJ of the maxillary central incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

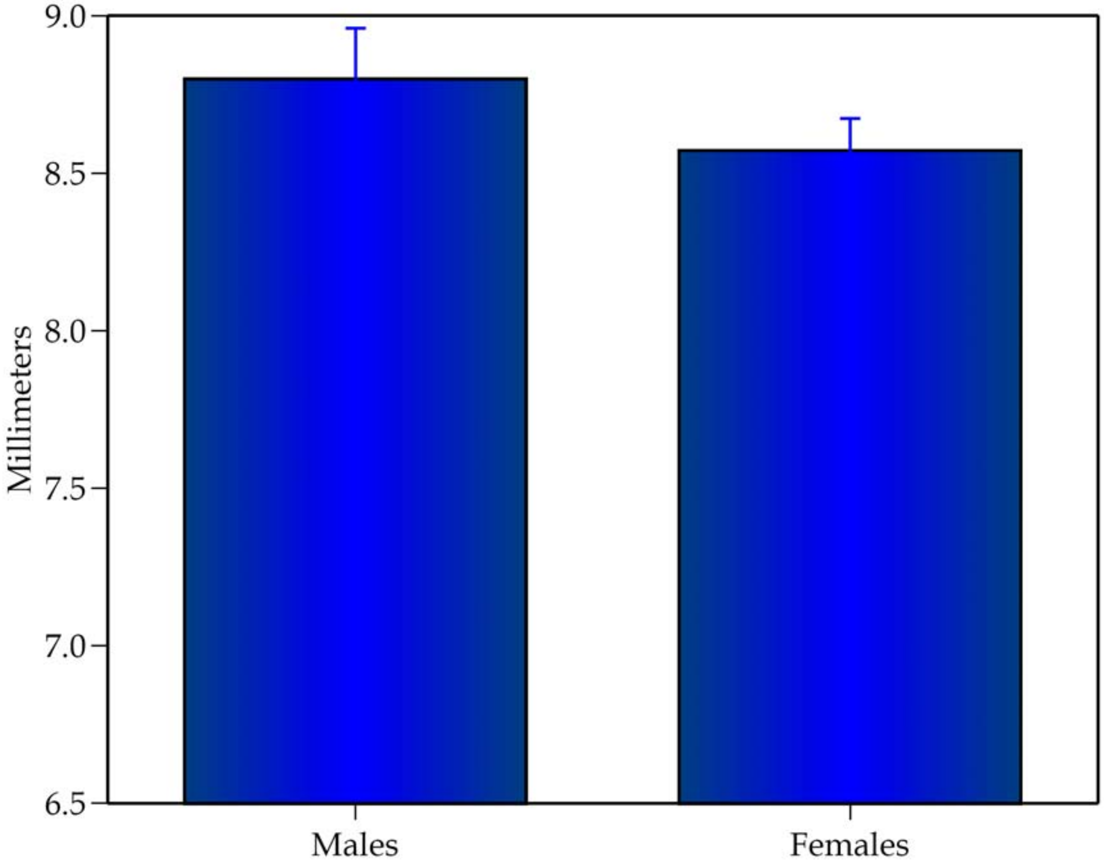


Figure 23. Mean dimension, by sex, for maximum mesiodistal crown width of the maxillary central incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

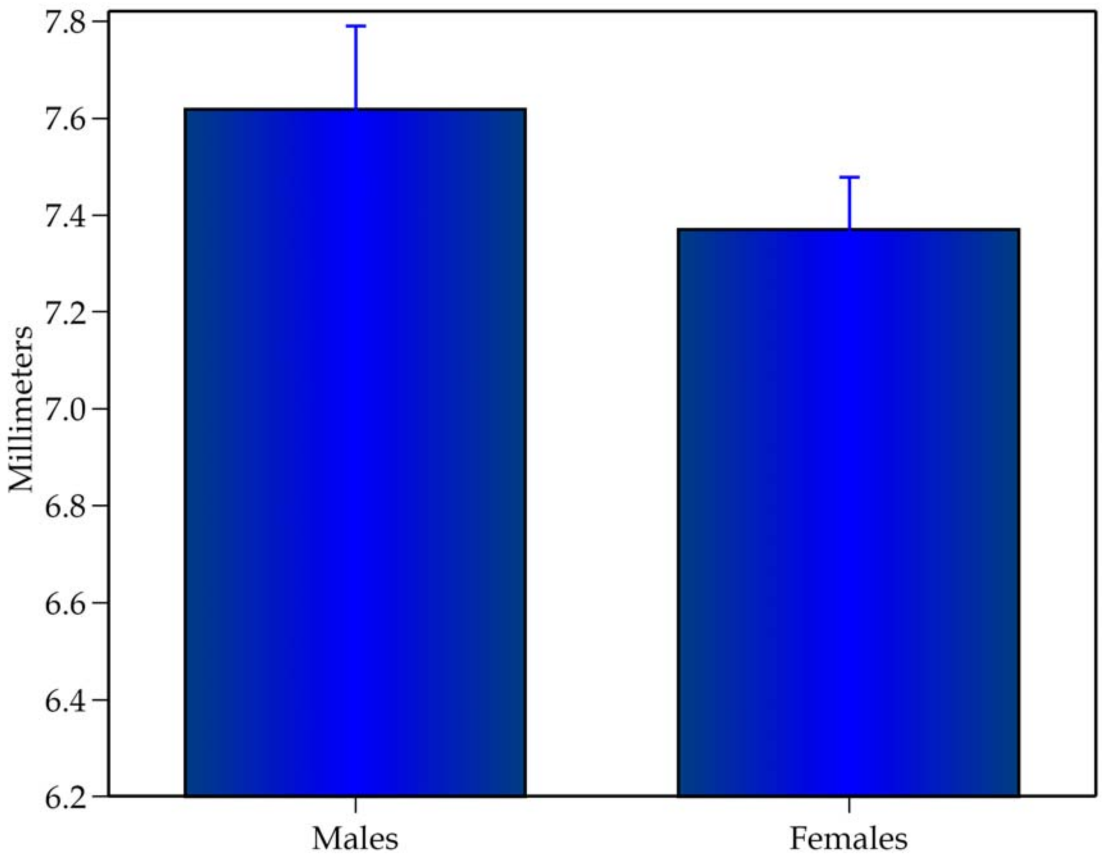


Figure 24. Mean dimension, by sex, for maximum mesiodistal crown width at the incisal edge of the maxillary central incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

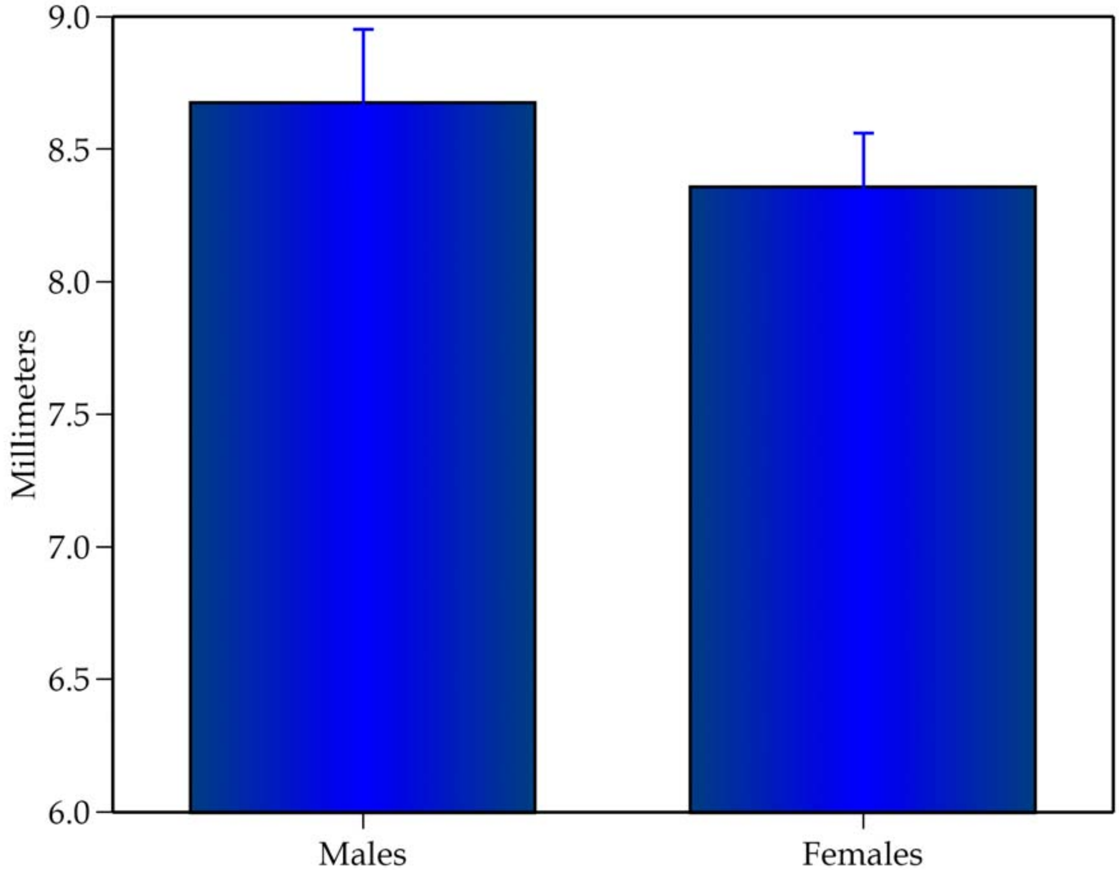


Figure 25. Mean dimension, by sex, for lateral crown height of the maxillary central incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

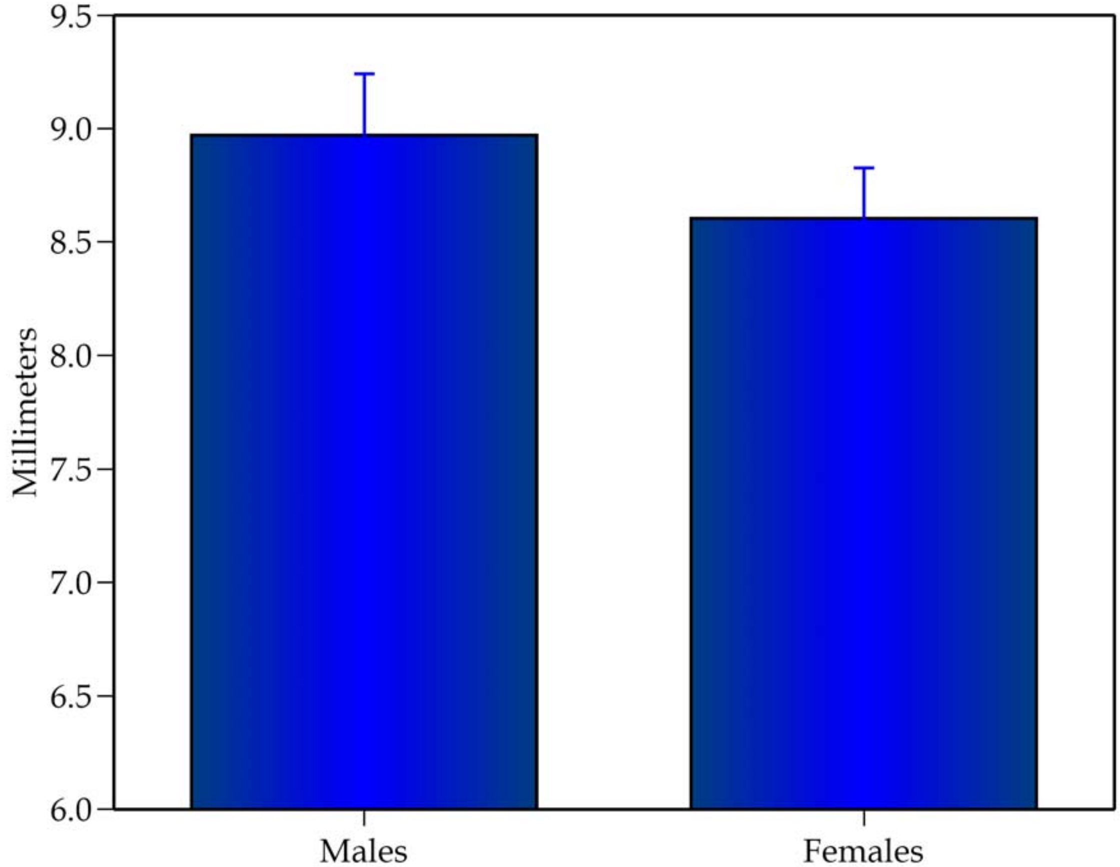


Figure 26. Mean dimension, by sex, for medial crown height of the maxillary central incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

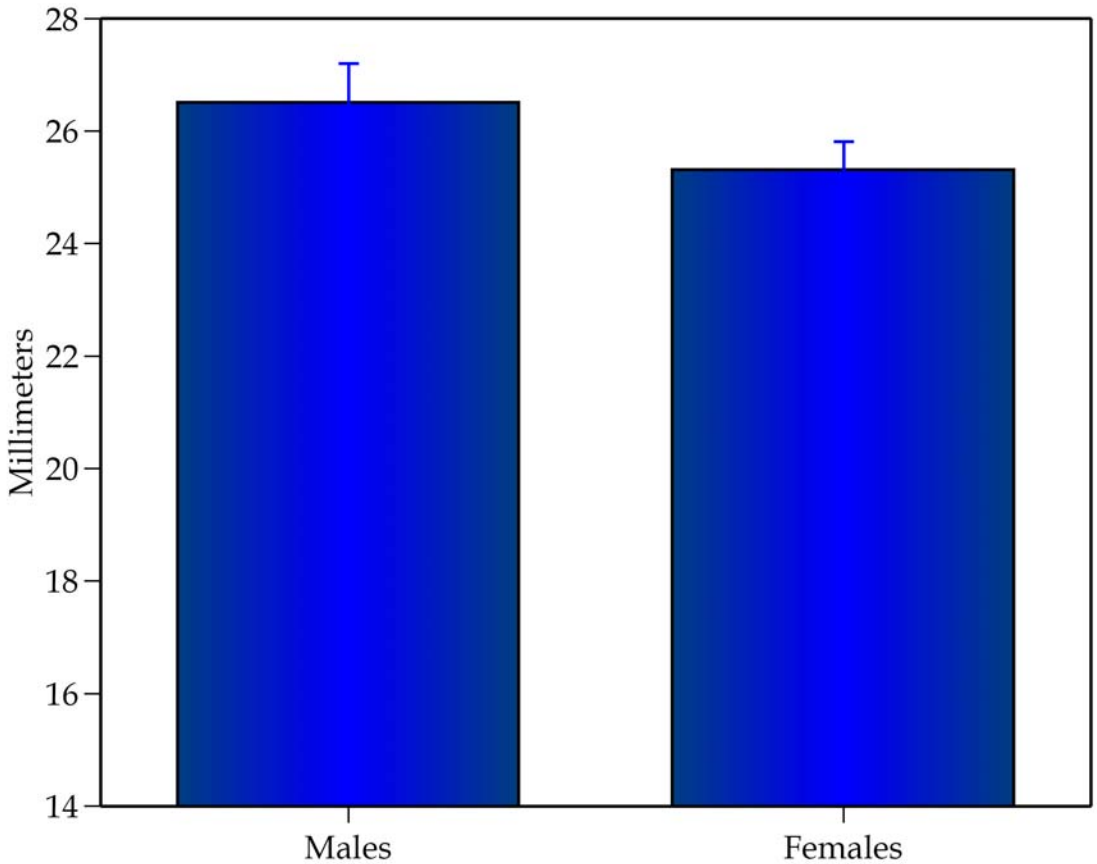


Figure 27. Mean dimension, by sex, for tooth length (root length + crown height) of the maxillary central incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

In contrast, none of the seven tooth size ratios is significant, implying that tooth *shape* differs very little (Figures 28-34). In other terms, the maxillary central incisor in males is an isometrically enlarged version of the tooth in females, at least with regard to these variables.

The statistical results are appreciably different for the maxillary lateral incisor (I2) (Table 2), and it needs to be kept in mind that this sample consists wholly of American whites who as a group are characterized as having disproportionately small incisors (*e.g.*, Harris and Rathbun 1991; Harris and Clark n.d.). As with the central incisor, mean values are absolutely larger in males (so percent sexual dimorphism is positive for all variables), but fewer variables achieve statistical significance.

For example, root length is not significantly dimorphic (Figure 35), though it is significant for the adjacent central incisor. Crown height (Figure 36) and maximum crown width (Figure 37) are significantly dimorphic for the lateral incisor on par with the central incisor. Rather surprisingly, mesiodistal I2 widths are not dimorphic when measured at the midcrown (Figure 38) or at the incisor edge (Figure 39).

Also in contrast to the central incisor, the medial and lateral crown heights of I2 are significantly dimorphic (Figures 40, 41), being 3 to 4% larger in males (Couch 2007).

Tooth length is marginally significantly greater in males (Figure 42), and, since root length by itself shows a nonsignificant sex difference, most of the overall difference in tooth length is attributable to sex differences in the I2 crown *per se*.

Three of the seven ratios are significantly dimorphic for I2, which contrasts with the complete lack of difference among the ratios measured on I1. The crown-root ratio (Figure 43) does not differ, nor does the crown length-width ratio (Figure 44), but the width-to-height ratio is sexually dimorphic for I2 (Figure 45) because crown height is a larger fraction of crown width in females. These ratios appear similar (*ca*. 0.28), but this ratio is significantly larger in females because their I2s are narrower in relationship to crown height. Comparably, the ratio of crown widths labeled Flare 1 is significantly larger in females (Figure 46) because I2 flares occlusally a bit more in females than males, thus leading to a larger ratio of widths. This is easy to visualize: I2 width at the CEJ is discernibly smaller in females, whereas maximum mesiodistal crown width differs little between the sexes, so I2 "flares" more in females as the crown is followed from the CEJ occlusally.

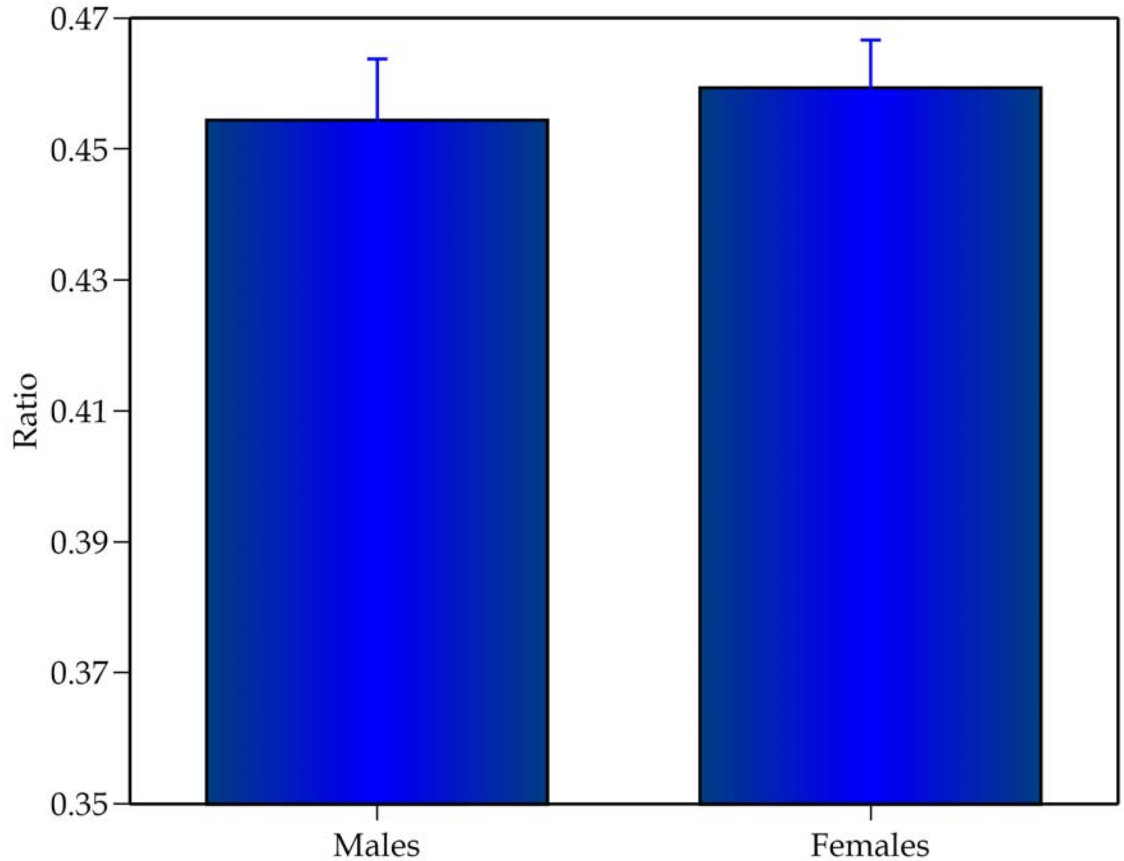


Figure 28. Mean dimension, by sex, for crown-to-root ratio (crown height/(crown height + root height)) of the maxillary central incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

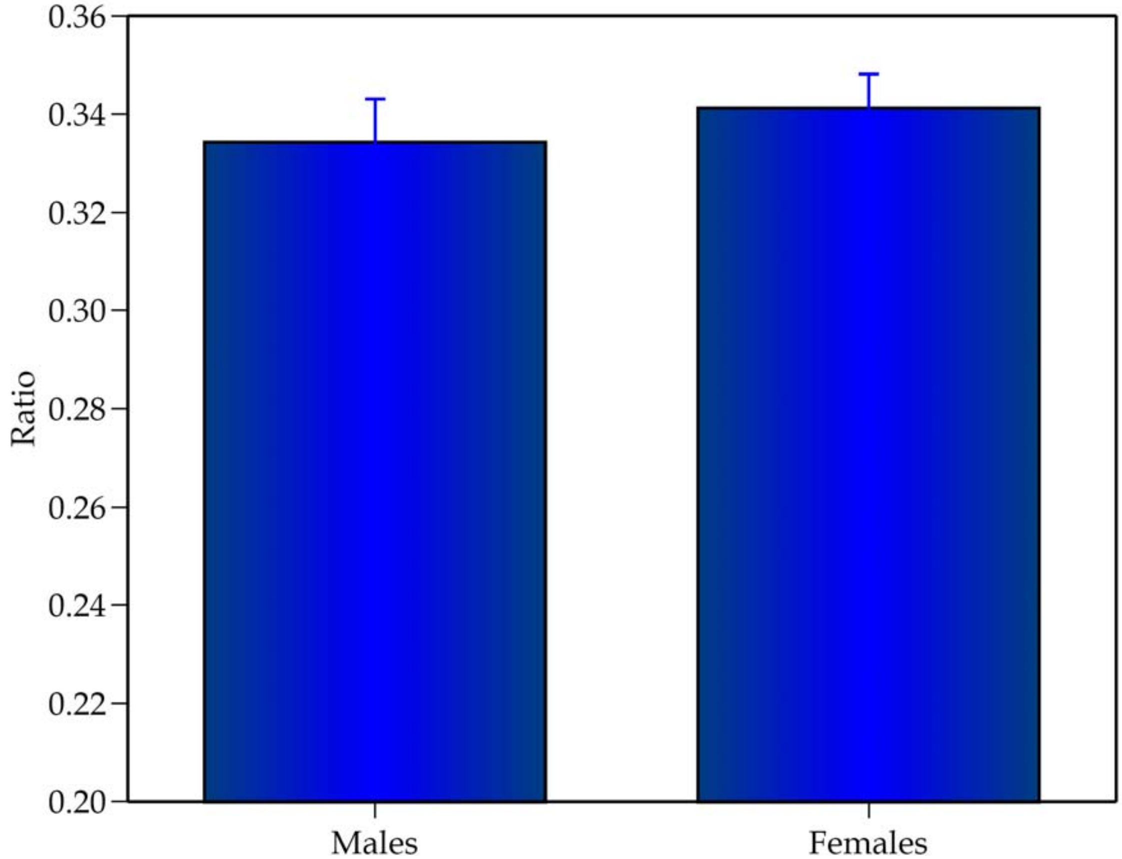


Figure 29. Mean dimension, by sex, for length-to-width ratio (maximum MD width/(crown height + root height)) of the maxillary central incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

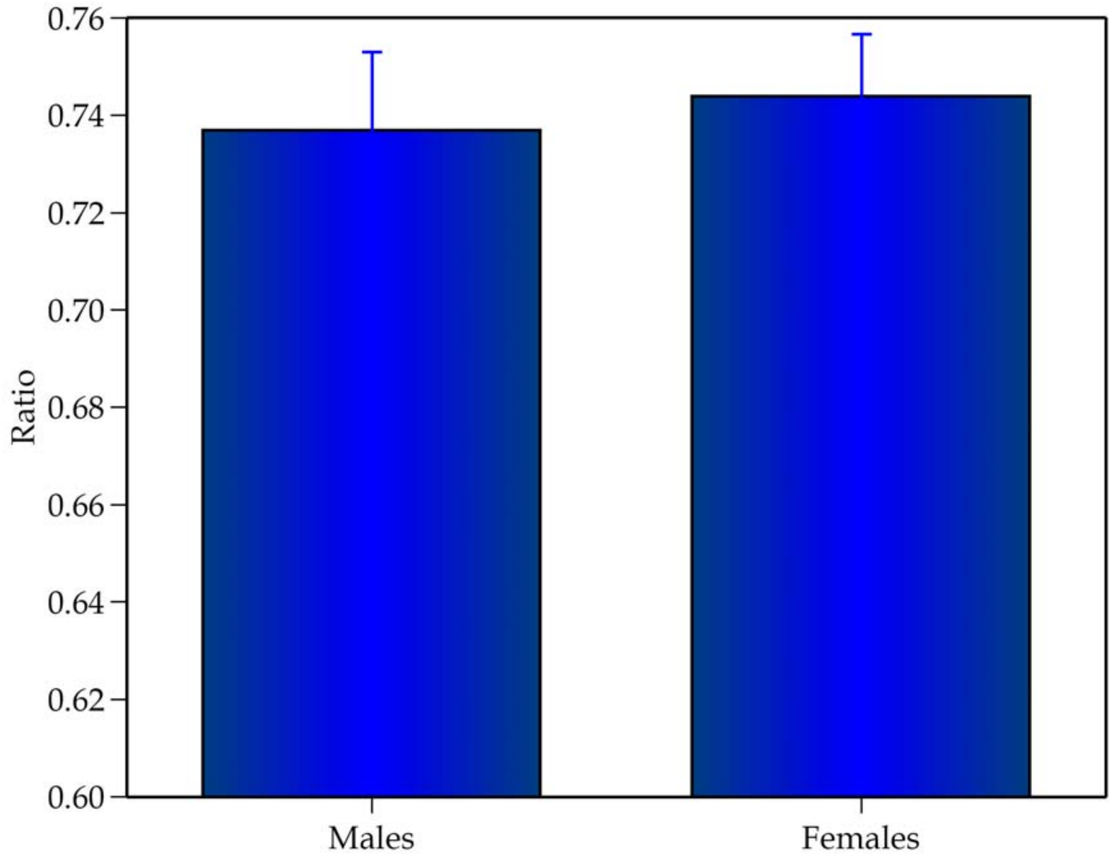


Figure 30. Mean dimension, by sex, for width-to-height ratio (maximum MD width/crown height) of the maxillary central incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

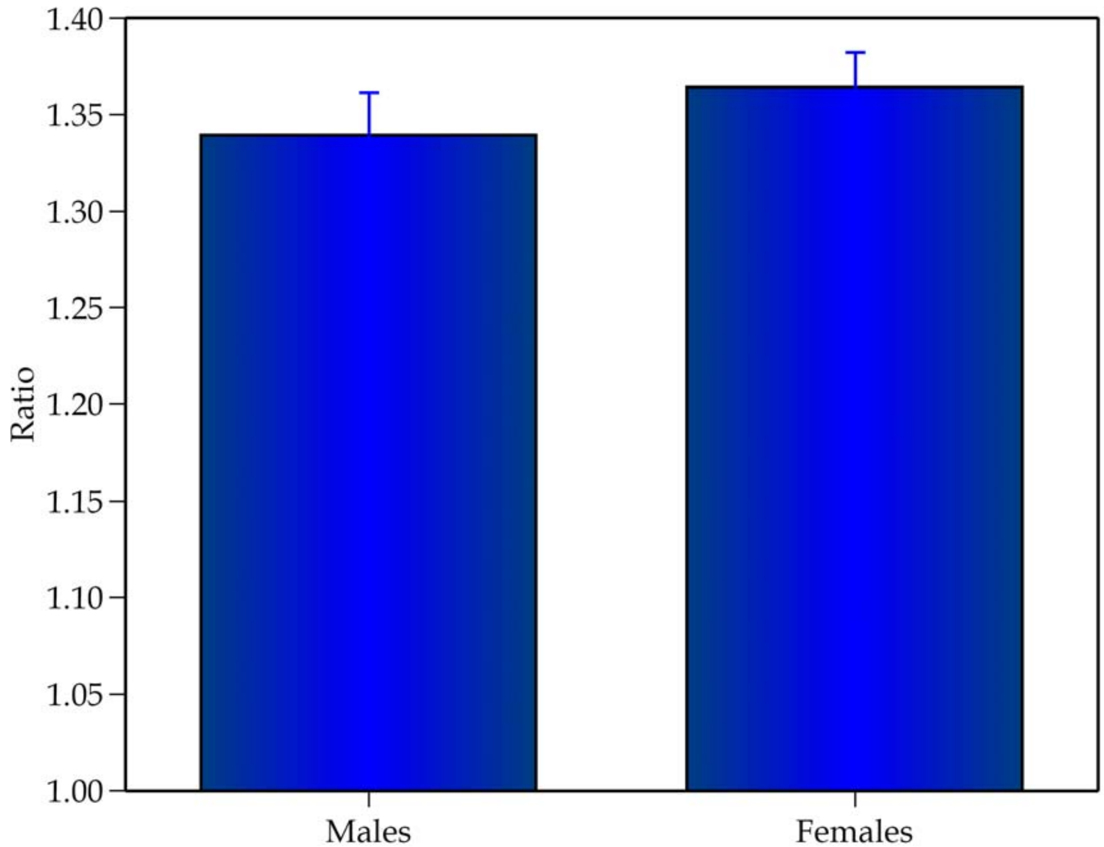


Figure 31. Mean dimension, by sex, for Flare 1 ratio (maximum MD width/CEJ width) of the maxillary central incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

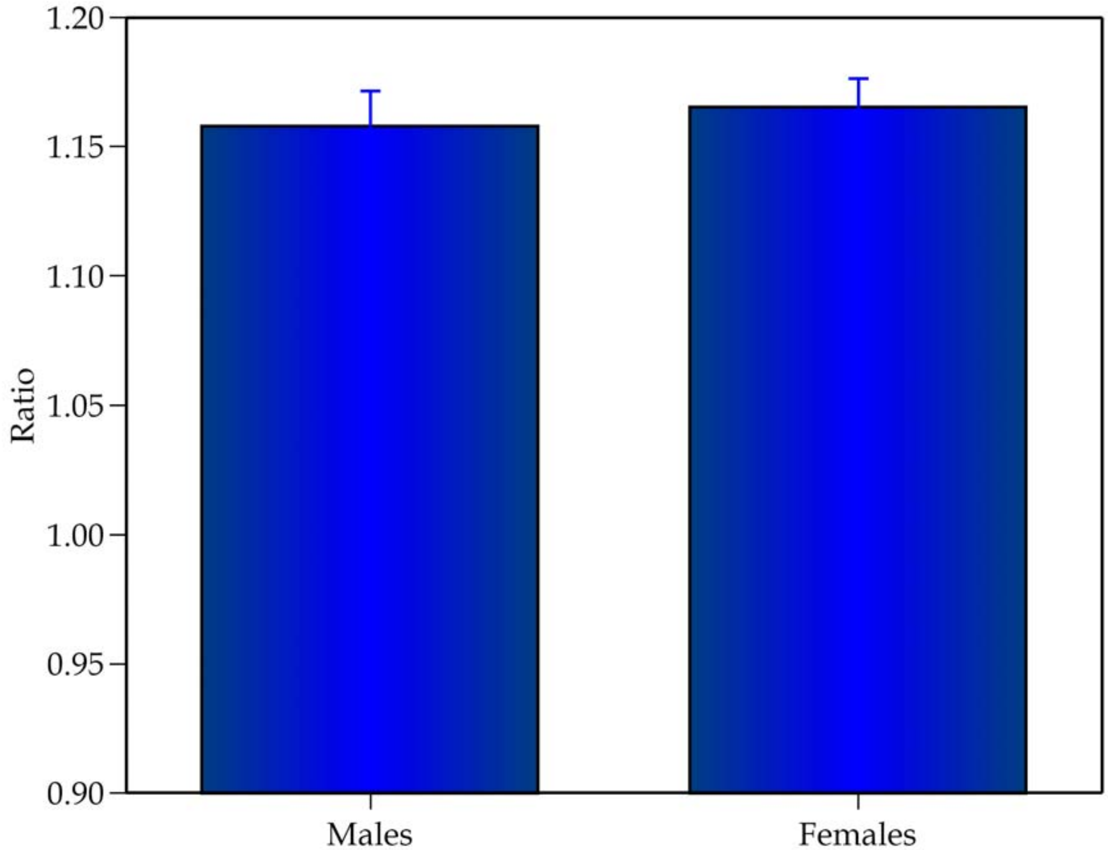


Figure 32. Mean dimensions, by sex, for Flare 2 ratio (maximum MD width/incisal MD width) of the maxillary central incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

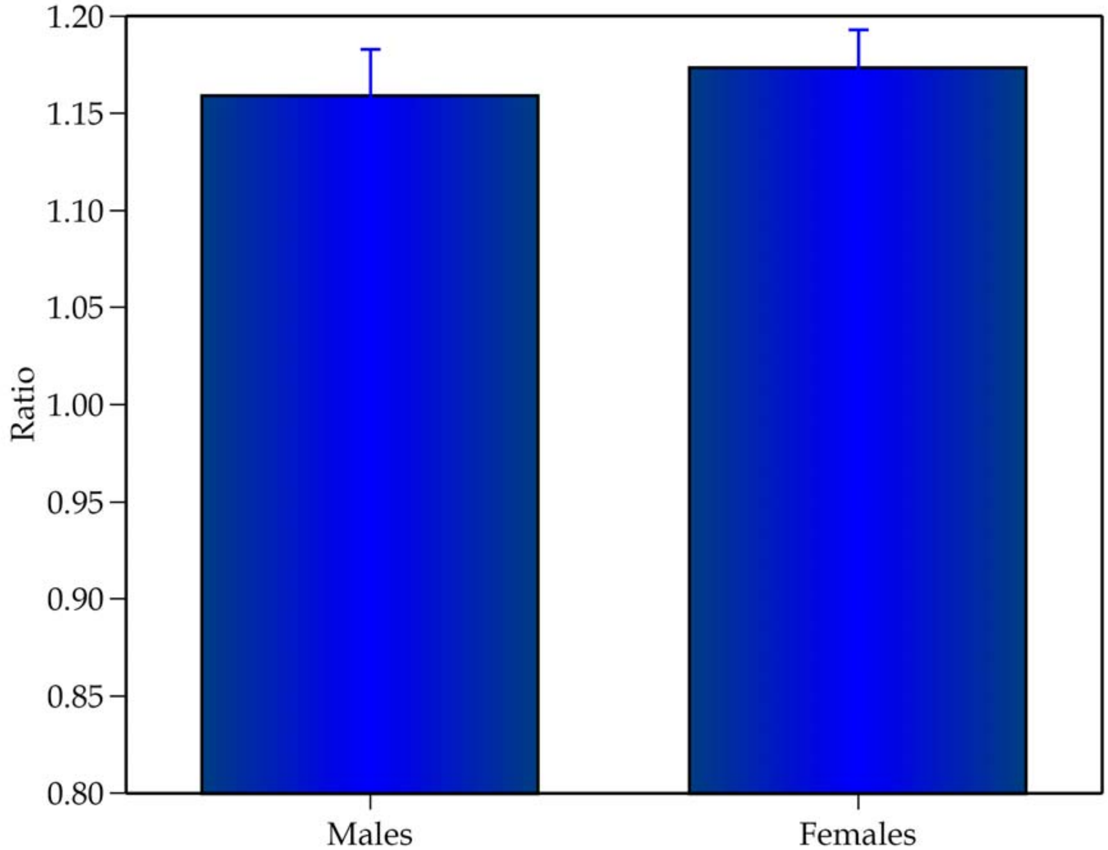


Figure 33. Mean dimension, by sex, for Flare 3 ratio (incisal MD width/CEJ width) of the maxillary central incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

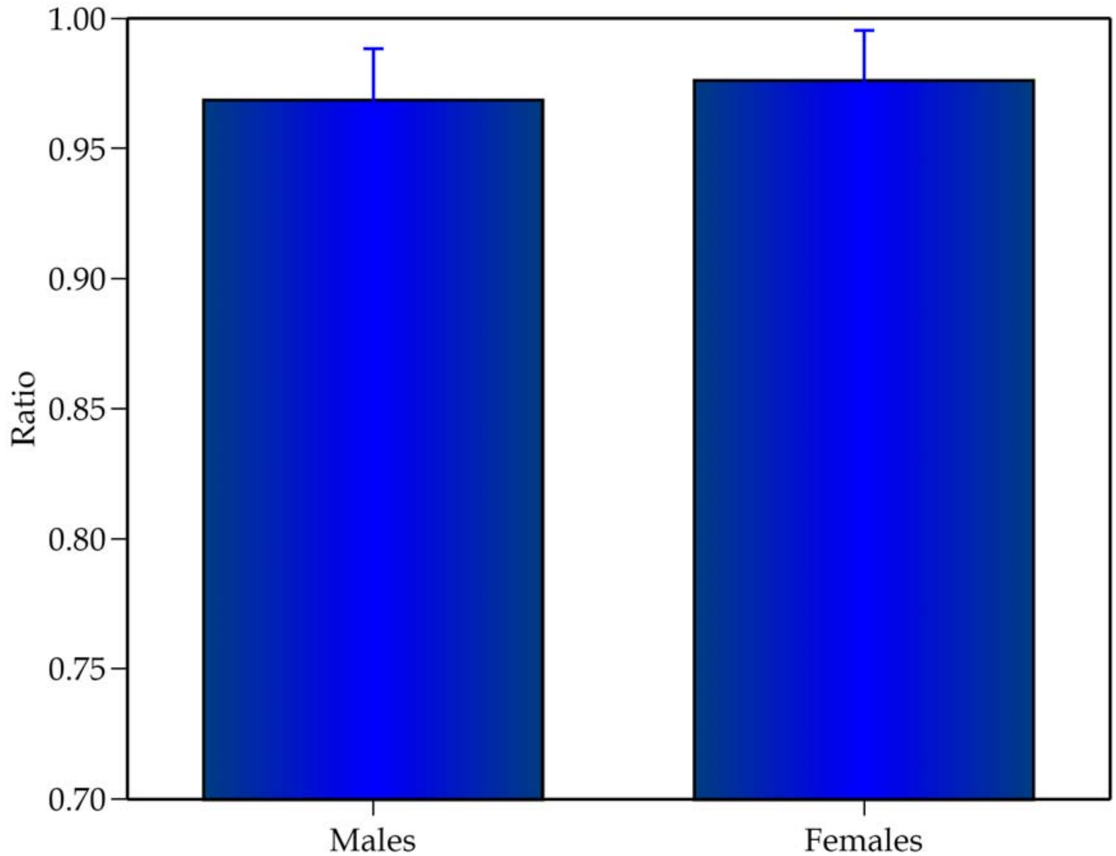


Figure 34. Mean dimension, by sex, for crown eccentricity ratio (medial height/lateral height) of the maxillary central incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

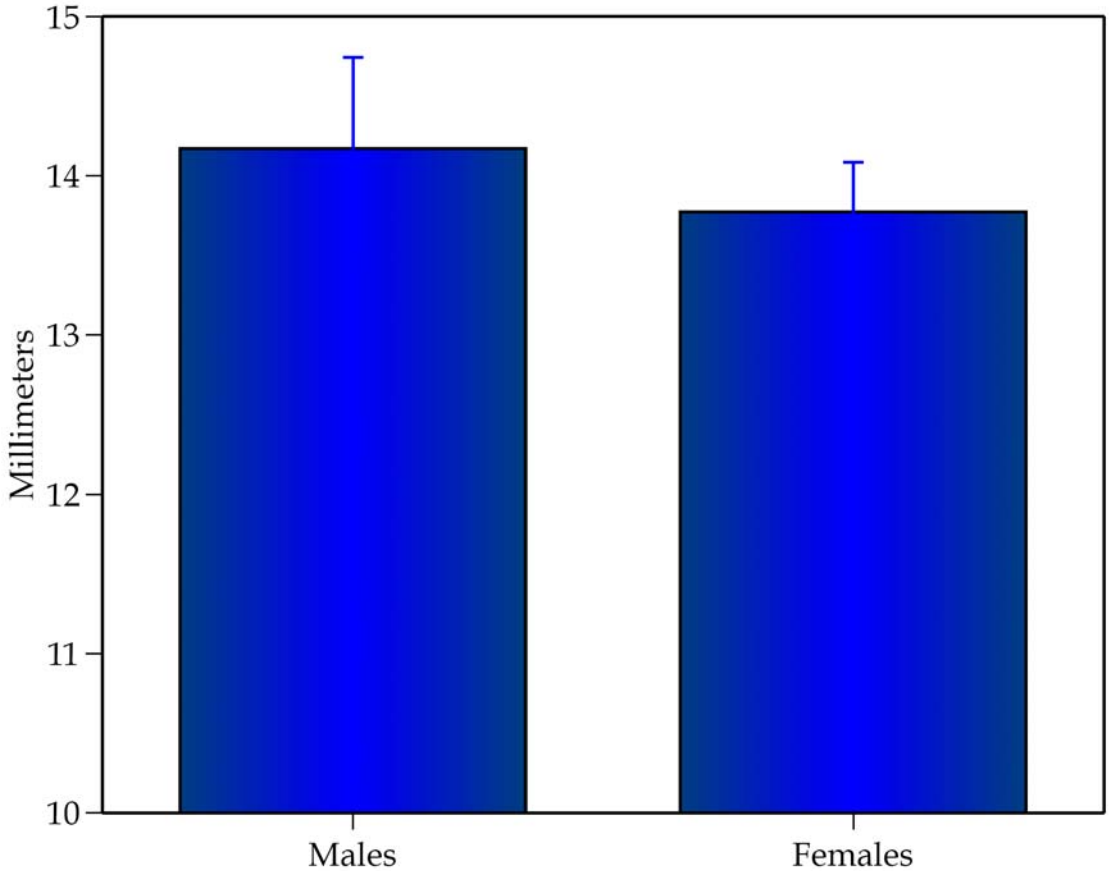


Figure 35. Mean dimension, by sex, for root height of the maxillary lateral incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

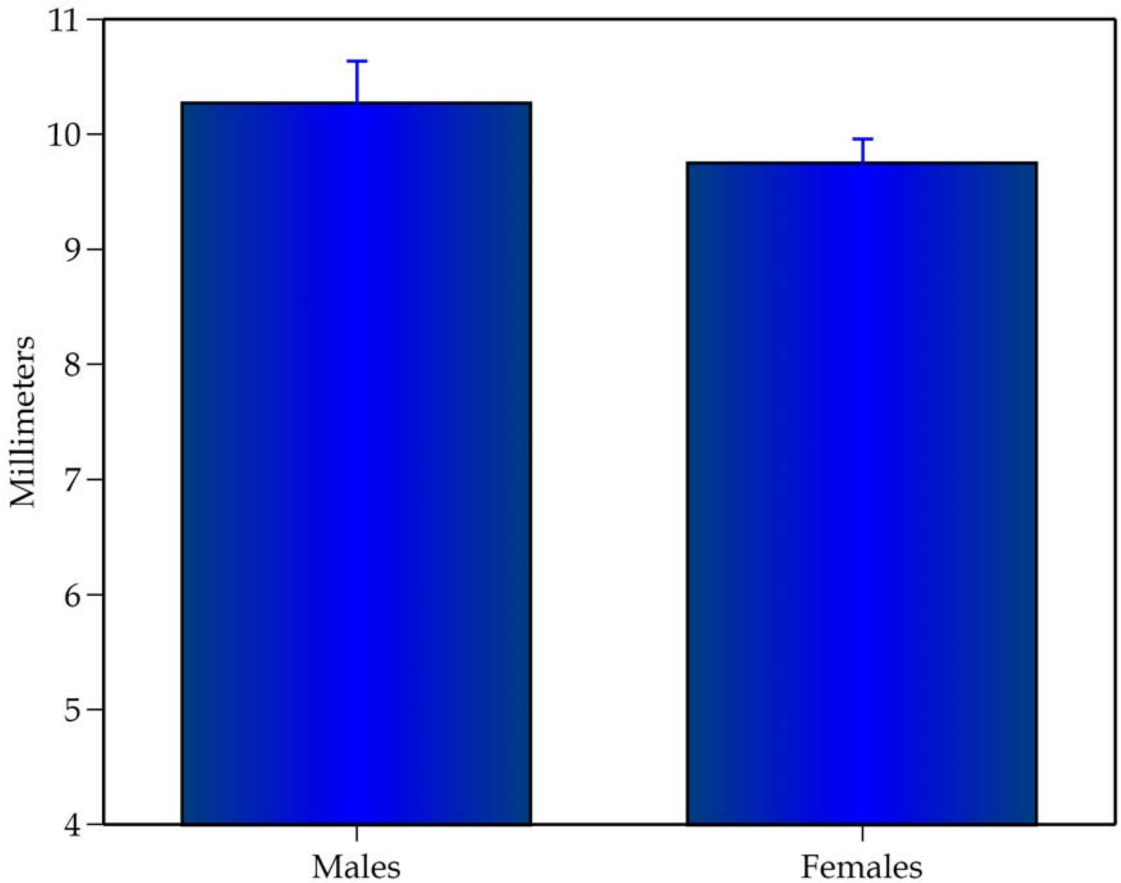


Figure 36. Mean dimension, by sex, for crown height of the maxillary lateral incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

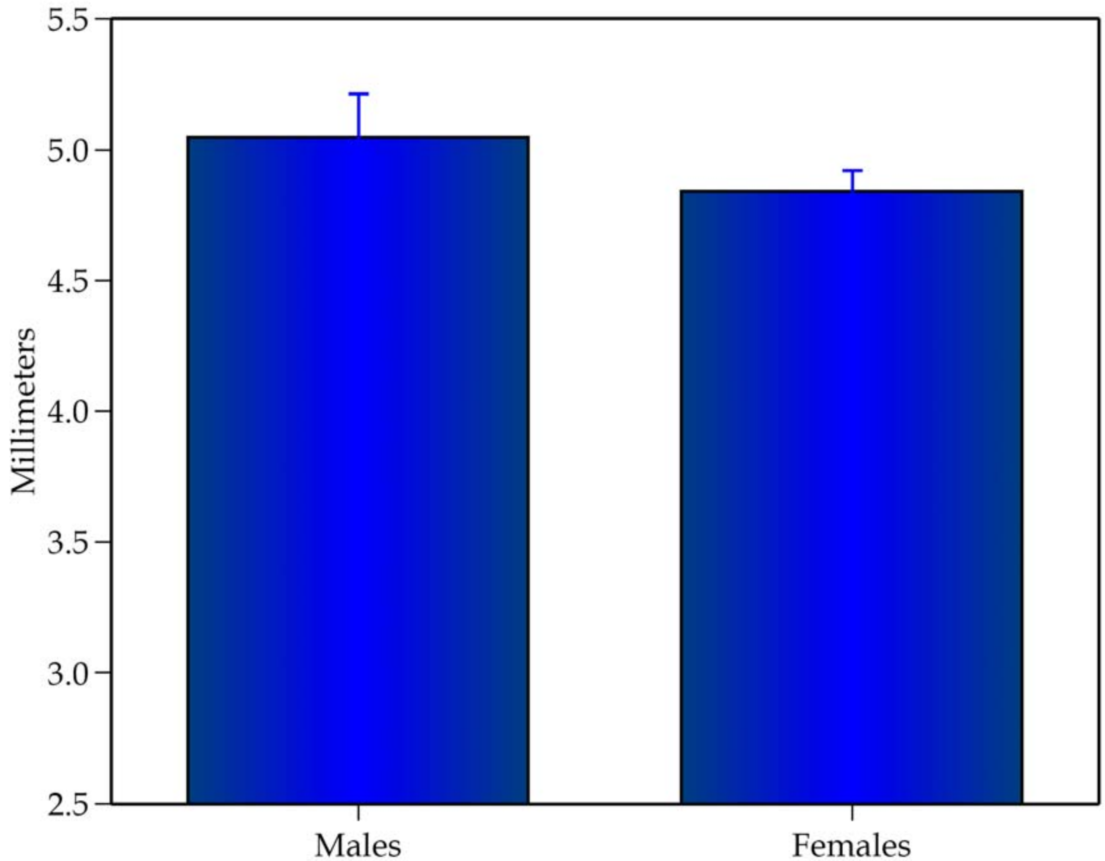


Figure 37. Mean dimension, by sex, for maximum mesiodistal crown width at the CEJ of the maxillary lateral incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

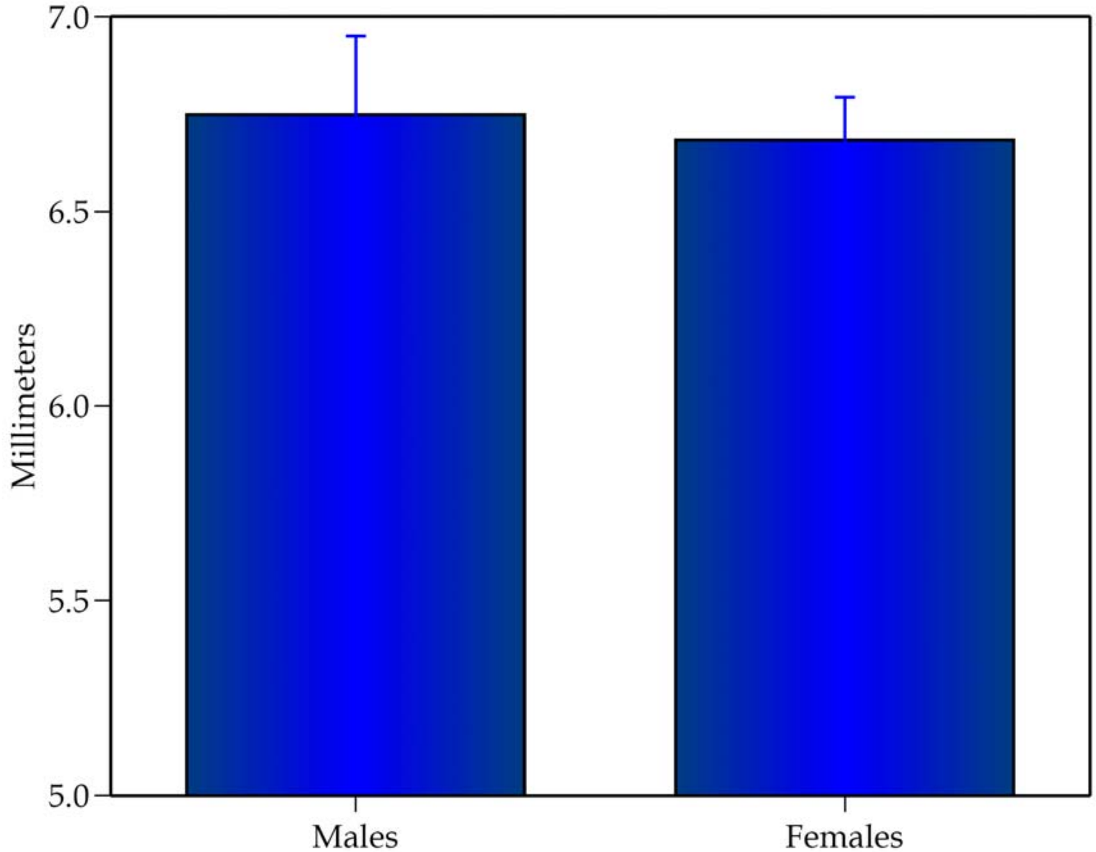


Figure 38. Mean dimension, by sex, for maximum mesiodistal crown width of the maxillary lateral incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

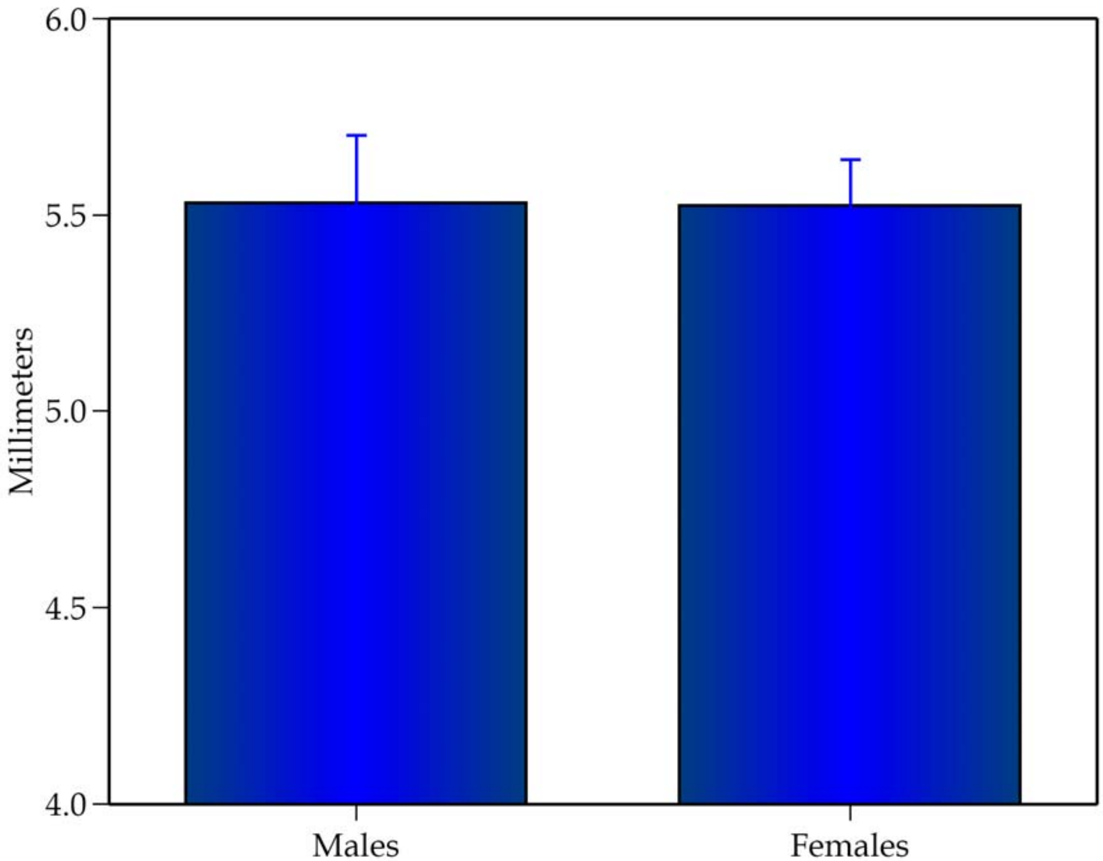


Figure 39. Mean dimension, by sex, for maximum mesiodistal crown width at the incisal edge of the maxillary lateral incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

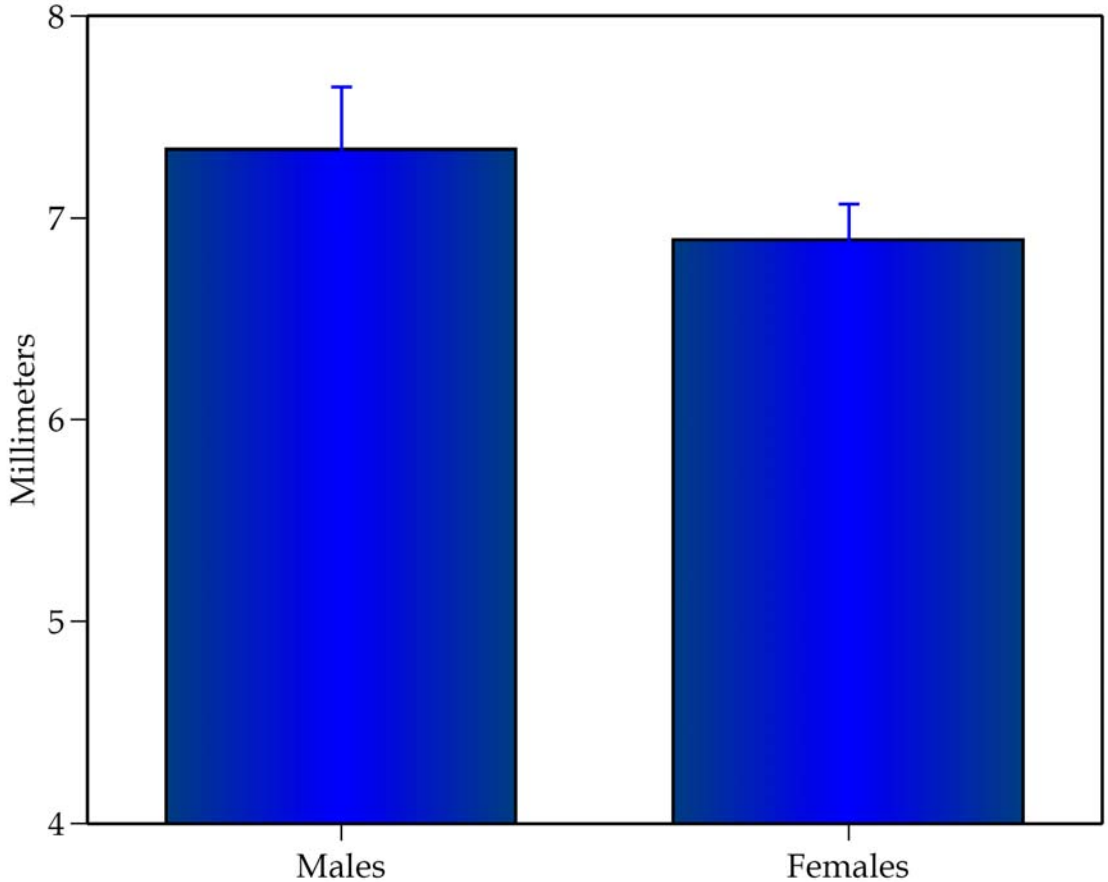


Figure 40. Mean dimension, by sex, for lateral crown height of the maxillary lateral incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

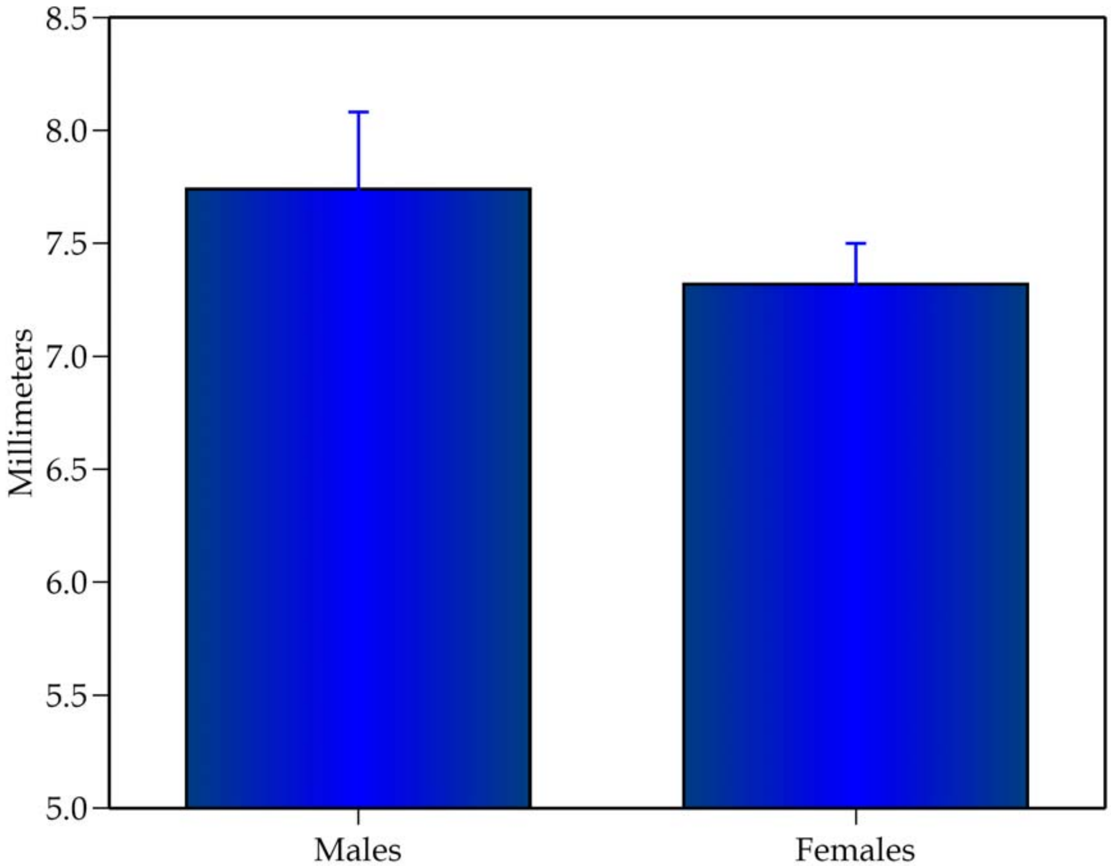


Figure 41. Mean dimension, by sex, for medial crown height of the maxillary lateral incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

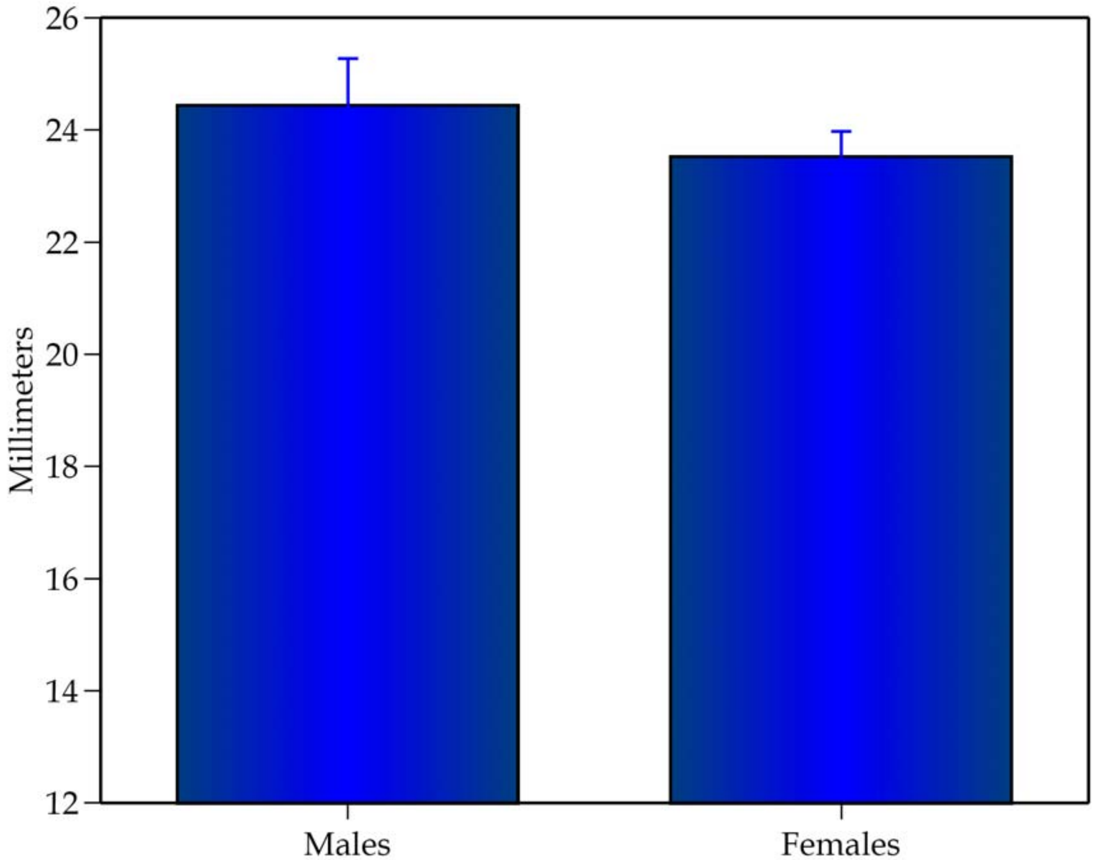


Figure 42. Mean dimension, by sex, for tooth length (root length + crown height) of the maxillary lateral incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

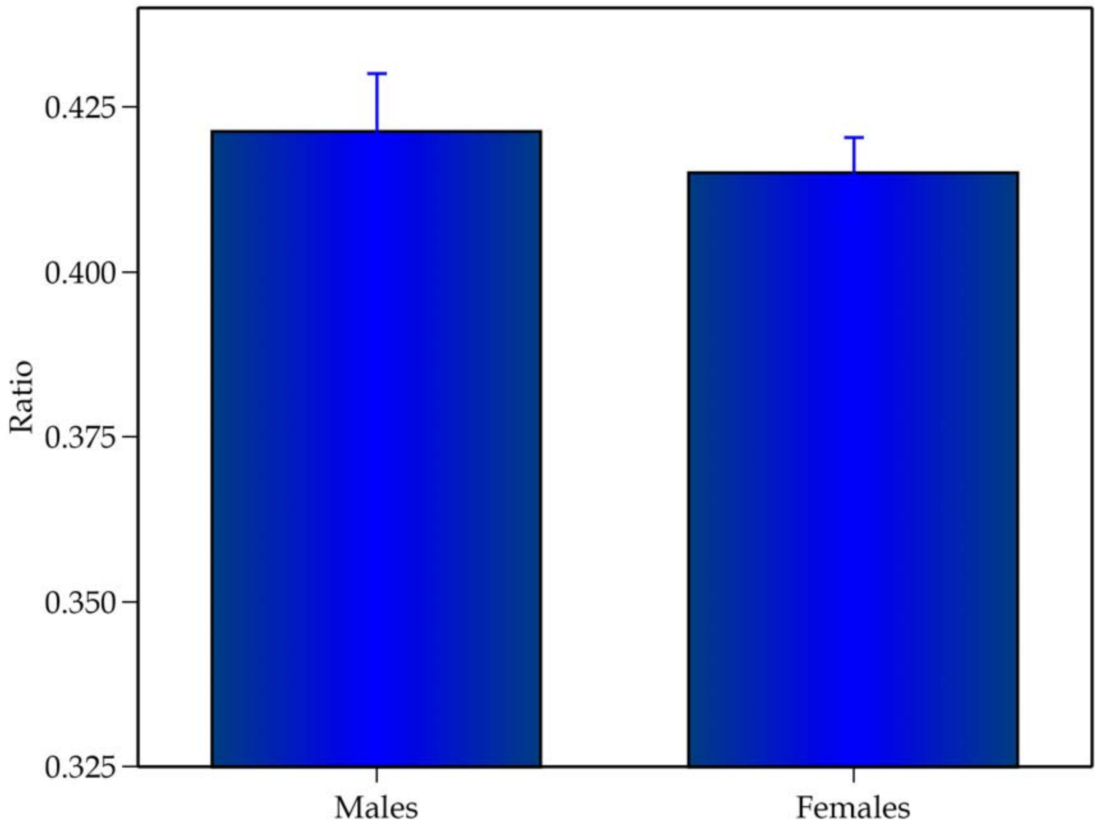


Figure 43. Mean dimension, by sex, for crown-to-root ratio (crown height/(crown height + root length)) of the maxillary lateral incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

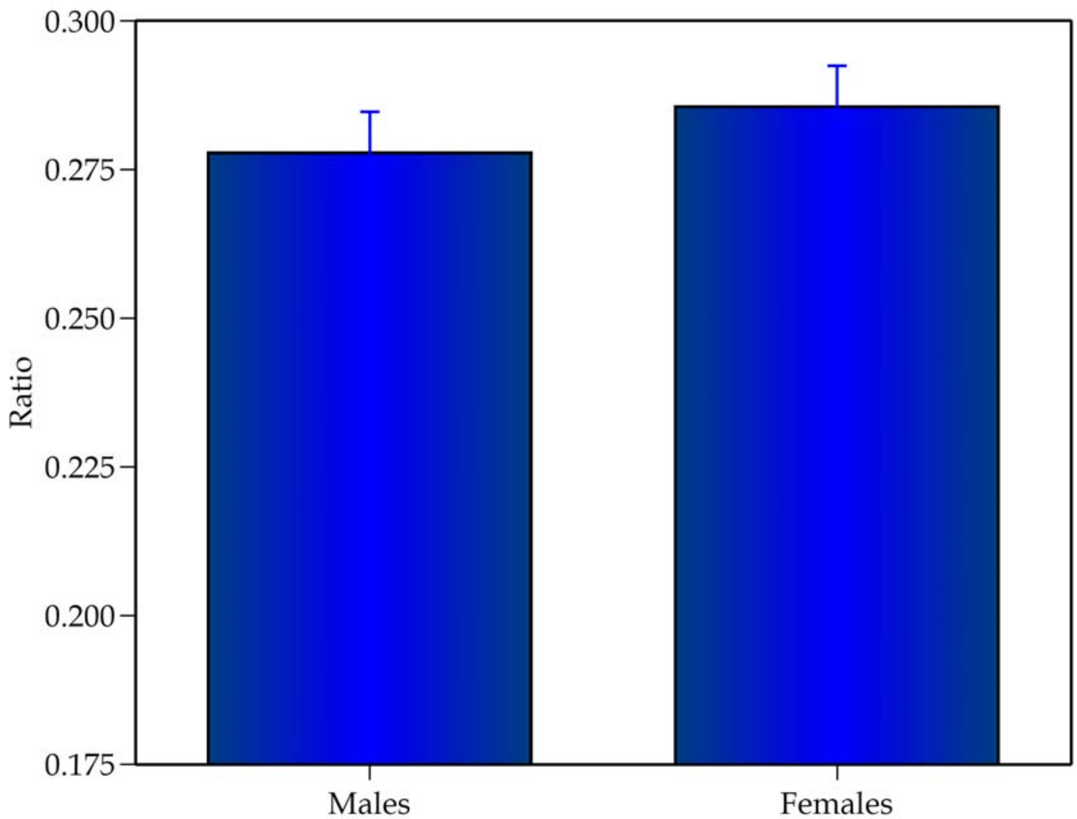


Figure 44. Mean dimension, by sex, for length-to-width ratio (maximum MD width/(crown height + root length)) of the maxillary lateral incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

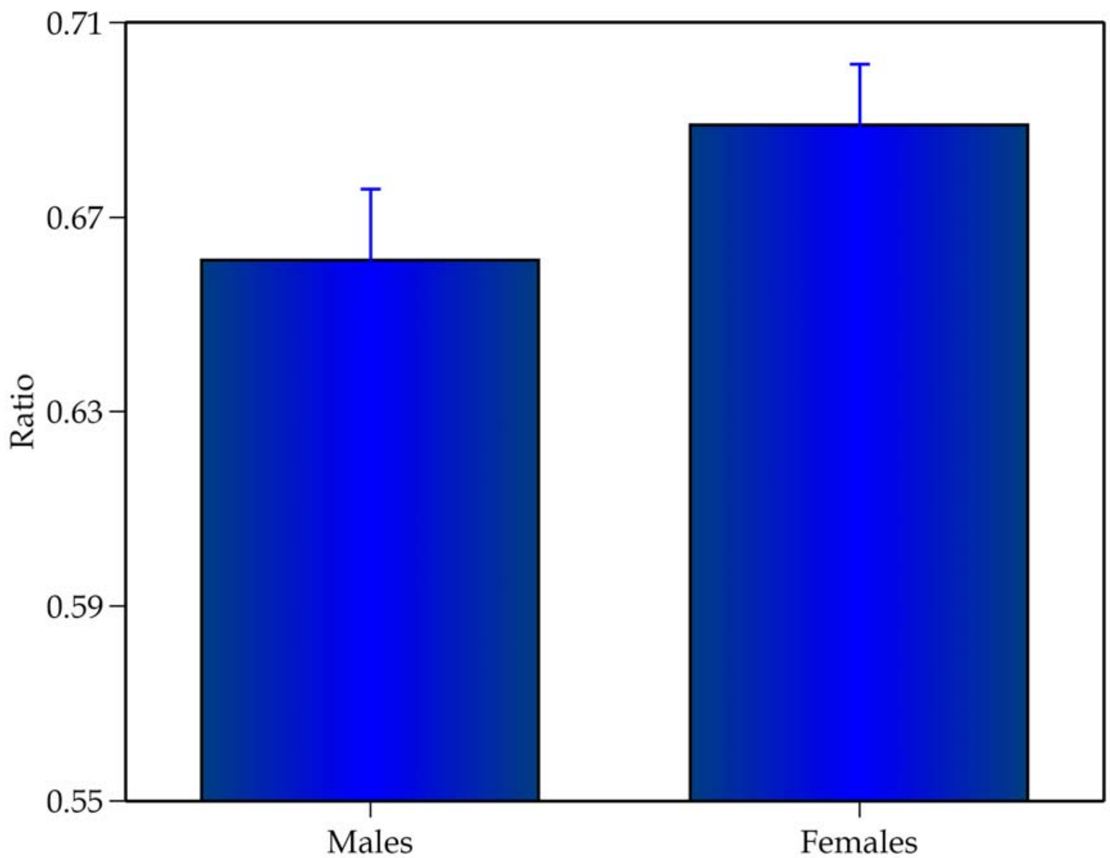


Figure 45. Mean dimension, by sex, for width-to-height ratio (maximum MD width/crown height) of the maxillary lateral incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

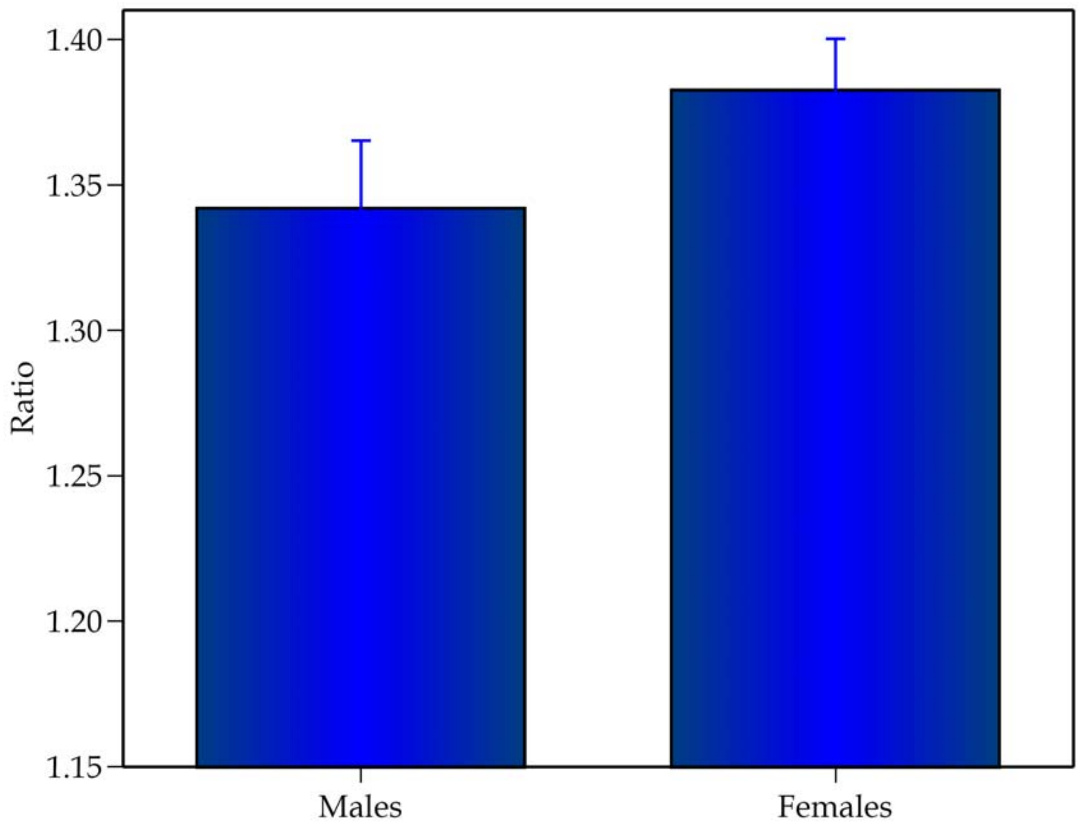


Figure 46. Mean dimension, by sex, for Flare 1 ratio (maximum MD width/CEJ width) of the maxillary lateral incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

This sex difference evidently does not continue through the midcrown portion of the crown because Flare 2 is not dimorphic (Figure 47). On the other hand, comparing CEJ width to crown width at the incisal edge (*i.e.*, Flare 3) discloses a highly significant difference (Figure 48). Again, females have a statistically larger ratio because I2 width at the CEJ is narrower in females compared to essentially no sex difference at the incisal edge.

The final variable assessed for I2, labeled eccentricity, shows no evidence of a sex difference. This measure of crown shape suggests that the vertical (occlusogingival) aspects of the I2 crown are the same between sexes (Figure 49).

For completeness, the possibility of sex differences was also tested for the four variables used to assess anterior crowding (Table 3). There is a substantial sex difference in incisor irregularity (P = 0.0026), with the mean for males being a full quarter larger than for females. This difference is commonly encountered (*e.g.*, Blair and Harris n.d.; Glassell and Harris n.d.), evidently because girls (and their parents) are more aware of esthetic dental issues and place more importance on them. This difference does point to another reason to control for "sex" in the statistical designs since the average girl presents with less-severe maxillary irregularity than the average boy.

"Tooth size," the summed mesiodistal size of the anterior six teeth is, predictably, greater in boys than in girls. This sum (space required) simply reiterates the sex difference described above for the individual incisors.

Of interest, arch size (space available) does not differ significantly between the sexes in this sample. Coupled with the greater space-required just noted, this suggests that boys ought to present with greater incisor irregularity—just as found here. Alternatively, TSASD does not differ between sexes in the present sample; both sexes exhibit a mean TSASD of about 1 mm. We have no ready explanation why these two measures of anterior crowding (irregularity and TSASD) yield different results, but the key inference is that they measure different aspects of a malocclusion (Harris *et al.* 1987).

Statistically, the association between irregularity and TSASD is low (Figure 50), with a correlation coefficient of -0.42 ($r^2 = 0.18$). In other words, the association is significant statistically (given the large sample size), but irregularity only shares about one-fifth of its variation with TSASD and *vice versa*. Figure 50 shows one major difference in these two measures in that incisor irregularity is essentially a measure of crowding (negative TSASD scores). Irregularity scores are lower when there is generalized spacing than when crowding occurs. This is evident when the least-squares regression line is fit to the data.

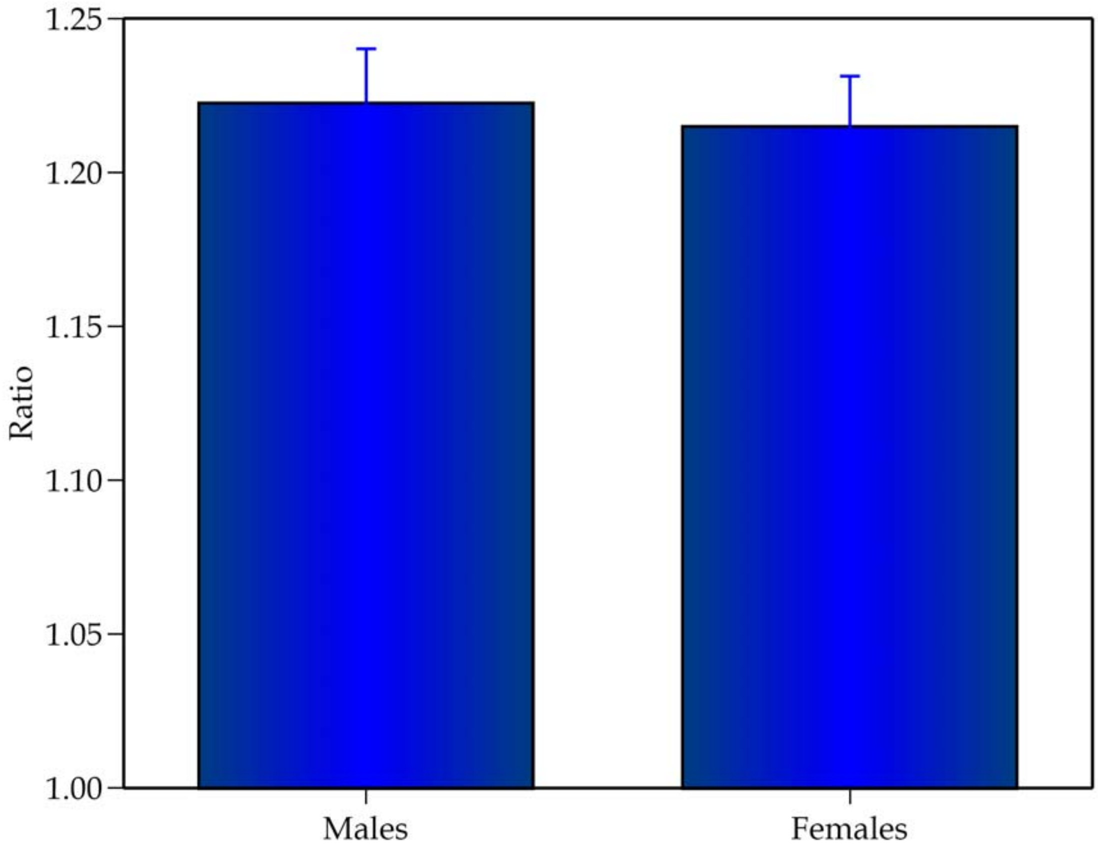


Figure 47. Mean dimension, by sex, for Flare 2 ratio (maximum MD width/incisal MD width) of the maxillary lateral incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

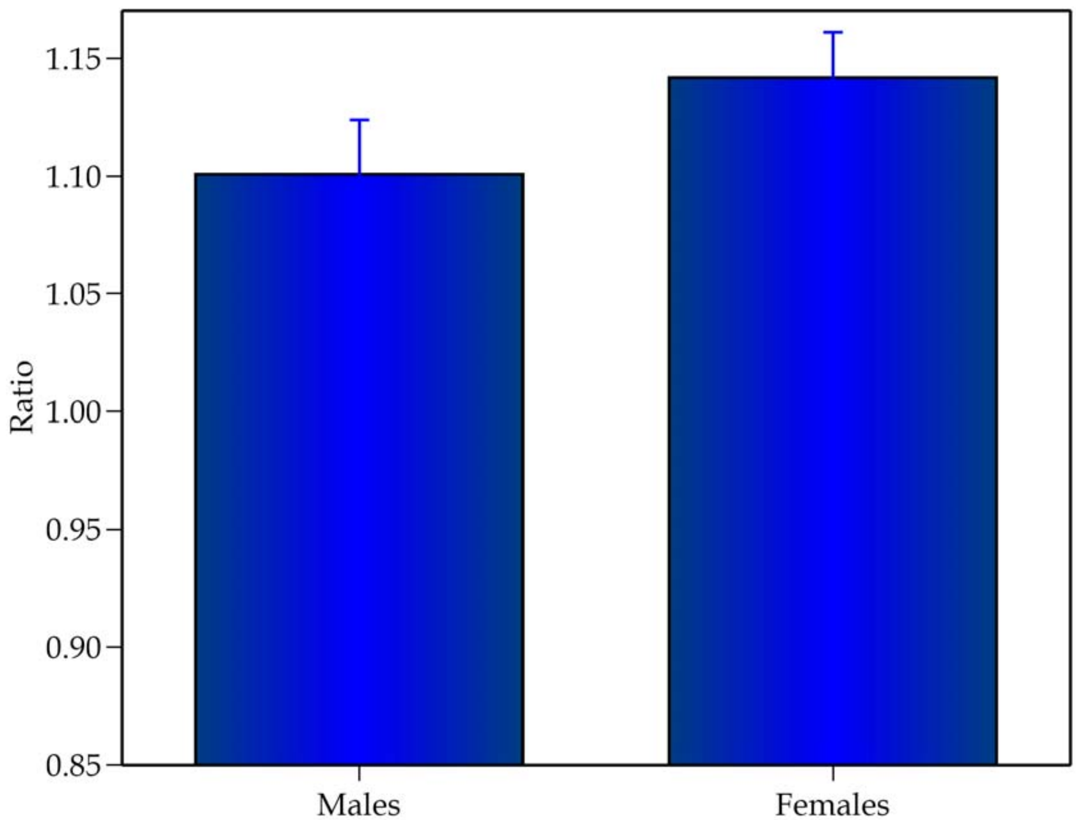


Figure 48. Mean dimension, by sex, for Flare 3 ratio (incisal MD width/CEJ width) of the maxillary lateral incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

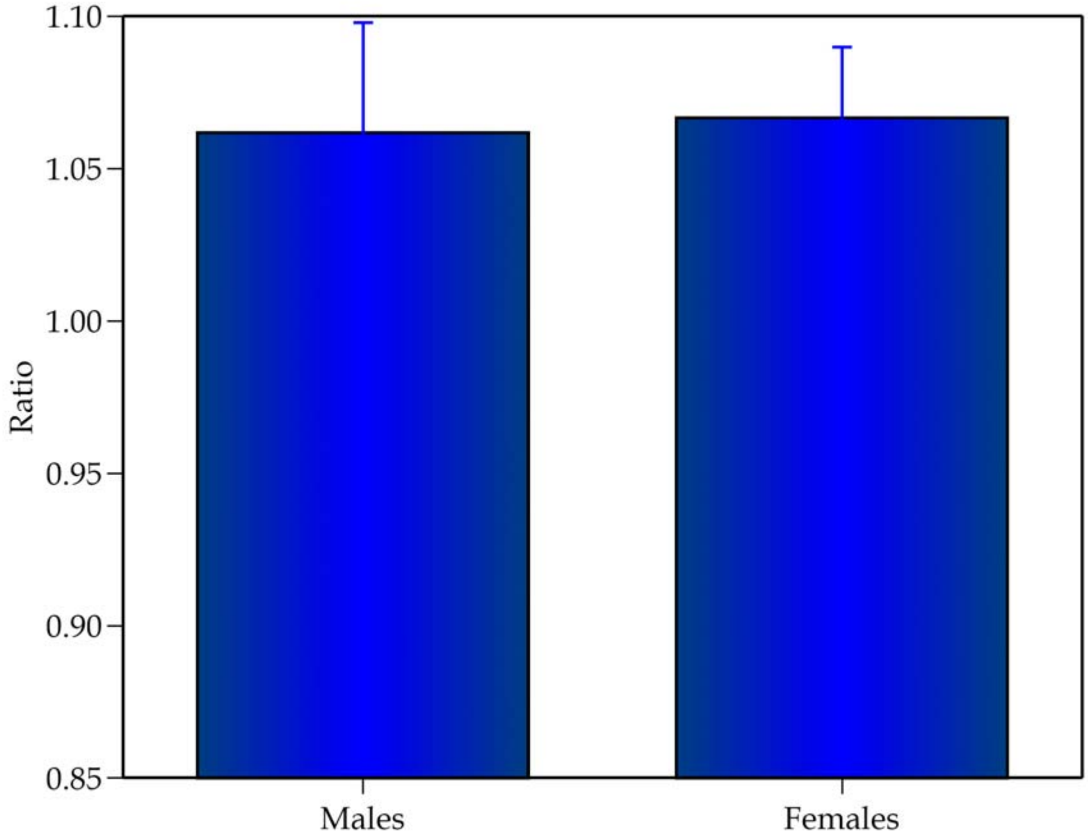


Figure 49. Mean dimension, by sex, for eccentricity ratio (medial height/lateral height) of the maxillary lateral incisor. Error bars are the 95% confidence limits of the mean. Approximately, two means are significantly different when the 95% confidence limits do not overlap vertically.

Table 3. Analysis of variance testing for sexual dimorphism in variables measured on the measures of malocclusion.

Variable	Male mean	Female mean	Percent Dimorphism	Analysis of Variance		
				MS	F Ratio	P Value
Irregularity Index	10.26	8.14	26.06	162.63	9.40	0.0026
Tooth Size	47.43	45.95	3.23	79.44	12.83	0.0005
Arch Size	48.23	47.02	2.58	53.06	3.10	0.0801
TSASD	0.80	1.07	-25.21	2.65	0.14	0.7131

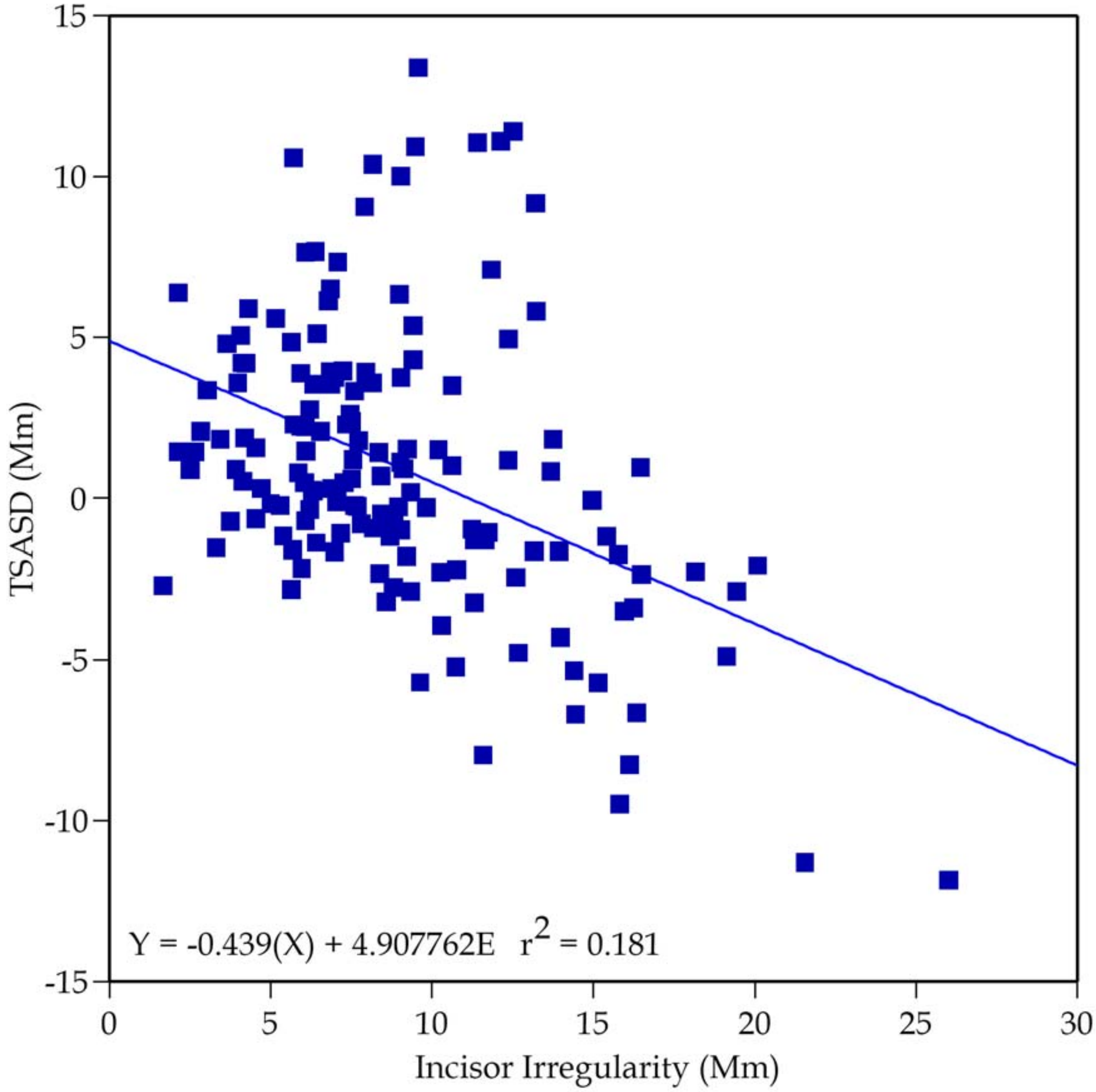


Figure 50. Scatterplot with the least squares line is fit to the data, showing the association between incisor irregularity and TSASD in the maxillary anterior segment.

Figure 50 also shows that the least-squares line does not reflect the scattering of cases in the top-left quadrant of the graph where there is little irregularity but appreciable spacing (large positive TSASD scores). A curve (polynomial model) probably would fit the data better. This is shown to be true (Figure 51). A linear model accounts for about one-fifth of the variation (r^2 = 18.1%), but the fit improves significantly with a second-order polynomial (r^2 = 23.1%).

Tooth Dimensions and Angle's Classification

There is some evidence that tooth sizes are tied statistically (and, then, by inference developmentally) to the type of malocclusion and measured by Angle's molar classification (Figure 52). Largely for completeness, we tested whether any of our 15 tooth dimensions and ratios differed by Angle's class. There were too few Class III cases, so the three classes tested were Class I, Class II division 1, and Class II division 2. Patient's sex was included in the two-way ANOVA model to account for this source of variation. Results are shown for the maxillary central incisor (Table 4) and lateral incisor (Table 5).

Associations between dimensions of the central incisor with Angle's classification seem to be trivial (Table 4). Only one of the 15 dimensions is marginally significant statistically ($0.05 > P > 0.01$), which is about the number expected from chance alone. On the other hand, five of the dimensions of the lateral incisor achieve significance, and these are reviewed in some detail.

Root height does not differ by Angle's Class (Figure 53), but crown height (Figure 54) differs significantly among classes because the Class II, division 2 group is shorter. By itself, this might be argued away because of the diminished crown root angulation (Harris *et al.* 1993) and, thus, the potentially altered crown-to-film angulation. However, the difference in collum angle does not account for the inter-class differences seen in mesiodistal dimensions. Mesiodistal width at the CEJ (Figure 55), at midcrown height (Figure 56), and at the incisal edge (Figure 57) all are significantly narrower in the Class II division 2 group. Of note, crown heights measured at the medial and lateral margins do not differ among groups (Figures 58, 59), which suggest that the smaller dimensions seen for other dimensions of the Class II division 2 sample are not due to foreshortening.

Tooth length by itself does not differ among classes (Figure 60), but the crown-root ratio is significantly smaller in the Class II, division 2 sample (Figure 61). None of the six other crown ratios differed among the three Classes tested (Figures 62-67).

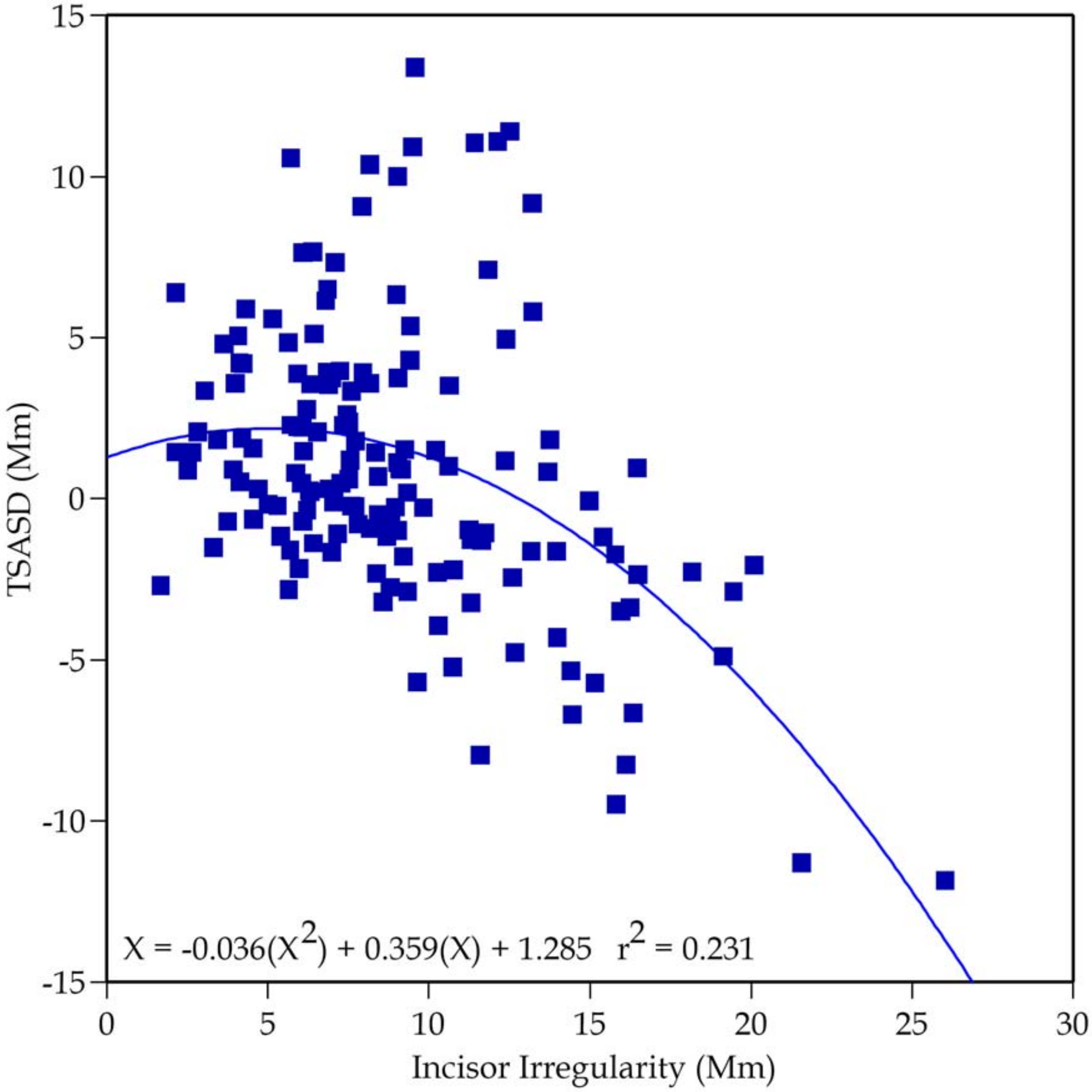


Figure 51. Scatterplot of a second order polynomial fit to the data, showing the association between incisor irregularity and TSASD in the maxillary anterior segment.

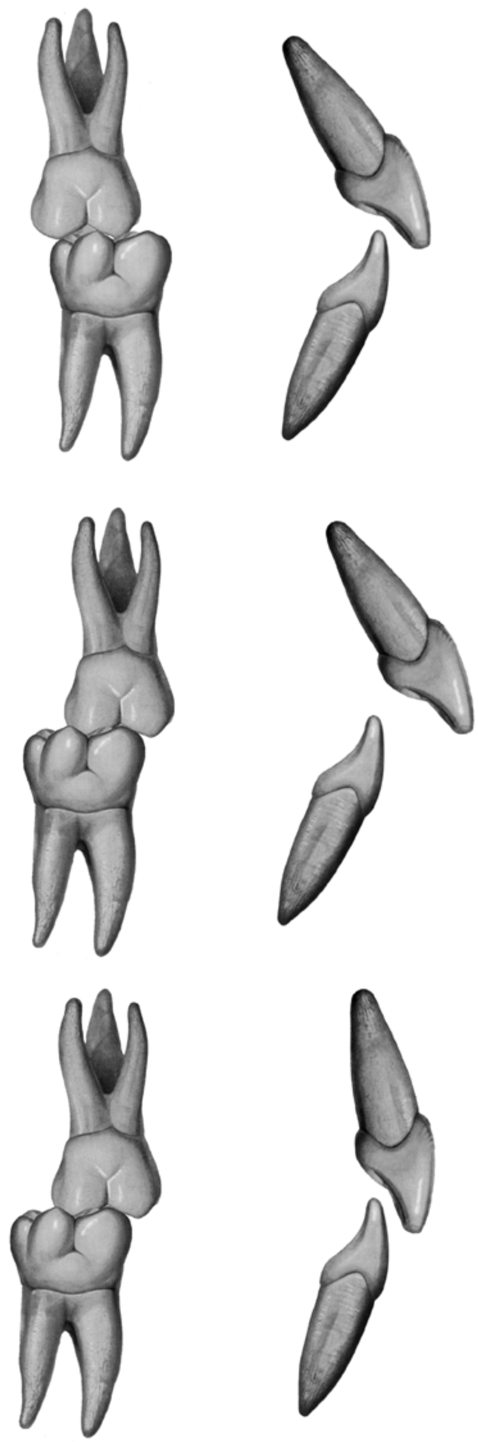


Figure 52. Schematic views of the three Angle classes tested here. ***Top***, Angle Class I, division 1. ***Middle***, Angle Class II, division 1. ***Bottom***, Angle Class II, division 2.

Table 4. Results of testing for differences among Angle Classes for the maxillary central incisor.

	Angle Classification			Patient's Sex			Interaction Effect		
Variable	df	F Ratio	P Value	df	F Ratio	P Value	df	F Ratio	P Value
Root Height	2	1.70	0.1860	1	3.74	0.0552	2	0.68	0.5095
Crown Height	2	1.58	0.2096	1	2.93	0.0891	2	1.13	0.3274
MD Width at CEJ	2	1.60	0.2056	1	8.24	0.0047	2	0.63	0.5339
Maximum MD Width	2	1.23	0.2962	1	4.59	0.0338	2	1.24	0.2941
Incisal MD Width	2	0.93	0.3953	1	6.58	0.0114	2	0.95	0.3897
Lateral Crown Height	2	3.67	0.0281	1	1.45	0.2309	2	1.54	0.2171
Medial Crown Height	2	1.17	0.3148	1	3.74	0.0551	2	1.49	0.2295
Tooth Length	2	2.03	0.1351	1	5.04	0.0264	2	1.19	0.3069
Crown-Root	2	1.13	0.3266	1	0.57	0.4514	2	0.03	0.9734
Length-Width	2	0.79	0.4574	1	0.66	0.4175	2	0.19	0.8313
Width-Height	2	0.24	0.7888	1	0.07	0.7982	2	0.19	0.8310
Flare 1	2	0.52	0.5985	1	2.11	0.1488	2	0.00	0.9983
Flare 2	2	0.07	0.9309	1	1.79	0.1830	2	0.35	0.7077
Flare 3	2	0.43	0.6514	1	0.13	0.7163	2	0.11	0.8941
Crown Eccentricity	2	1.26	0.2866	1	1.60	0.2074	2	0.90	0.4090

Table 5. Results of testing for differences among Angle Classes for the maxillary lateral incisor.

	Angle Classification			Patient's Sex			Interaction Effect		
Variable	df	F Ratio	P Value	df	F Ratio	P Value	df	F Ratio	P Value
Root Height	2	1.81	0.1676	1	2.39	0.1247	2	1.24	0.2928
Crown Height	2	4.67	0.0110	1	3.56	0.0614	2	1.89	0.1544
MD Width at CEJ	2	3.80	0.0248	1	2.33	0.1290	2	0.70	0.5001
Maximum MD Width	2	7.21	0.0011	1	0.07	0.7931	2	3.32	0.0390
Incisal MD Width	2	4.52	0.0126	1	0.14	0.7077	2	1.64	0.1982
Lateral Crown Height	2	2.44	0.0914	1	4.80	0.0302	2	1.35	0.2627
Medial Crown Height	2	0.88	0.4167	1	3.72	0.0559	2	0.62	0.5388
Tooth Length	2	2.57	0.0802	1	3.52	0.0627	2	0.73	0.4826
Crown-Root	2	3.58	0.0305	1	0.04	0.8482	2	4.47	0.0131
Length-Width	2	2.21	0.1136	1	6.02	0.0154	2	3.42	0.0355
Width-Height	2	0.04	0.9642	1	7.32	0.0077	2	0.28	0.7585
Flare 1	2	0.78	0.4616	1	6.80	0.0101	2	1.94	0.1480
Flare 2	2	0.18	0.8371	1	0.01	0.9400	2	1.19	0.3064
Flare 3	2	0.15	0.8574	1	4.51	0.0355	2	0.43	0.6489
Crown Eccentricity	2	2.13	0.1223	1	0.00	0.9598	2	0.15	0.8586

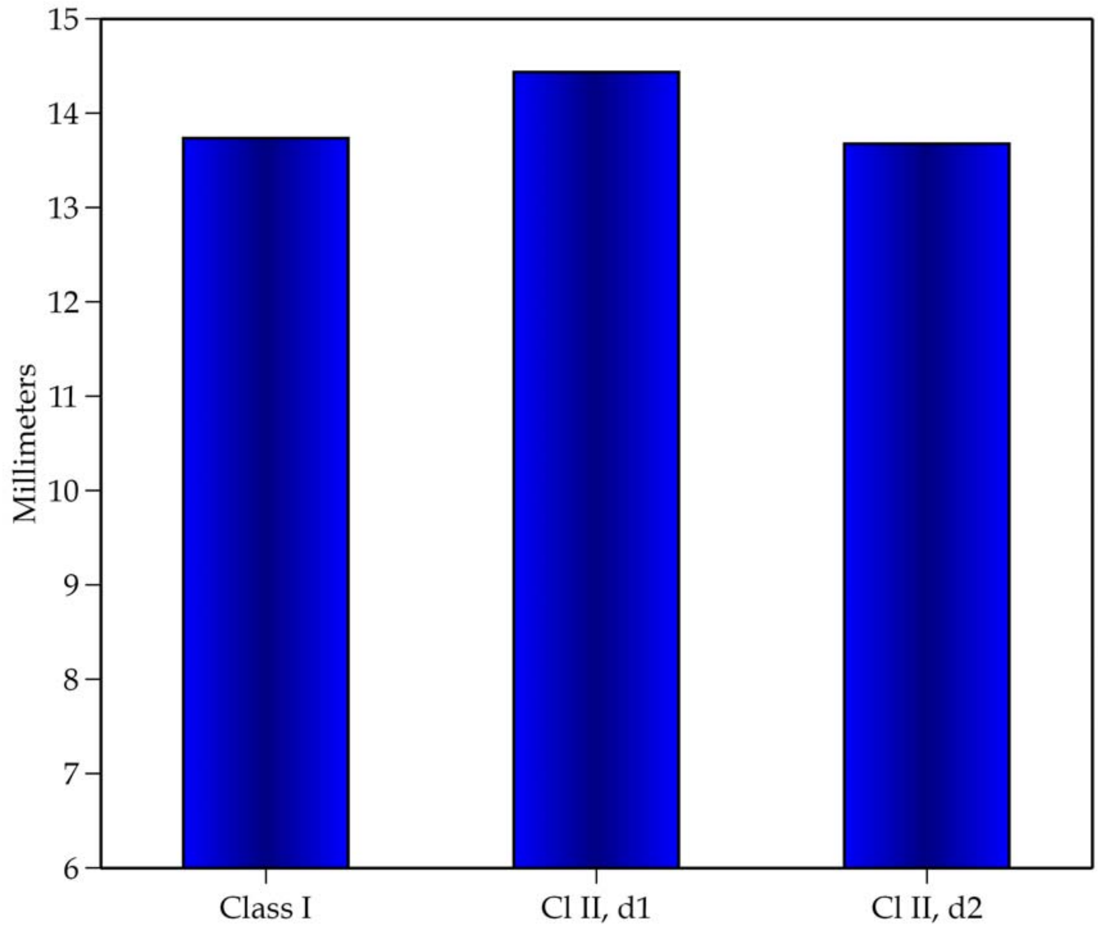


Figure 53. Results of a two-way ANOVA between root height and Angle's class for the lateral incisor.

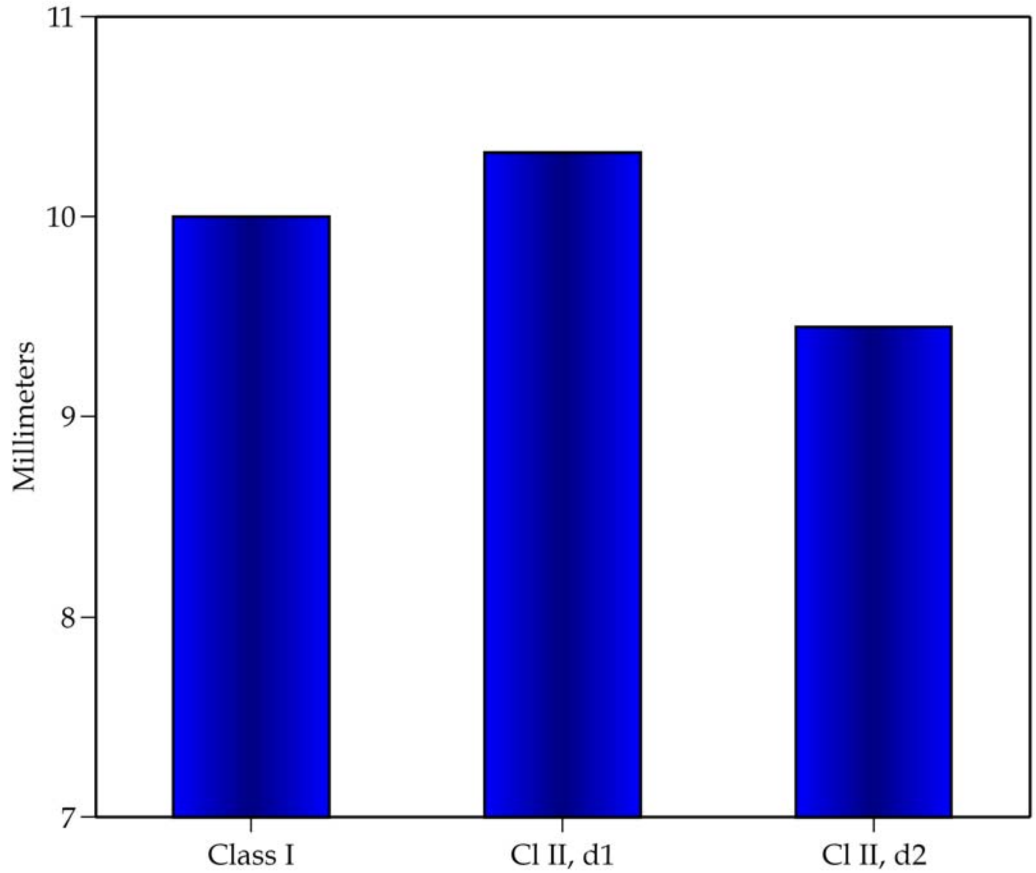


Figure 54. Results of a two-way ANOVA between crown height and Angle's class for the lateral incisor.

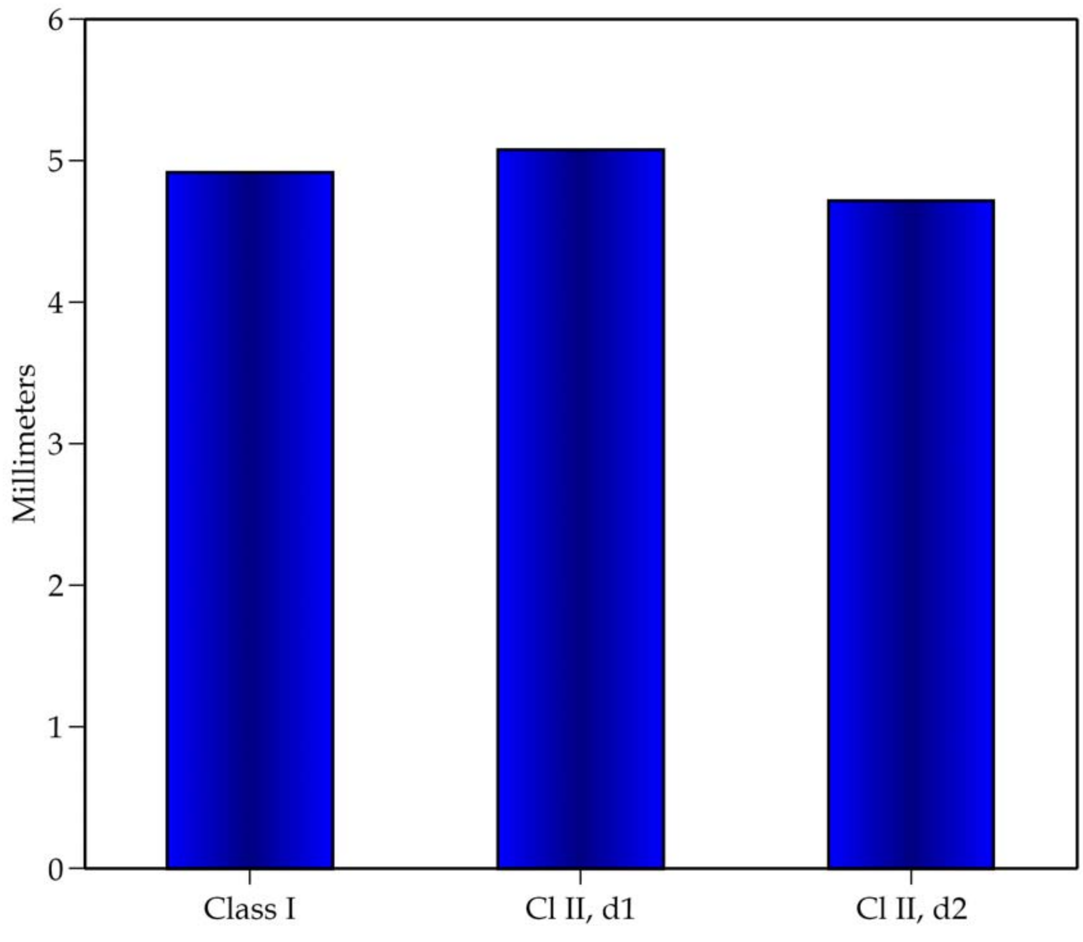


Figure 55. Results of a two-way ANOVA between MD width at CEJ and Angle's class for the lateral incisor.

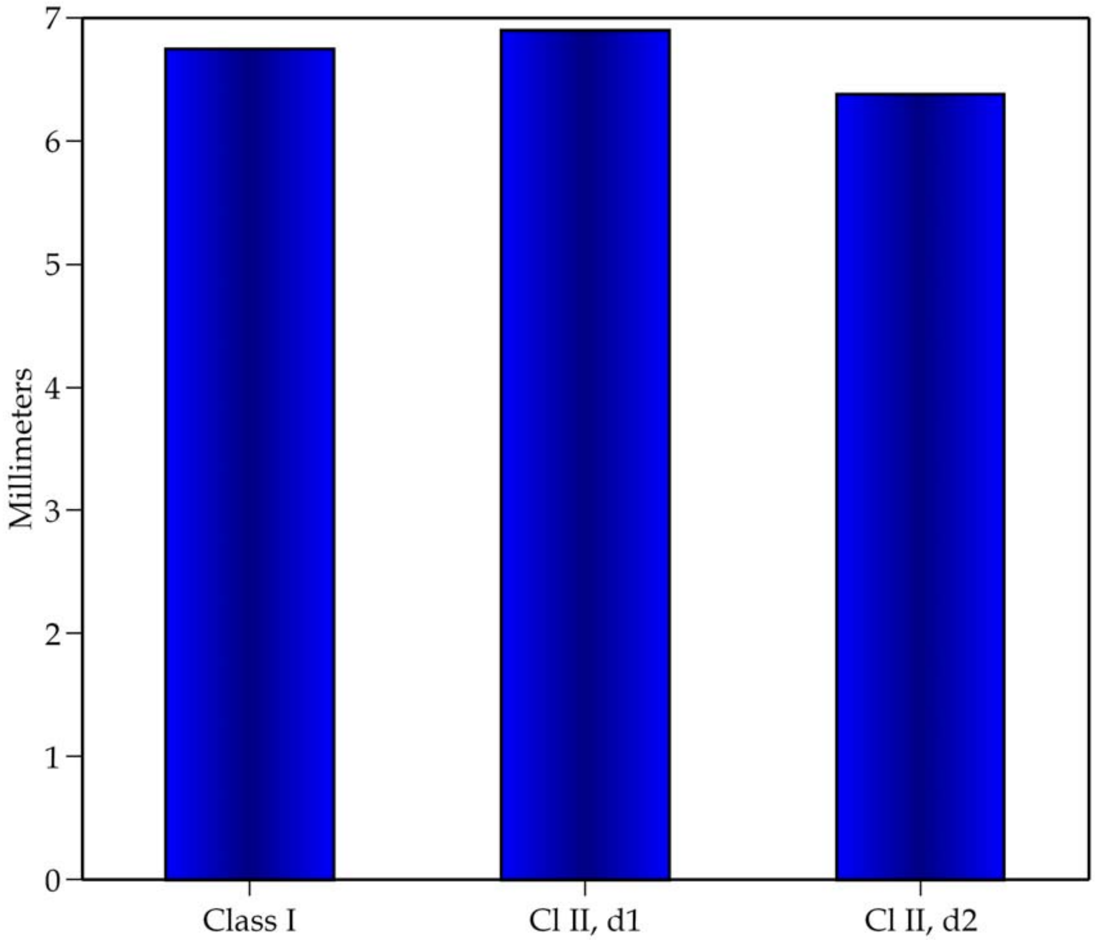


Figure 56. Results of a two-way ANOVA between maximum MD width and Angle's class for the lateral incisor.

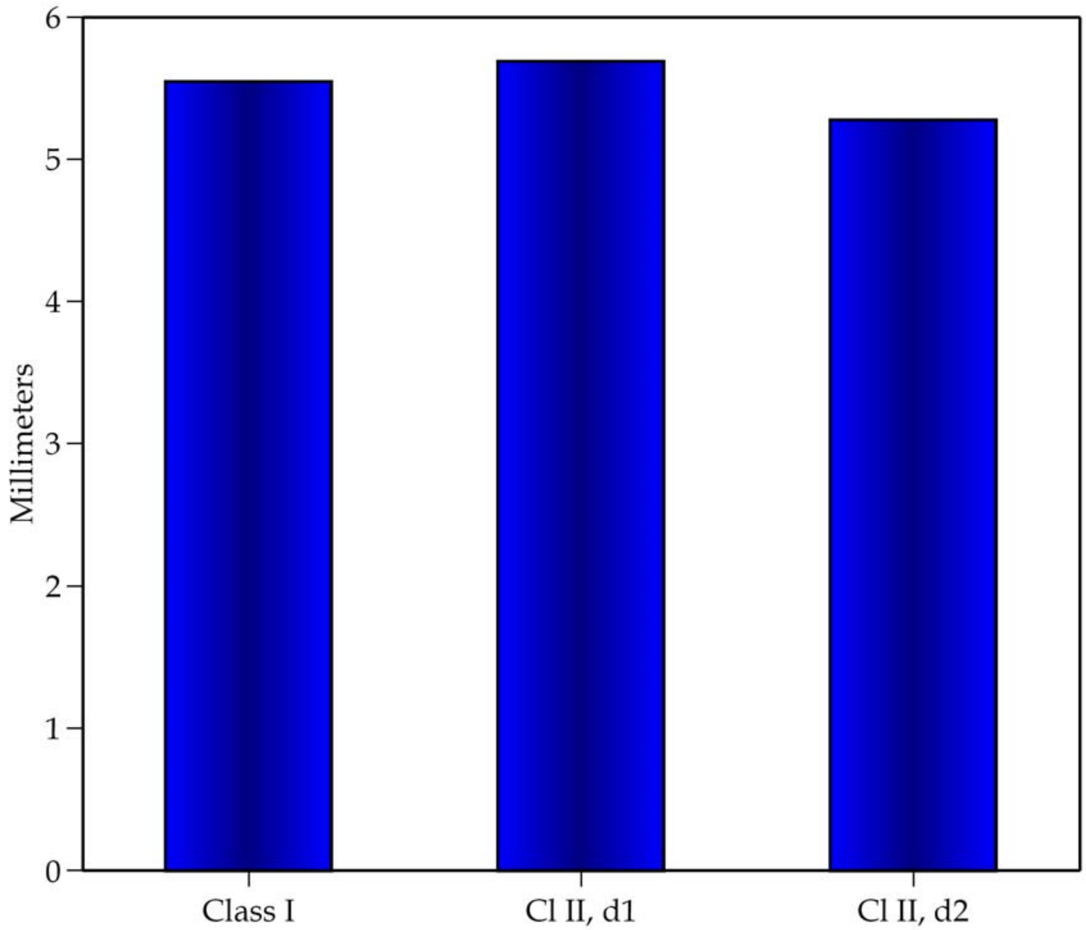


Figure 57. Results of a two-way ANOVA between incisal MD width and Angle's class for the lateral incisor.

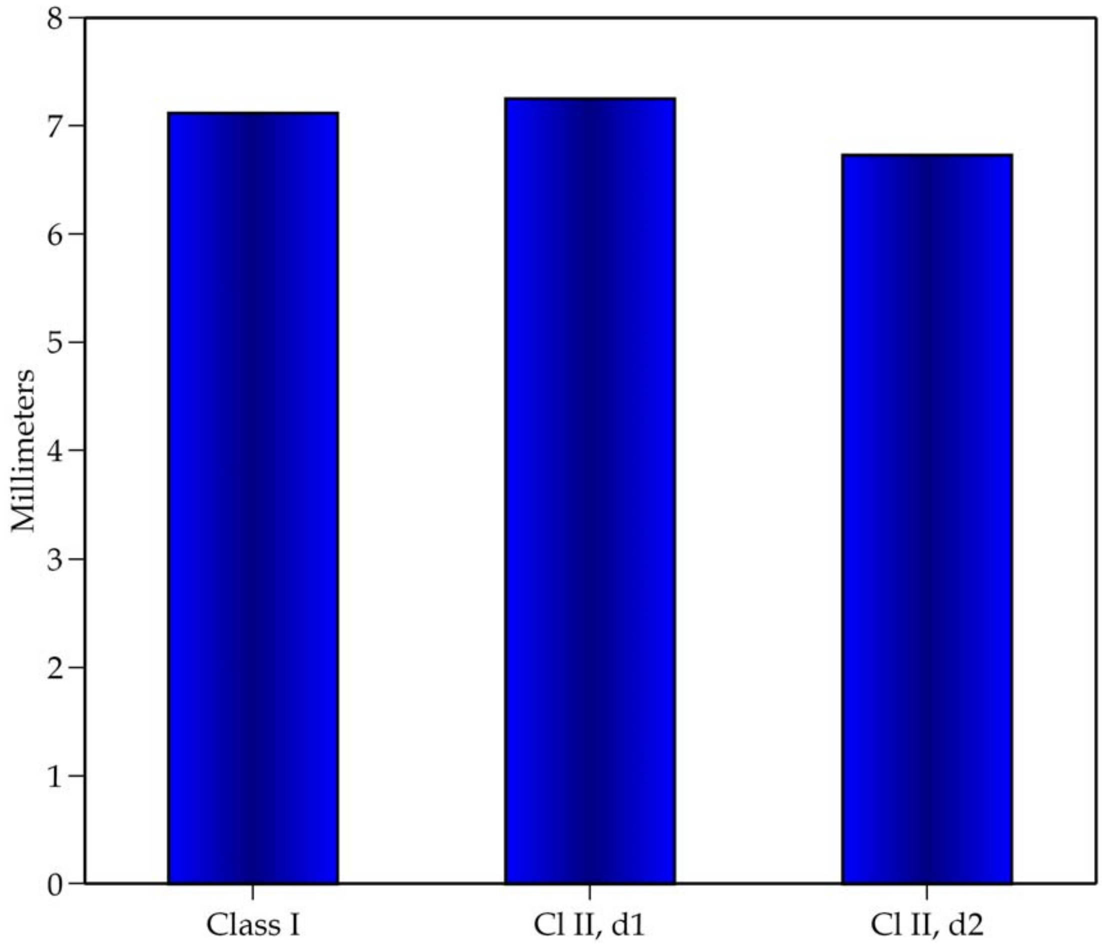


Figure 58. Results of a two-way ANOVA between lateral crown height and Angle's class for the lateral incisor.

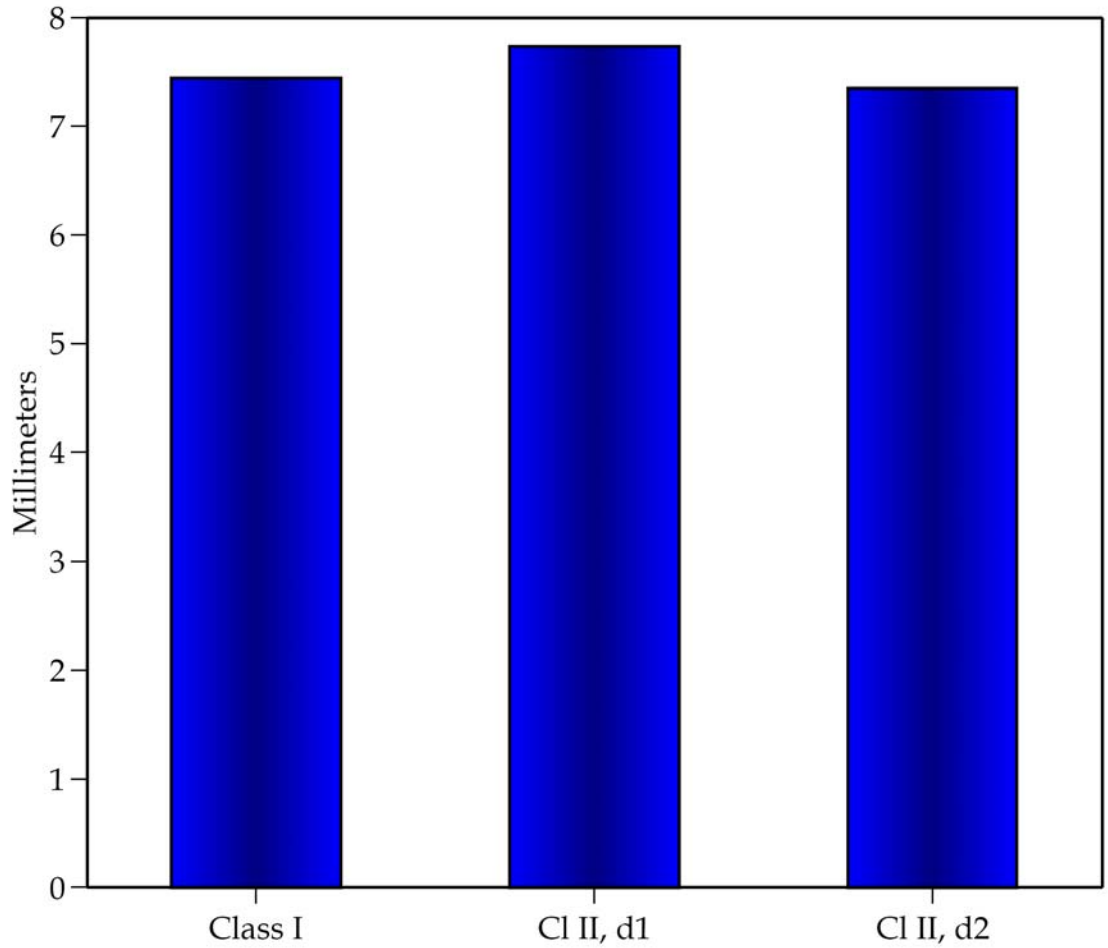


Figure 59. Results of a two-way ANOVA between medial crown height and Angle's class for the lateral incisor.

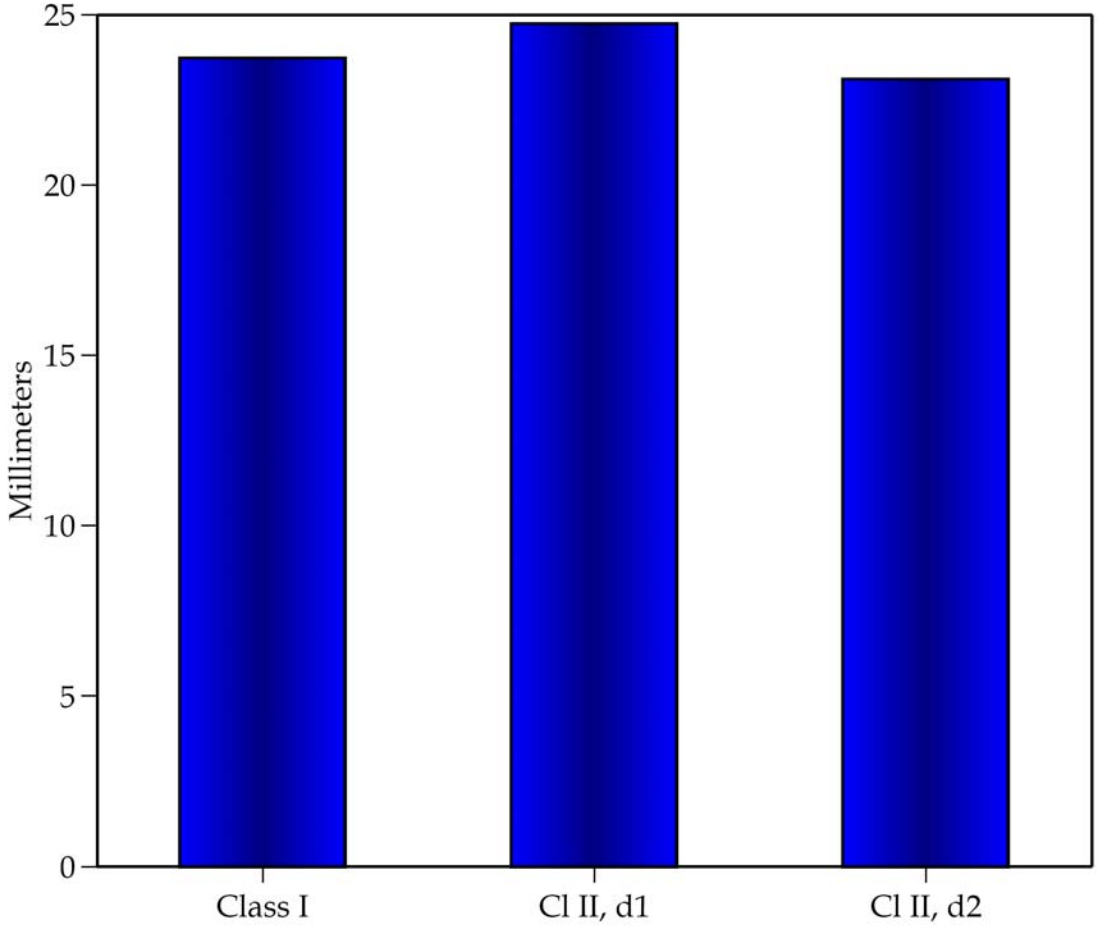


Figure 60. Results of a two-way ANOVA between tooth length and Angle's class for the lateral incisor.

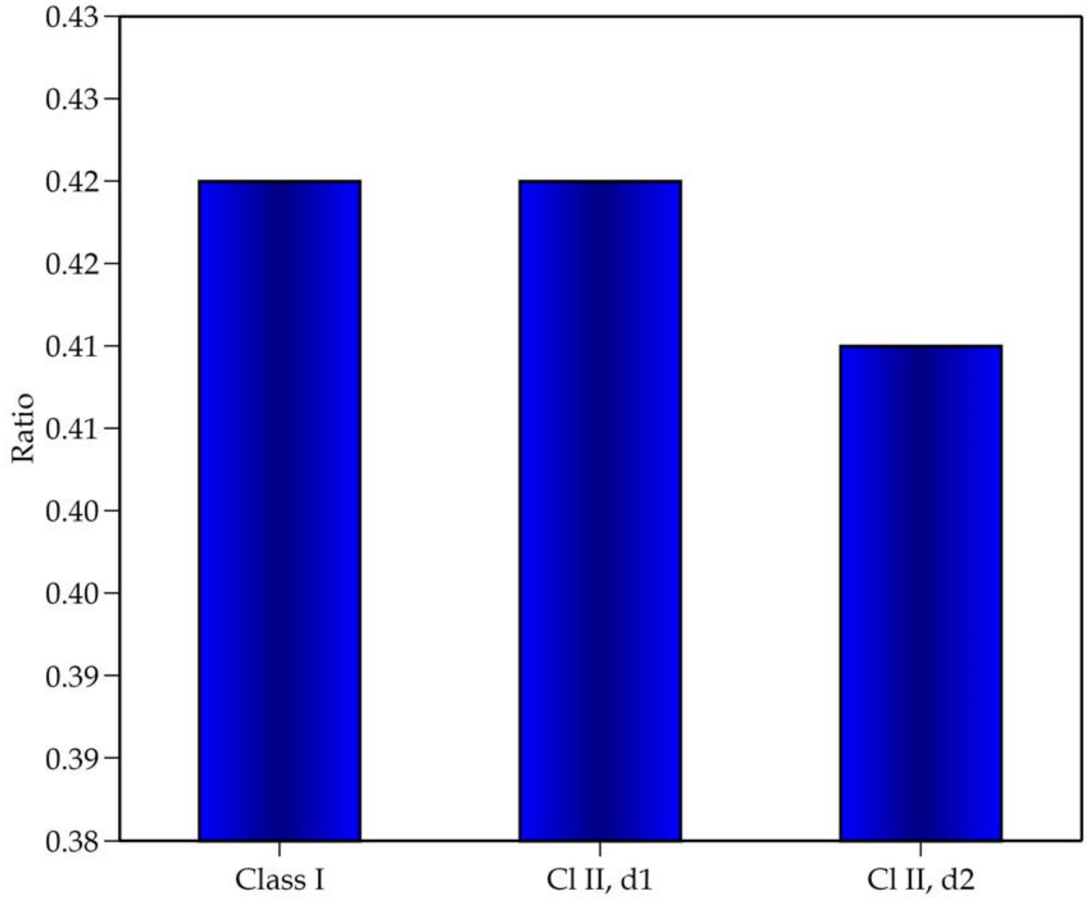


Figure 61. Results of a two-way ANOVA between crown-to-root ratio and Angle's class for the lateral incisor.

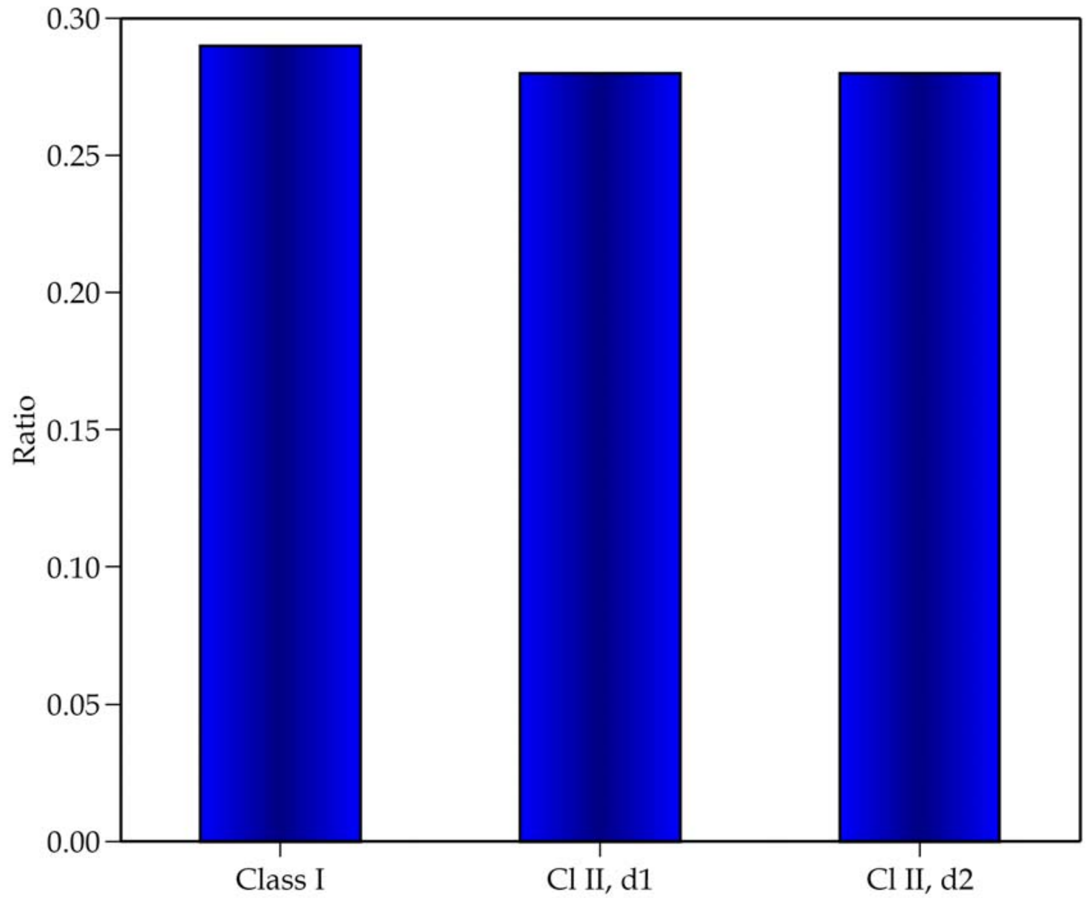


Figure 62. Results of a two-way ANOVA between length-to-width ratio and Angle's class for the lateral incisor.

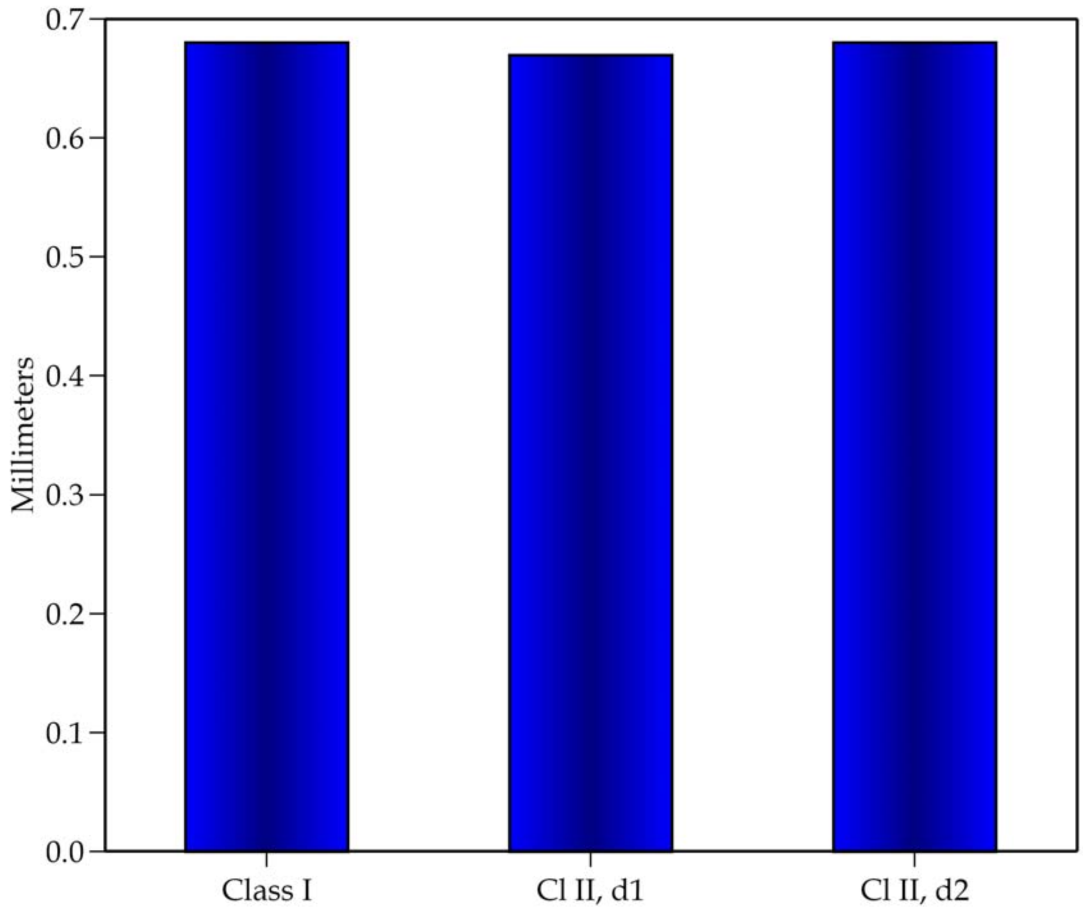


Figure 63. Results of a two-way ANOVA between width-to-height ratio and Angle's class for the lateral incisor.

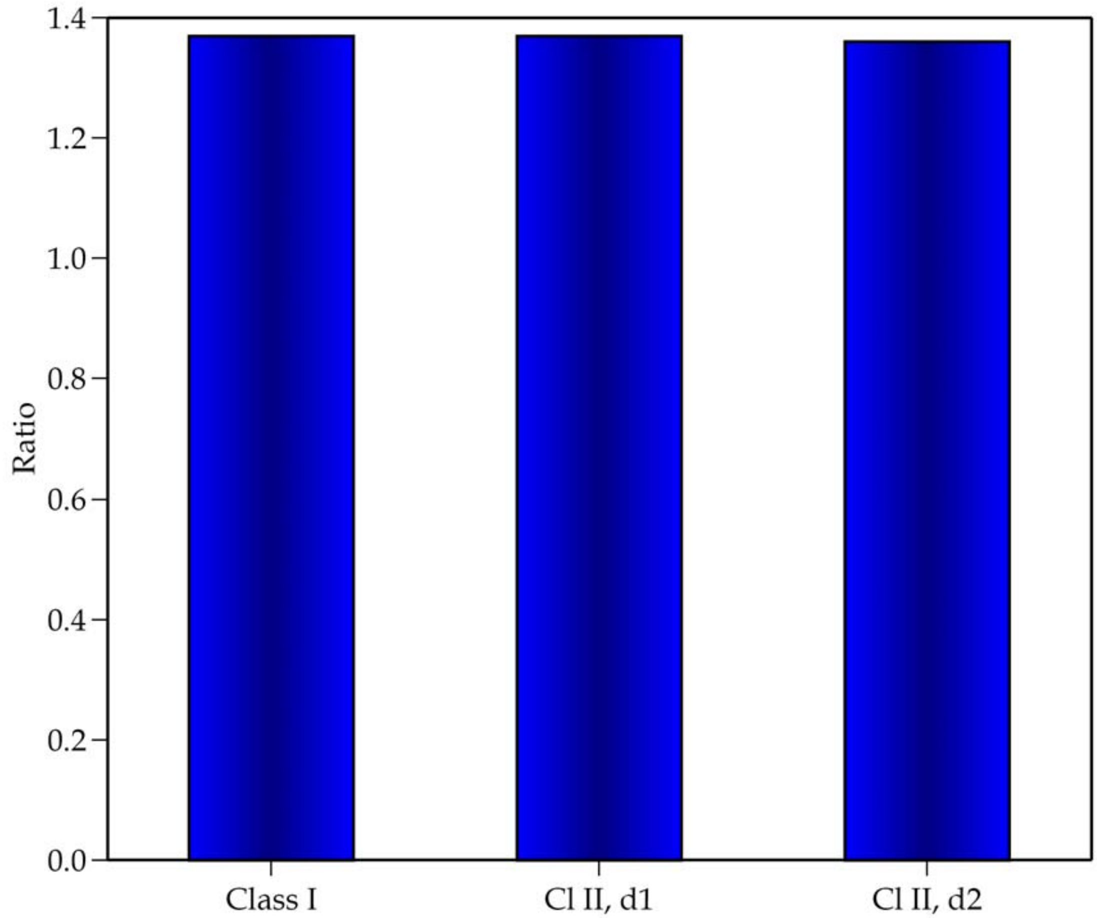


Figure 64. Results of a two-way ANOVA between Flare 1 and Angle's class for the lateral incisor.

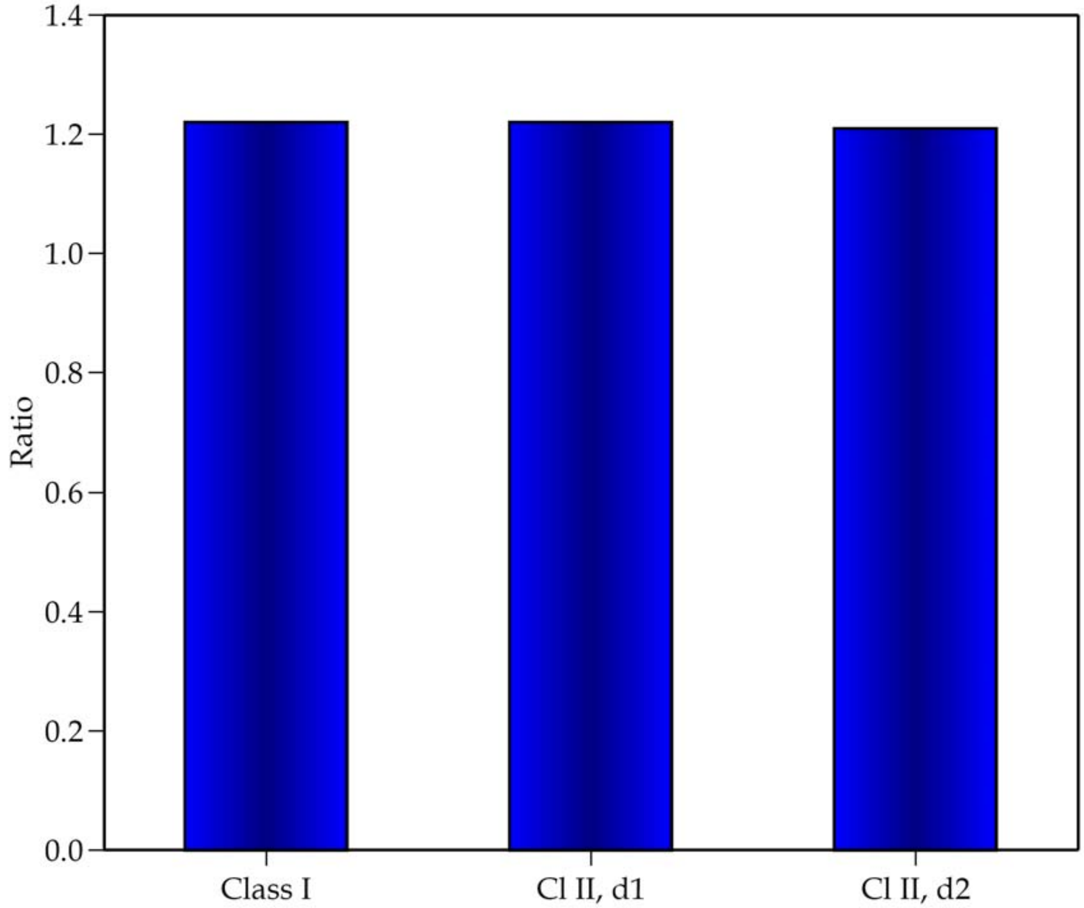


Figure 65. Results of a two-way ANOVA between Flare 2 and Angle's class for the lateral incisor.

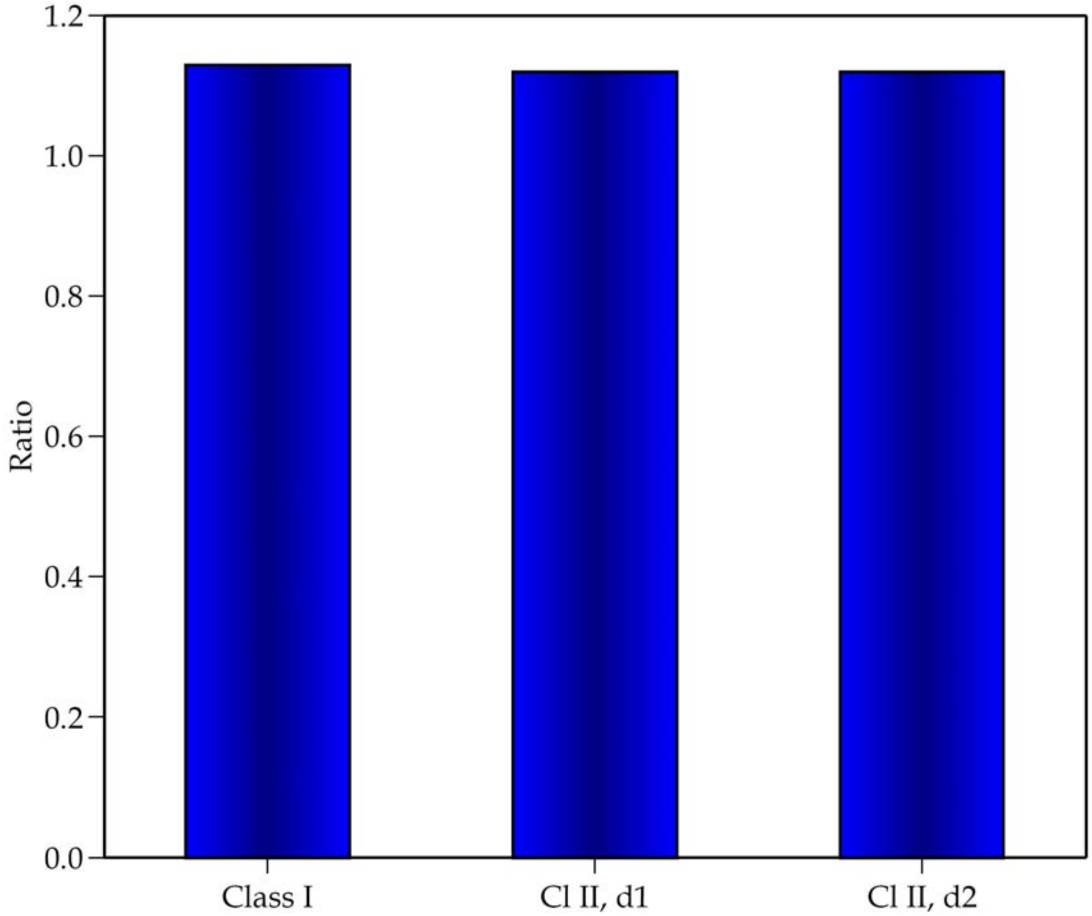


Figure 66. Results of a two-way ANOVA between Flare 3 and Angle's class for the lateral incisor.

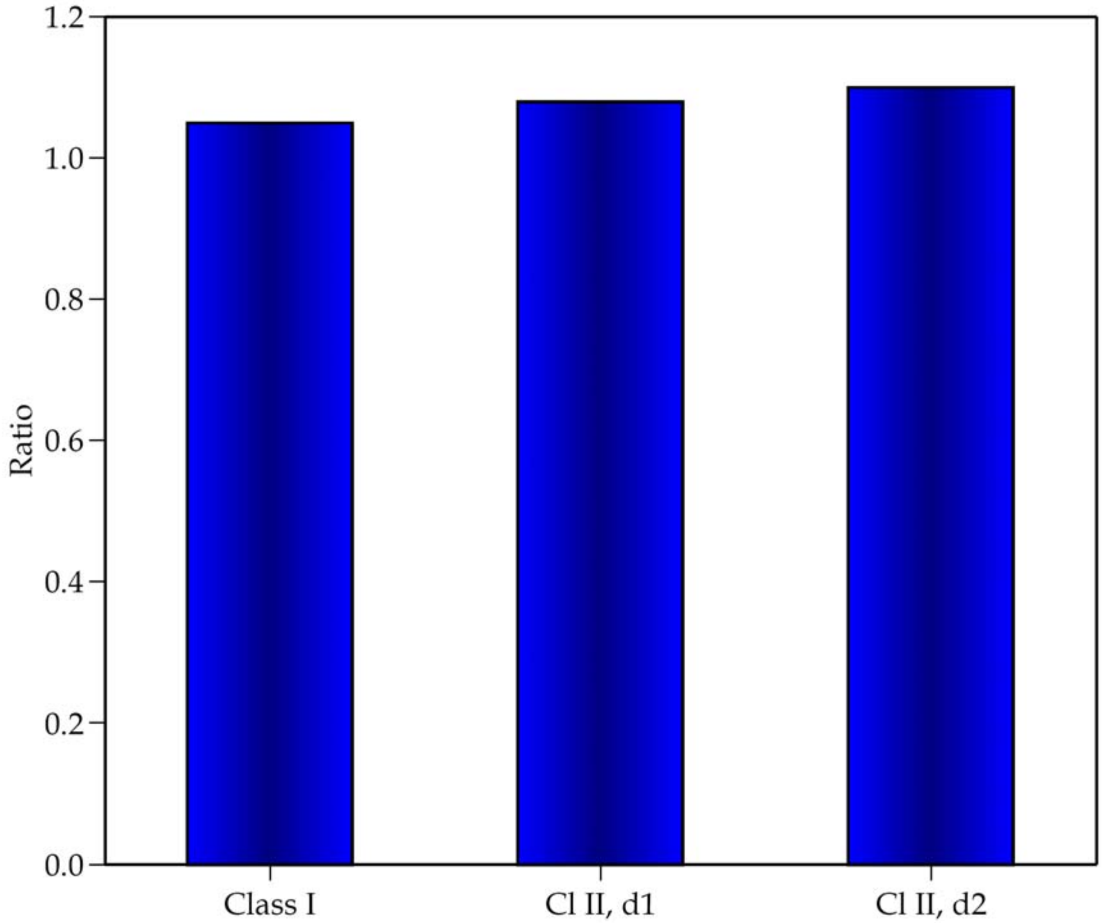


Figure 67. Results of a two-way ANOVA between crown eccentricity and Angle's class for the lateral incisor.

In overview, the upper central incisor shows no arguable statistical dependency among Angle's classes. There are, in contrast, several significant associations with crown size of the lateral incisor: shorter, narrower I2 crowns seem to characterize Class II, division 2 malocclusions. Again, the scarcity of Class III cases in this sample prevented us from testing that type of skeletodental malrelationship.

Tooth Size, Shape and Anterior Malocclusion

The central focus in this study is whether maxillary incisor size and/or shape are predictive of the extent of malocclusion of the maxillary anterior segment. We measured malocclusion of the anterior segment in two complementary manners, namely maxillary incisor irregularity (Little 1976) and TSASD (tooth size arch size discrepancy) as described by Merrifield (1978). These two variables reflect different aspects of anterior crowding, and the correlation between them is just $r = 0.39$. While highly significantly correlated statistically, the coefficient of determination is low ($r^2 = 18\%$). Consequently, the following results examine the statistical relationships between incisor dimensions and the two measures of malocclusion separately.

Tooth-Size Arch-Size Discrepancy

Central Incisor

The 15 variables for the maxillary central incisor are listed in Table 6. As shown in prior sections, it is prudent to evaluate the data separately by sex. A generalized linear model was used (A) to test for a linear regression between a tooth variable and TSASD, (B) to control (account for) sex differences, and (C) to test for a sex-by-trait interaction. This latter interaction effect would be significant if the strengths of the intertrait associations differed significantly between the two sexes.

Just three of the 15 I1 variables are significantly associated with the severity of TSASD. In passing, none of the sex effects and none of the interaction effects is significant. Two of these variables are closely related anatomically, namely (1) cown width measured at the maximum mesiodistal width (maximum mesiodistal width) and (2) crown width measured at the incisal edge. In both situations, the broader the incisor, the greater the TSASD.

Table 6. Results of tests of whether maxillary central incisor tooth dimensions are dependent on maxillary tooth size arch size discrepancy (TSASD).

	Patient's Sex			TSASD			Interaction		
Source	df	F Ratio	P Value	df	F Ratio	P Value	df	F Ratio	P Value
Root Height	1	0.08	0.7821	1	0.74	0.3915	1	0.77	0.3808
Crown Height	1	0.23	0.6300	1	0.03	0.8743	1	0.21	0.6499
MD Width at the CEJ	1	0.04	0.8334	1	0.70	0.4028	1	0.68	0.4095
Maximum MD Width	1	0.00	0.9458	1	8.75	0.0036	1	0.70	0.4055
Incisal MD Widht	1	0.02	0.8828	1	9.00	0.0032	1	0.26	0.6089
Lateral Crown Height	1	0.41	0.5240	1	0.51	0.4770	1	0.31	0.5773
Medial Crown Height	1	0.26	0.6112	1	0.01	0.9381	1	0.50	0.4810
Tooth Length	1	0.08	0.7797	1	0.59	0.4455	1	0.24	0.6247
Crown-Root	1	0.17	0.6838	1	0.89	0.3481	1	1.92	0.1676
Length-Width	1	0.39	0.5358	1	1.44	0.2320	1	0.26	0.6103
Width-Height	1	0.41	0.5215	1	5.14	0.0249	1	0.36	0.5518
Flare 1	1	0.49	0.4832	1	2.76	0.0989	1	1.65	0.2018
Flare 2	1	0.14	0.7074	1	1.28	0.2601	1	0.44	0.5065
Flare 3	1	0.37	0.5444	1	3.47	0.0646	1	0.44	0.5070
Crown Eccentricity	1	0.18	0.6731	1	1.72	0.1919	1	0.20	0.6578

Figure 68 is the scattergram between I1 maximum MD width and TSASD. TSASD averages about zero (but with considerable variability) when I1 midcrown size is most narrow. As tooth breadth increases, the trend is for TSASD to become lower as tooth size exceeds arch size. This linear regression is significant ($b = -2.08$; $P = 0.0010$), with the two variables sharing 7.0% of the variability (r^2).

The association between I1 incisal width and TSASD is comparable (Figure 69). TSASD is, on average, about neutral when I1 is narrow at its incisal edge, and TSASD becomes negative as crown width increases. Linear regression here is significant ($b = -1.93$; $P = 0.0011$), with an r^2 of 6.9%.

The other significant predictor of TSASD in Table 6 is the I1 width-to-height crown index. As graphed in Figure 70, TSASD averages about zero to the left of the X-axis (but with considerable variability), and it decreases (greater crowding) as the I1 width-to-height ratio increases. On the X-axis (abscissa), a small ratio denotes a narrow-tall crown shape, while a large ratio denotes a broad-short crown shape. This linear regression model (Figure 70) is significant statistically ($b = -13.11$; $P = 0.0229$), but with a modest r^2 of 3.4%.

<u>Lateral Incisor</u>

Three of the measures of I2 are significantly associated with TSASD (Table 7). As with the I1 analyses, none of the sex effects nor any of the interaction effects attained statistical significance.

Occlusogingival crown height of I2 is statistically associated with TSASD (Figure 71). Obviously, crown height does not affect TSASD directly. Instead, we suppose this statistical association occurs because I2 crown height is positively intercorrelated with I2 crown width, so the cause-to-effect relationship is indirect. In other words, crown height is significant here because it serves as a proxy for crown width. This becomes clear when these data are evaluated multivariately in a later section. The association between these two variables (Figure 71) is that TSASD is smallest when I2 crown height is tall, and TSASD becomes negative—a space deficit—as crown height increases. The regression coefficient is -0.76 ($P = 0.0107$), with an r^2 of 4.3%.

The two other significant predictors of TSASD (Table 7) are identical to the two that were flagged previously for I1, namely (A) midcrown width of I2 and (B) incisal width of I2, and the same metrical relationships are seen. For I2 maximum MD width (Figure 72), crowding (a negative TSASD) increases as I2

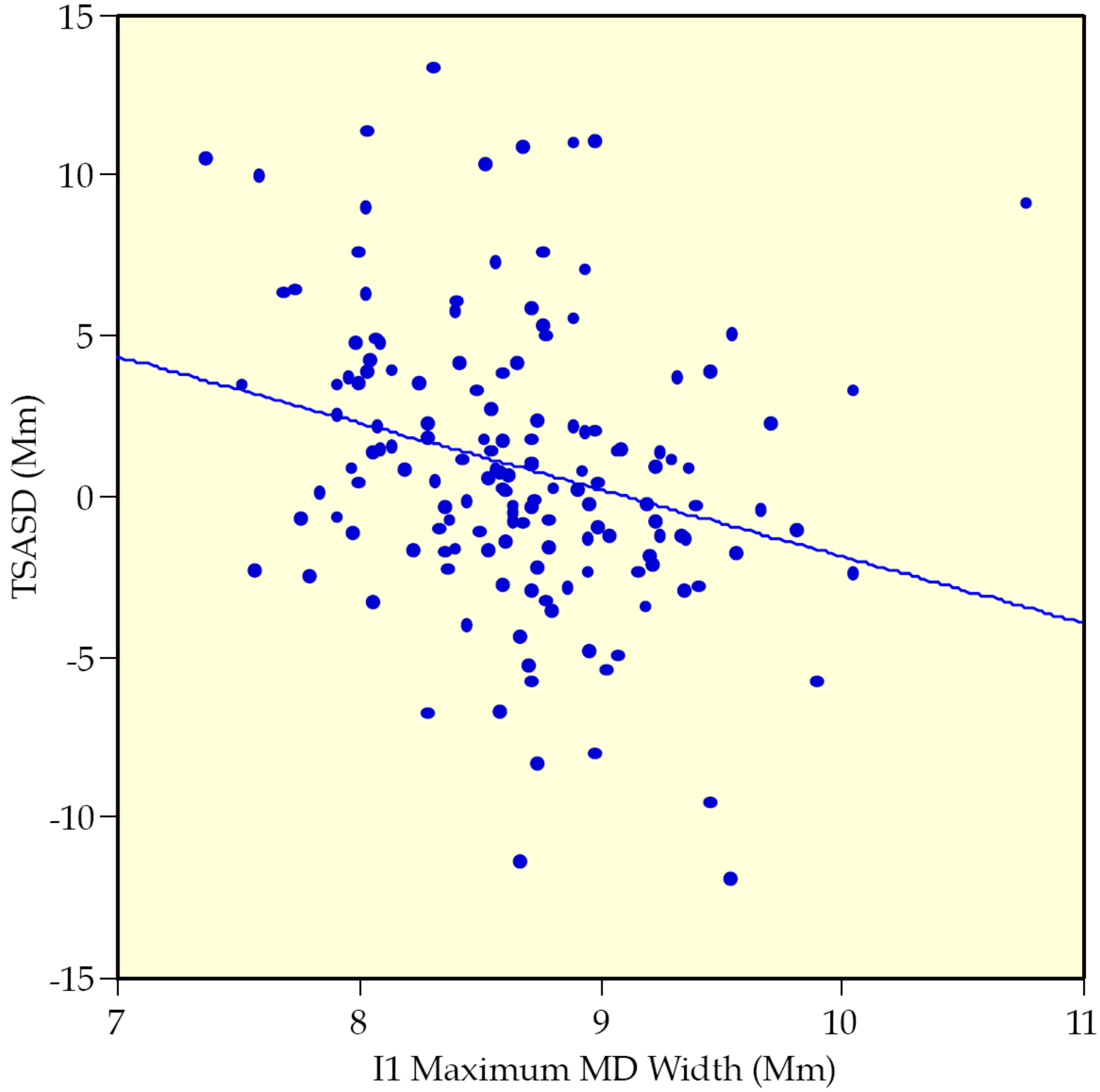


Figure 68. Scattergram showing the relationship between maxillary central incisor maximum MD width and TSASD. The best fit regression line is shown.

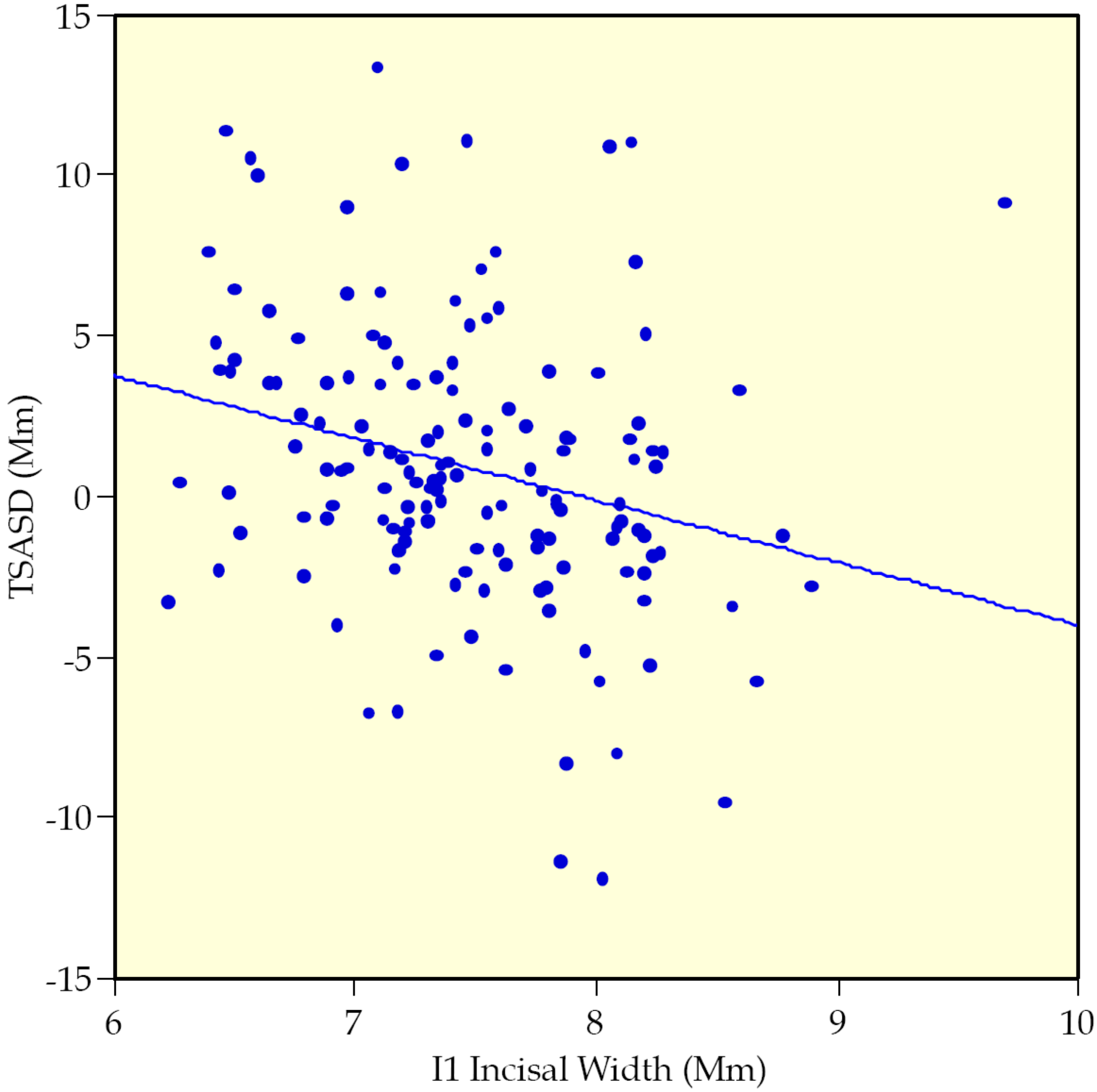


Figure 69. Scattergram showing the relationship between maxillary central incisor incisal MD width and TSASD. The best fit regression line is shown.

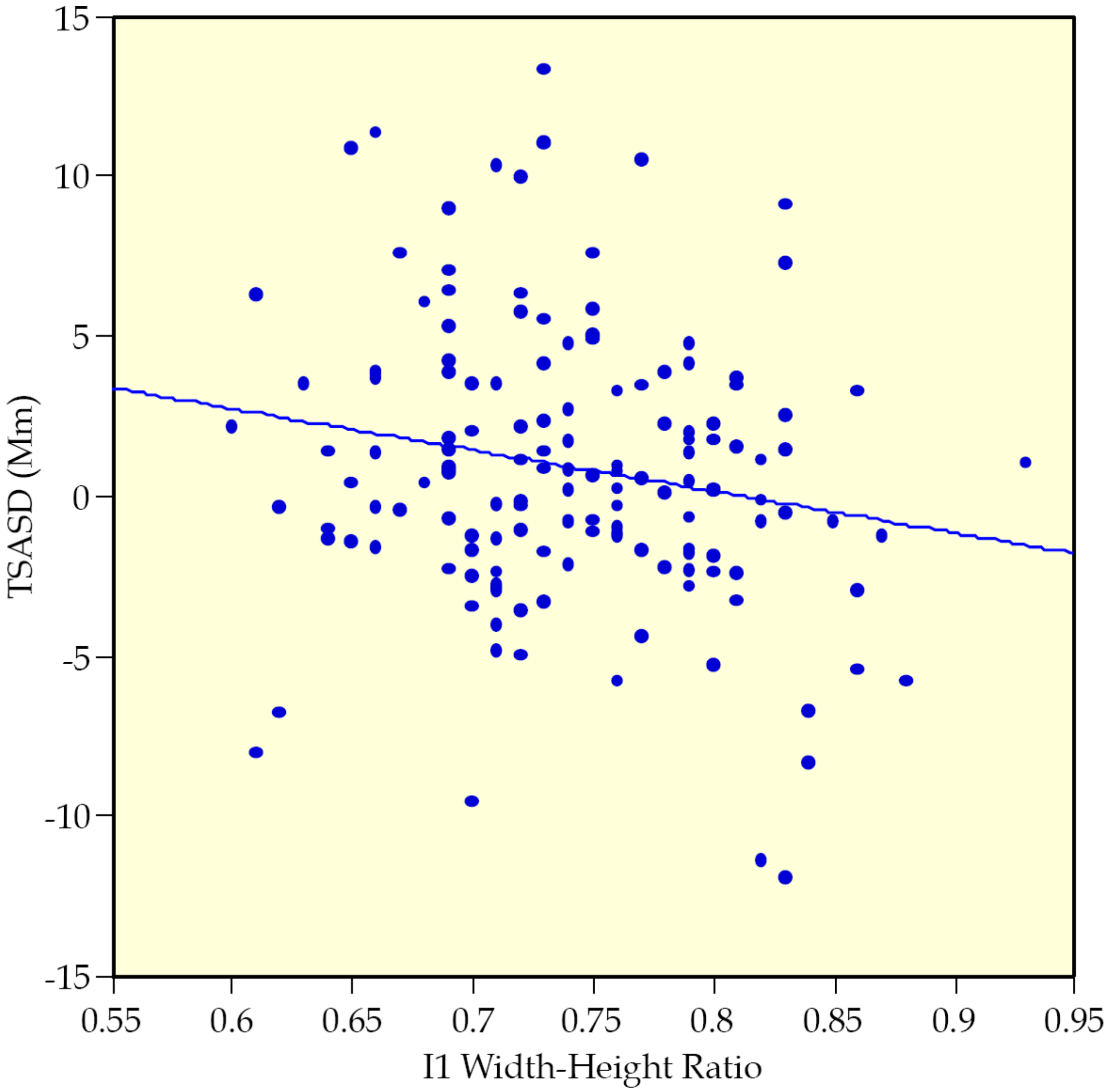


Figure 70. Scattergram showing the relationship between maxillary central incisor width-to-height ratio and TSASD. The best fit regression line is shown.

Table 7. Results of tests of whether maxillary lateral incisor tooth dimensions are dependent on maxillary tooth size arch size discrepancy (TSASD).

	Patient's Sex			TSASD			Interaction		
Source	df	F Ratio	P Value	df	F Ratio	P Value	df	F Ratio	P Value
Root Height	1	0.16	0.6926	1	0.78	0.3775	1	0.23	0.6294
Crown Height	1	0.00	0.9827	1	4.96	0.0275	1	0.13	0.7240
MD Width at the CEJ	1	0.05	0.8228	1	1.23	0.2690	1	1.36	0.2460
Maximum MD Width	1	0.10	0.7511	1	8.09	0.0051	1	0.06	0.8026
Incisal MD Width	1	0.14	0.7117	1	8.66	0.0038	1	0.71	0.3998
Lateral Height	1	0.13	0.7236	1	0.76	0.3863	1	1.23	0.2687
Medial Height	1	0.06	0.8097	1	1.67	0.1986	1	0.15	0.6966
Tooth Length	1	0.04	0.8342	1	2.47	0.1181	1	0.19	0.6627
Crown-Root	1	0.17	0.6848	1	0.76	0.3854	1	0.10	0.7540
Length-Width	1	0.39	0.5315	1	0.85	0.3578	1	0.01	0.9342
Width-Height	1	0.41	0.5256	1	0.32	0.5707	1	0.10	0.7544
Flare 1	1	0.65	0.4214	1	3.45	0.0654	1	1.48	0.2263
Flare 2	1	0.26	0.6136	1	0.30	0.5873	1	0.08	0.7830
Flare 3	1	0.64	0.4258	1	3.58	0.0606	1	0.28	0.6003
Crown Eccentricity	1	0.27	0.6034	1	1.02	0.3147	1	1.45	0.2308

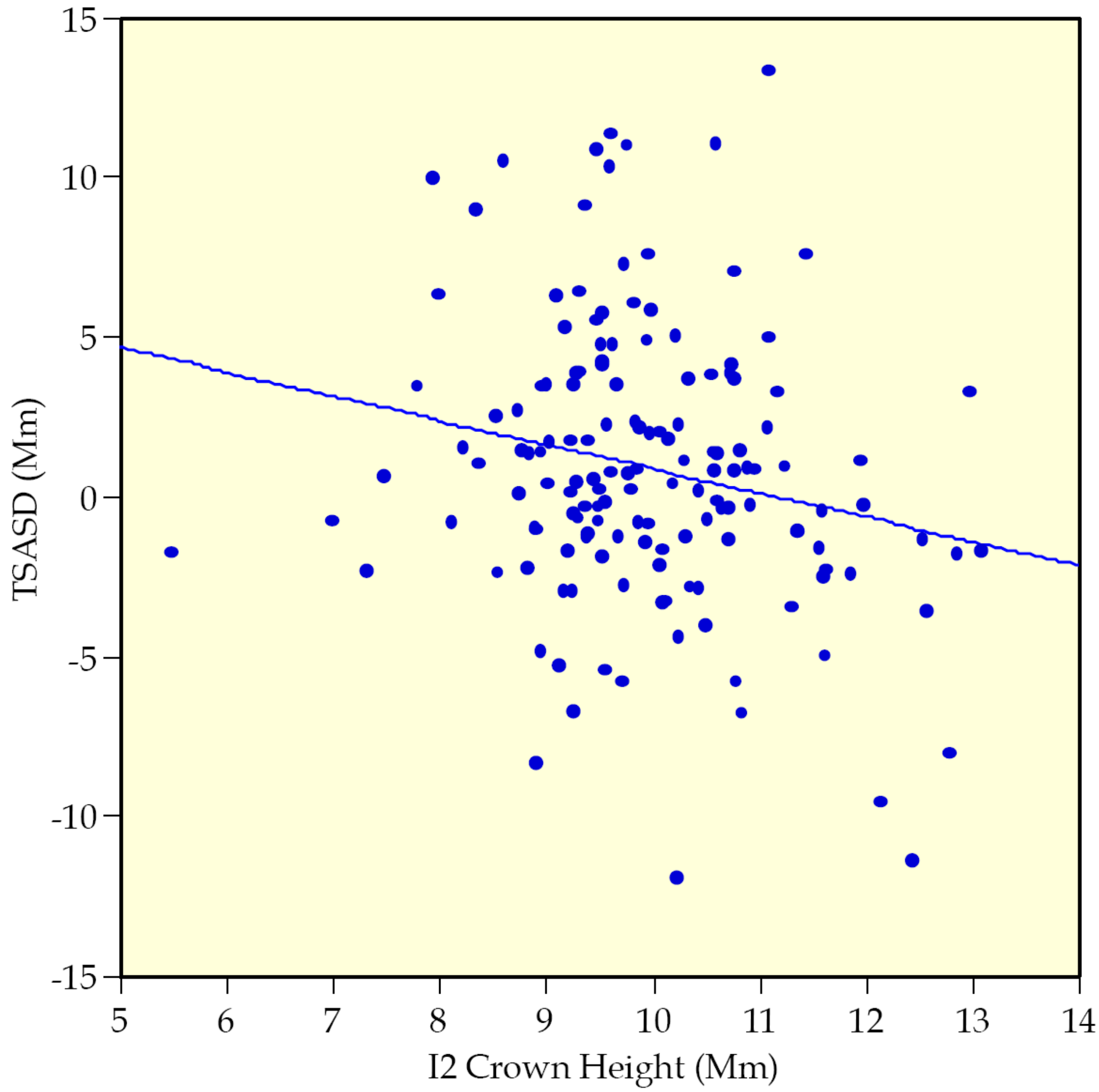


Figure 71. Scattergram showing the relationship between maxillary lateral incisor crown height and TSASD. The best fit regression line is shown.

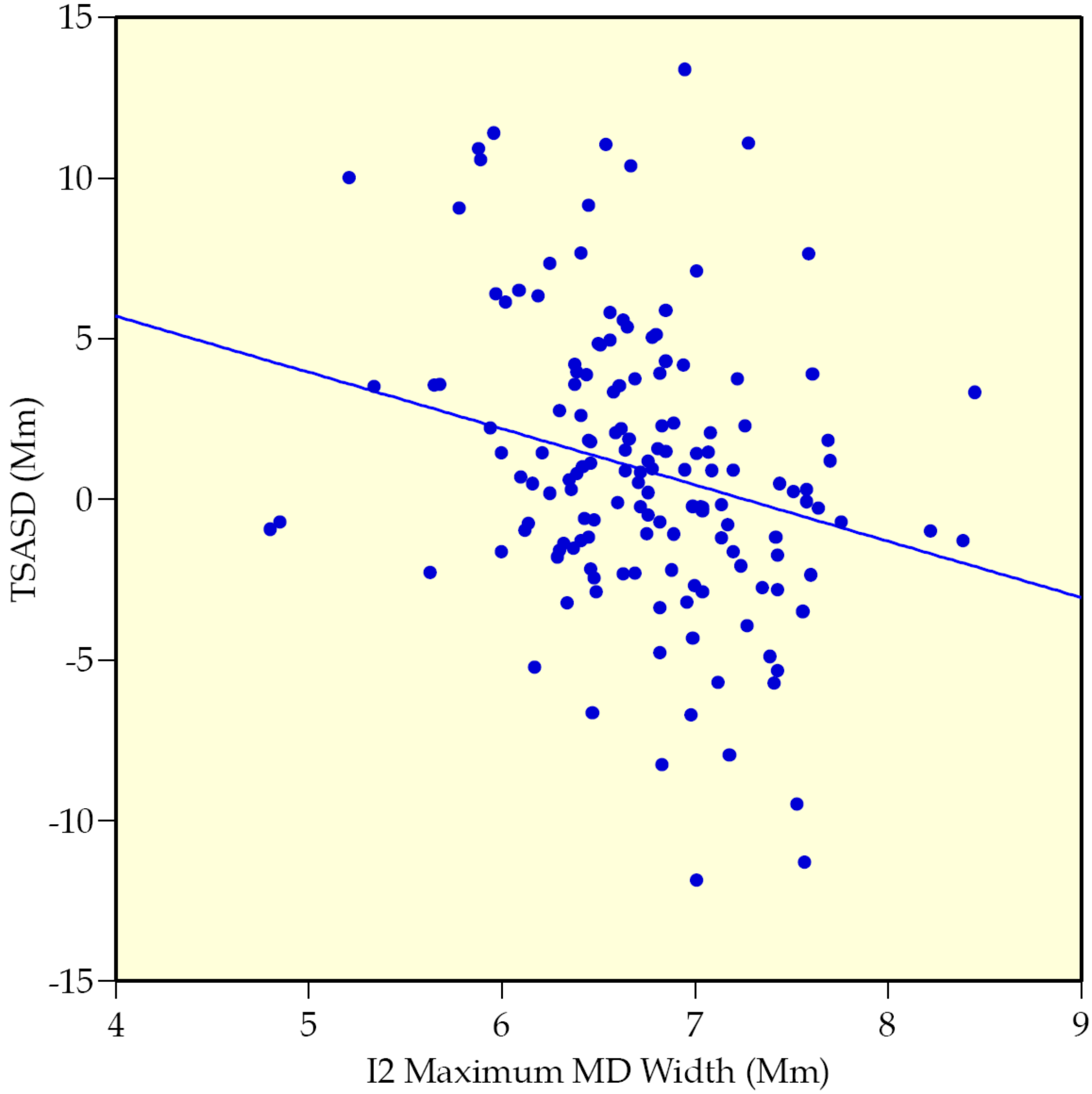


Figure 72. Scattergram showing the relationship between maxillary lateral incisor maximum MD width and TSASD. The best fit regression line is shown.

width increases. The linear regression coefficient is highly significant (b = -1.75; P = 0.0015), and r^2 is 6.5%.

Figure 73 is the plot between I2 incisal width and TSASD. Broader I2 crowns are associated with greater crowding. The linear regression coefficient is significantly different from zero (b = -1.75; P = 0.028), with an r^2 of 5.8%.

Incisor Irregularity

An obvious feature in the prior sections dealing with TSASD is the absence of sex difference for TSASD; that is, "sex" was input into the ANCOVA model to account for sex differences, but there were none. Just the opposite occurs in the tests using the maxillary incisor irregularity: Every test for sexual dimorphism is significant, reflecting the significantly greater incisor irregularity in boys in this study. On the other hand, very few of the sex-by-irregularity interactions effects are statistically significant.

Central Incisor

Two of the 15 associations between I1 size and incisor irregularity are statistically significant, and two others are suggestive (0.10 > P > 0.05). Midcrown width and the width-height ratio achieve significance (Table 8).

I1 maximum MD width is positively associated with incisor irregularity (Figure 74). Broader crowns tend to exhibit greater irregularity. The linear relationship is b = 2.02 (P = 0.0010; r^2 = 7.0%).

I1 incisor irregularity also is dependent on the crown's width-height ratio (Table 8), but the interaction term also is significant here. Plotting the association by sex (Figure 75) makes it evident that the interaction effect is due to a significant, positive association in males, but effectively no association in females. The linear regression for males alone is b = 26.50 (P = 0.0055), whereas for females alone b = 0.33 (P = 0.9595).

For completeness, we also looked at the two "marginal" associations in Table 8 (0.10 > P > 0.05). I1 incisal width has a positive association with incisor irregularity (Figure 76). By linear regression the coefficient is b = 1.34 (P = 0.0203). The I1 length-width also is weakly associated with irregularity (Figure 77). By linear regression the coefficient is b = 13.73 (P = 0.1801).

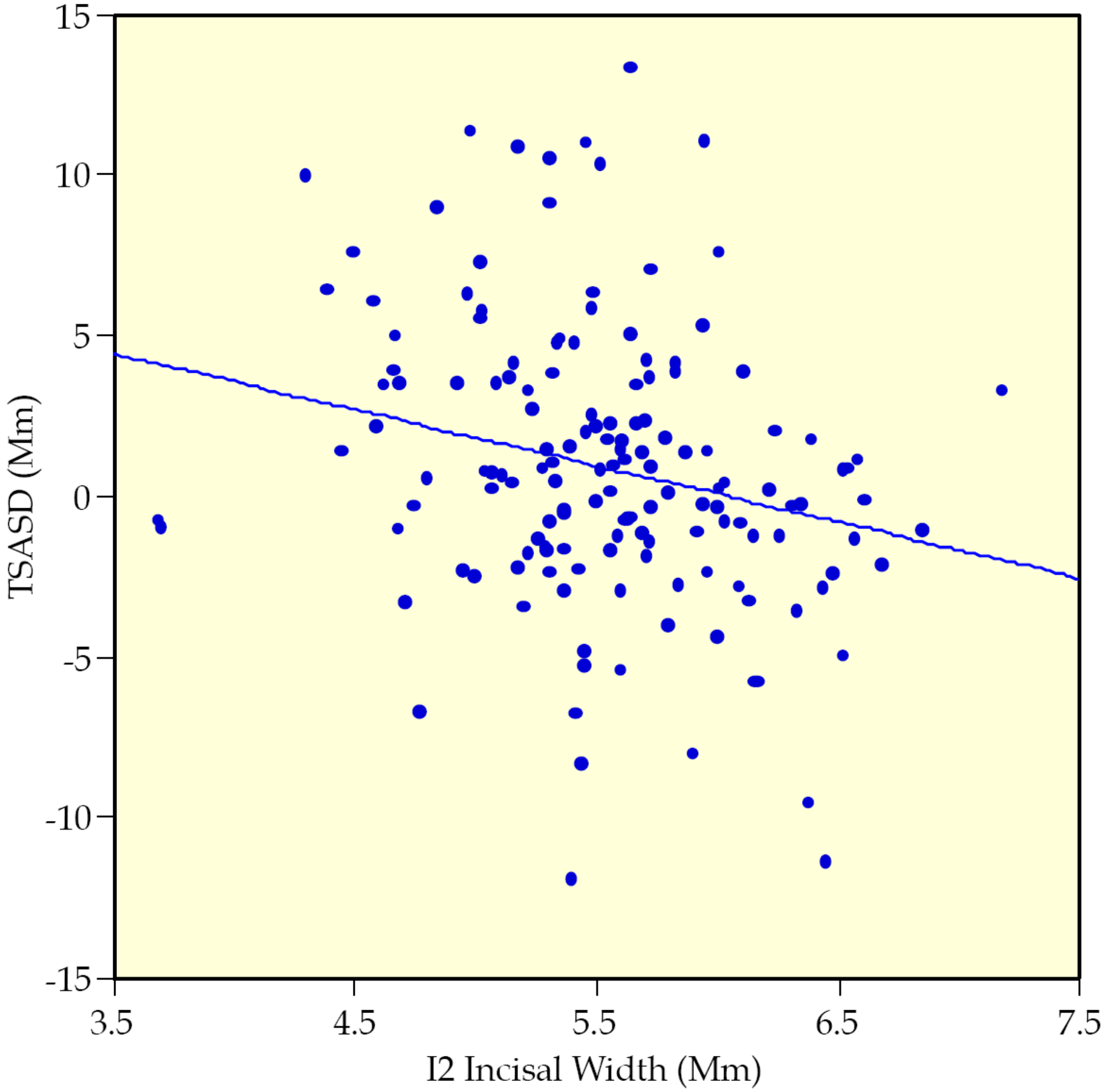


Figure 73. Scattergram showing the relationship between maxillary lateral incisor incisal MD width and TSASD. The best fit regression line is shown.

Table 8. Results of tests of whether maxillary central incisor tooth dimensions are dependent on maxillary incisor irregularity.

	Patient's Sex			Incisor Irregularity			Interaction		
Source	df	F Ratio	P Value	df	F Ratio	P Value	df	F Ratio	P Value
Root Height	1	8.55	0.0040	1	0.04	0.8489	1	0.44	0.5081
Crown Height	1	9.69	0.0022	1	0.04	0.8518	1	2.82	0.0952
MD Width at the CEJ	1	6.76	0.0103	1	1.26	0.2634	1	0.47	0.4955
Maximum MD Width	1	6.25	0.0136	1	8.00	0.0053	1	0.00	0.9521
Incisal MD Width	1	7.00	0.0090	1	3.22	0.0749	1	0.01	0.9240
Lateral Height	1	8.65	0.0038	1	1.02	0.3146	1	2.36	0.1265
Medial Height	1	8.43	0.0043	1	0.80	0.3739	1	1.10	0.2970
Tooth Length	1	8.59	0.0039	1	0.02	0.8748	1	0.03	0.8569
Crown-Root	1	9.12	0.0030	1	0.13	0.7180	1	3.18	0.0765
Length-Width	1	10.61	0.0014	1	3.22	0.0747	1	0.44	0.5062
Width-Height	1	10.95	0.0012	1	6.15	0.0143	1	5.85	0.0168
Flare 1	1	10.45	0.0015	1	2.04	0.1557	1	0.04	0.8324
Flare 2	1	9.60	0.0023	1	0.61	0.4361	1	0.01	0.9061
Flare 3	1	9.53	0.0024	1	0.41	0.5224	1	0.05	0.8246
Crown Eccentricity	1	9.17	0.0029	1	0.07	0.7857	1	0.49	0.4868

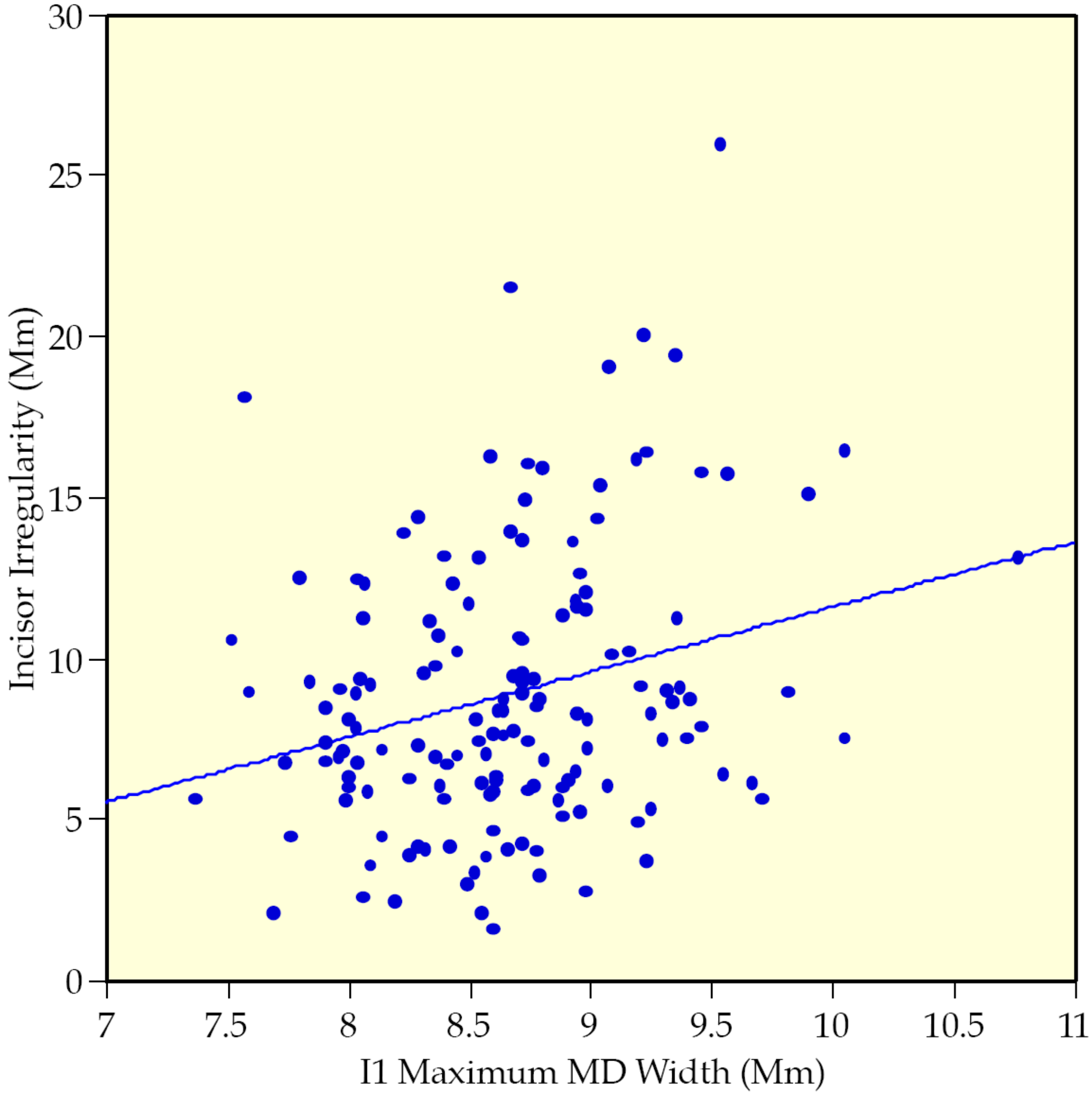


Figure 74. Scattergram showing the relationship between maxillary central incisor maximum MD width and incisor irregularity. The best fit regression line is shown.

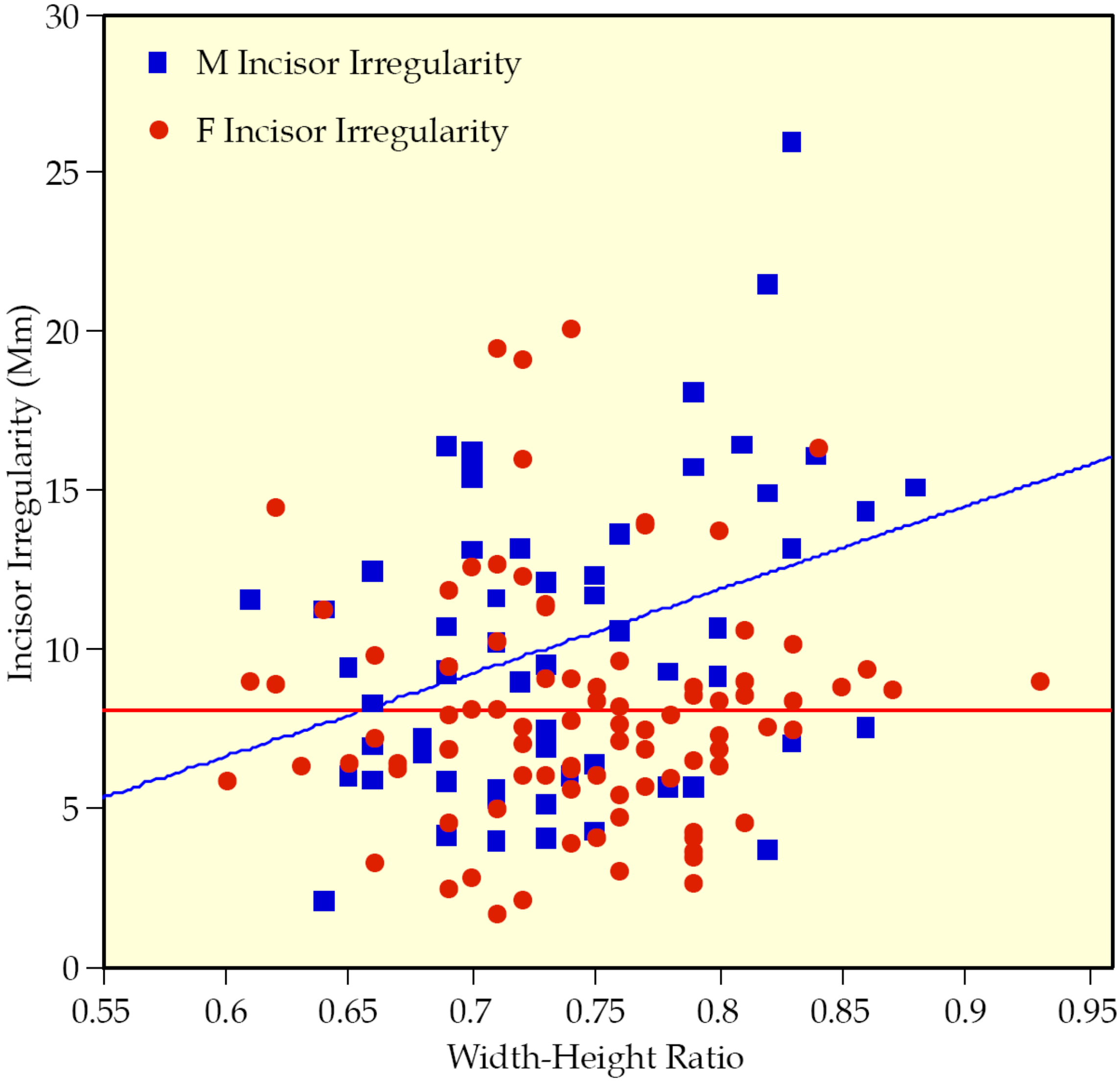


Figure 75. Scattergram showing the relationship between width-to-height ratio and incisor irregularity for males and females. The best fit linear regression lines are shown.

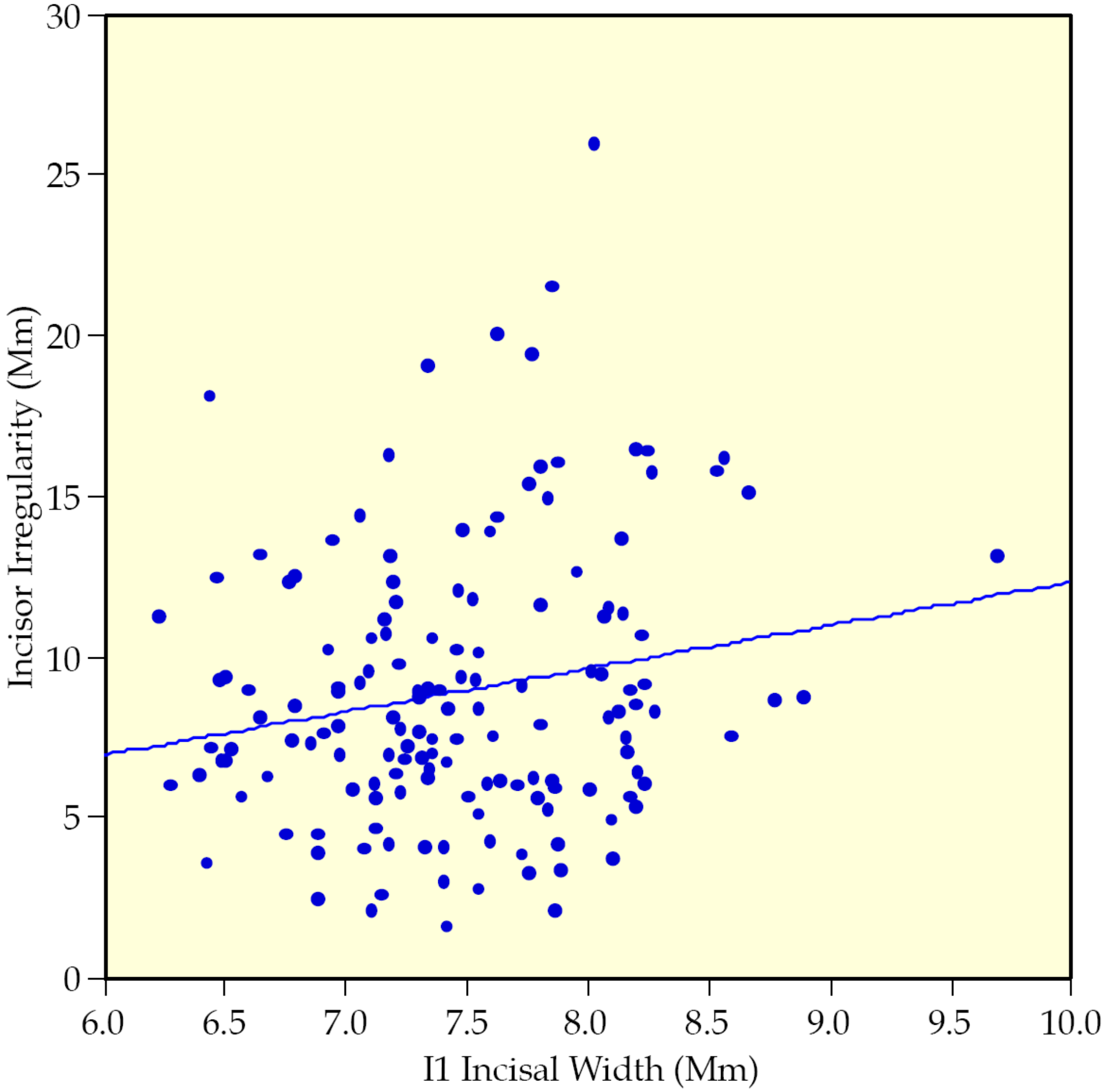


Figure 76. Scattergram showing the relationship between maxillary central incisor incisal MD width and incisor irregularity. The best fit regression line is shown.

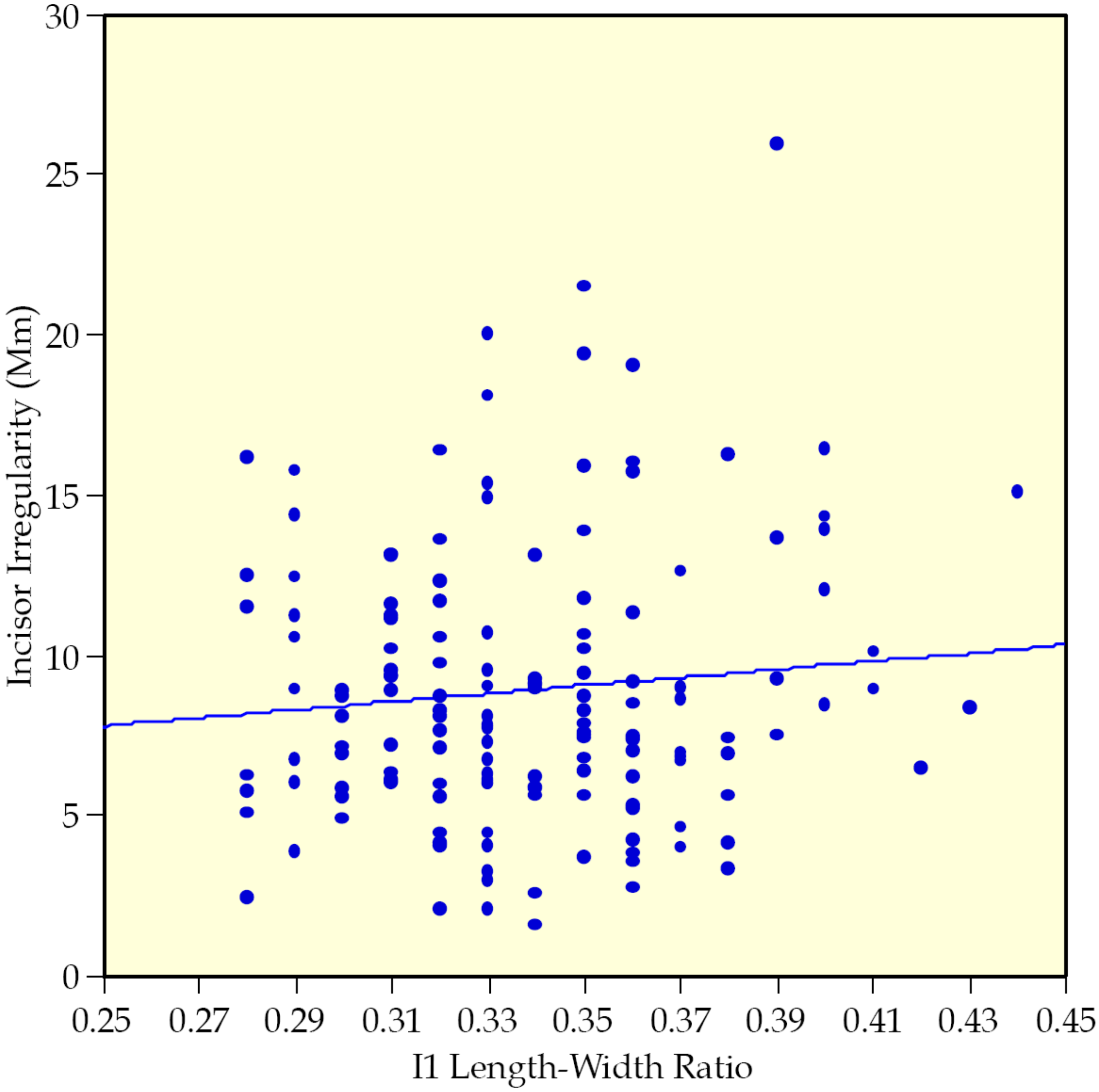


Figure 77. Scattergram showing the relationship between maxillary central incisor length-to-width ratio and incisor irregularity. The best fit regression line is shown.

Lateral Incisor

All of the sex effects are significant for the lateral incisor (Table 9), just as for the central incisor, again because males have greater irregularity in the present sample. These I2 dimensions are predictive of the extent of irregularity ($P < 0.05$), and another is statistically marginal ($0.10 > P > 0.05$).

Mesiodistal width at the CEJ is highly predictive of maxillary irregularity (Figure 78). The association is positive: Larger I2 widths are predictive of greater irregularity. By linear regression, $b = 2.40$ ($P = 0.0003$; $r^2 = 8.4\%$).

Comparably, I2 midcrown width is positively associated with irregularity (Figure 79). By linear regression, $b = 1.42$ ($P = 0.0084$; $r^2 = 4.6\%$).h

Mesiodistal I2 width at the incisal edge also is predictive of the severity of irregularity (Figure 80). By linear regression, $b = 1.13$ ($P = 0.0469$; $r^2 = 2.6\%$).

What is seen for I2, then, is that its crown width—measured at each of these levels of the crown—is significantly tied to the severity of irregularity. The common theme is that the broader the crown, the greater the irregularity. We assume that, as simple as it seems, the situation is just that bigger (mesiodistally broader) incisors require more space, and thus, increase the risk and severity of incisor irregularity. The details are not shown here, but a straight line fits the associations better in each case than a curvilinear relationship.

The Multivariate Model

Our prior analysis has been univariate, meaning that each tooth dimension was examined individually. The two-fold shortcoming here is that (1) there is statistical redundancy among the results because the variables are developmentally interrelated as to size and (2) the opportunity to exploit multiple, statistically independent sources of variation is ignored. Stepwise multiple linear regression is used in the present section (*e.g.*, Freund and Littell 1991) to develop sets of tooth-size variables predictive of anterior crowding—where crowding (the outcome variable) is measured either as Little's incisor irregularity or TSASD. Prior analysis shows that these two measures of anterior crowding measure different aspects of the condition, so the results based on each are different.

Table 9. Results of tests of whether maxillary lateral incisor tooth dimensions are dependent on maxillary incisor irregularity.

	Patient's Sex			Incisor Irregularity			Interaction		
Source	df	F Ratio	P Value	df	F Ratio	P Value	df	F Ratio	P Value
Root Height	1	8.96	0.0032	1	0.09	0.7686	1	3.21	0.0755
Crown Height	1	6.70	0.0106	1	3.61	0.0594	1	0.26	0.6075
MD Width at the CEJ	1	6.26	0.0135	1	7.06	0.0087	1	1.50	0.2229
Maximum MD Width	1	8.88	0.0034	1	6.23	0.0137	1	0.04	0.8437
Incisal MD Width	1	9.49	0.0025	1	4.27	0.0405	1	0.71	0.4002
Lateral Height	1	7.33	0.0076	1	2.47	0.1181	1	0.91	0.3418
Medial Height	1	7.47	0.0071	1	2.57	0.1109	1	0.39	0.5355
Tooth Length	1	7.93	0.0055	1	1.06	0.3059	1	2.02	0.1569
Crown-Root	1	8.85	0.0034	1	1.36	0.2461	1	2.42	0.1216
Length-Width	1	9.69	0.0022	1	0.62	0.4328	1	1.12	0.2907
Width-Height	1	9.15	0.0029	1	0.11	0.7458	1	0.00	0.9757
Flare 1	1	6.93	0.0094	1	1.63	0.2041	1	5.95	0.0159
Flare 2	1	9.20	0.0029	1	0.07	0.7923	1	0.10	0.7472
Flare 3	1	7.01	0.0090	1	1.57	0.2123	1	2.53	0.1140
Crown Eccentricity	1	9.31	0.0027	1	0.06	0.8131	1	0.10	0.7510

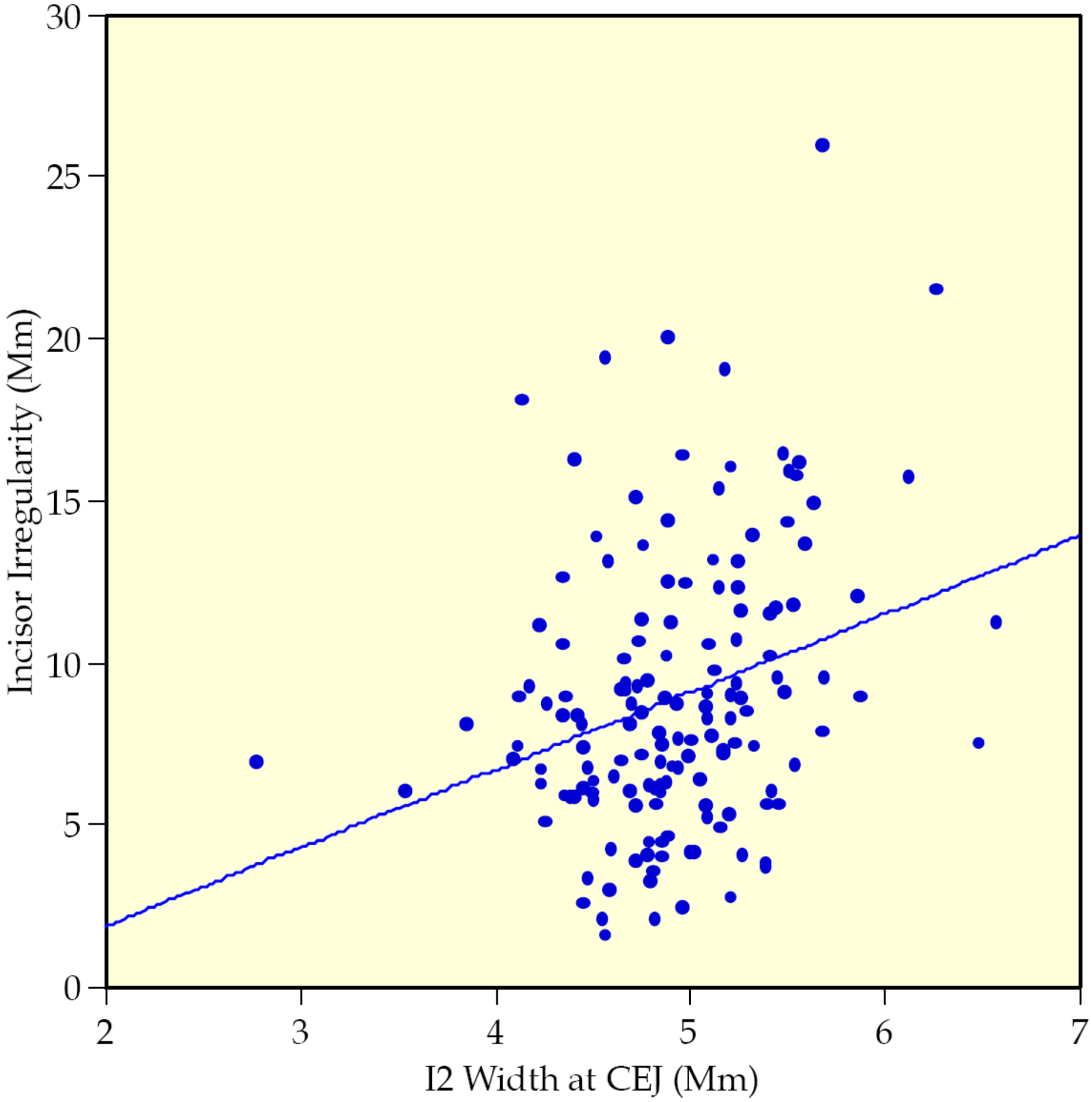


Figure 78. Scattergram showing the relationship between maxillary lateral incisor MD width at the CEJ and incisor irregularity. The best fit regression line is shown.

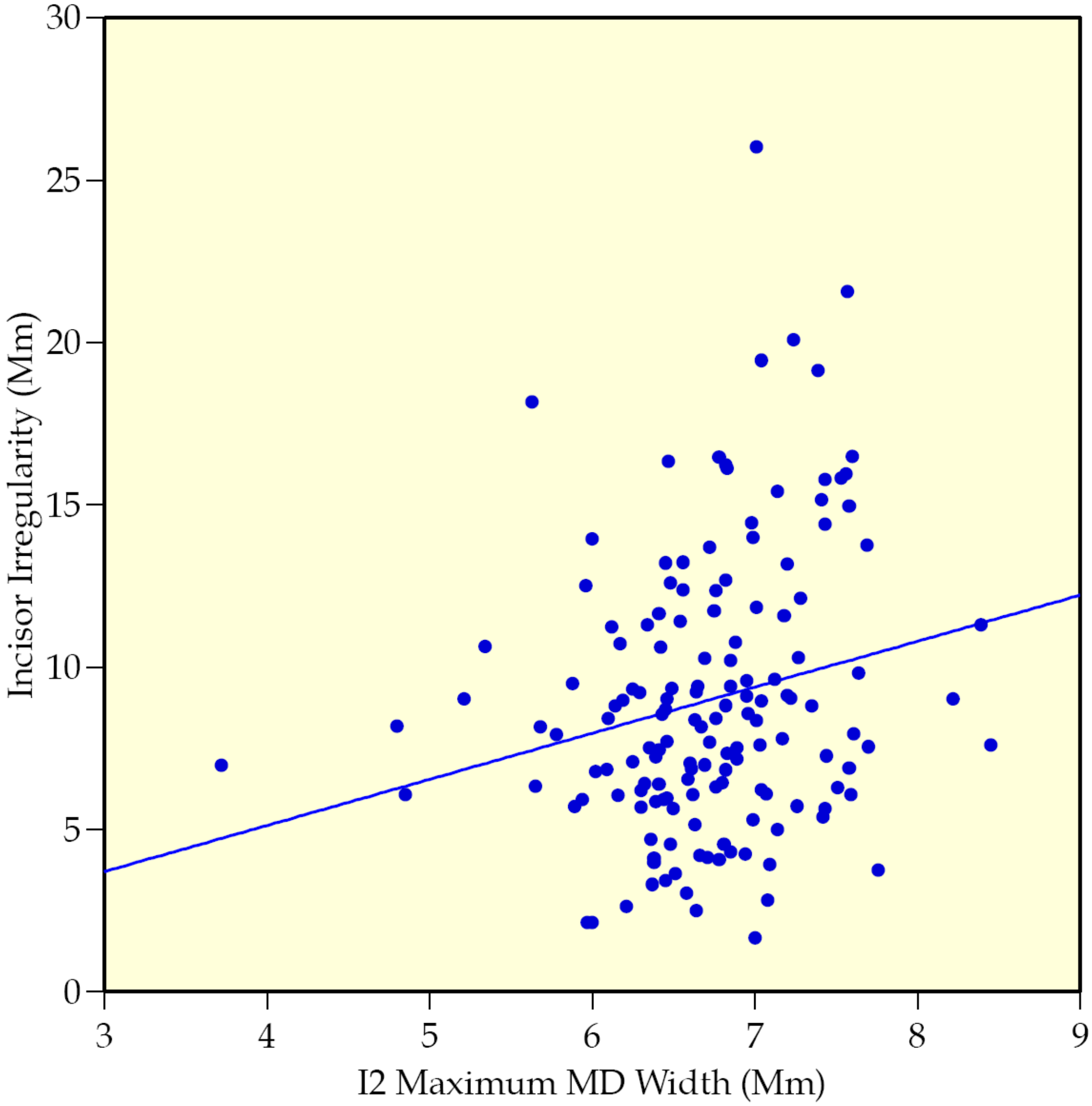


Figure 79. Scattergram showing the relationship between maxillary lateral incisor maximum MD width and incisor irregularity. The best fit regression line is shown.

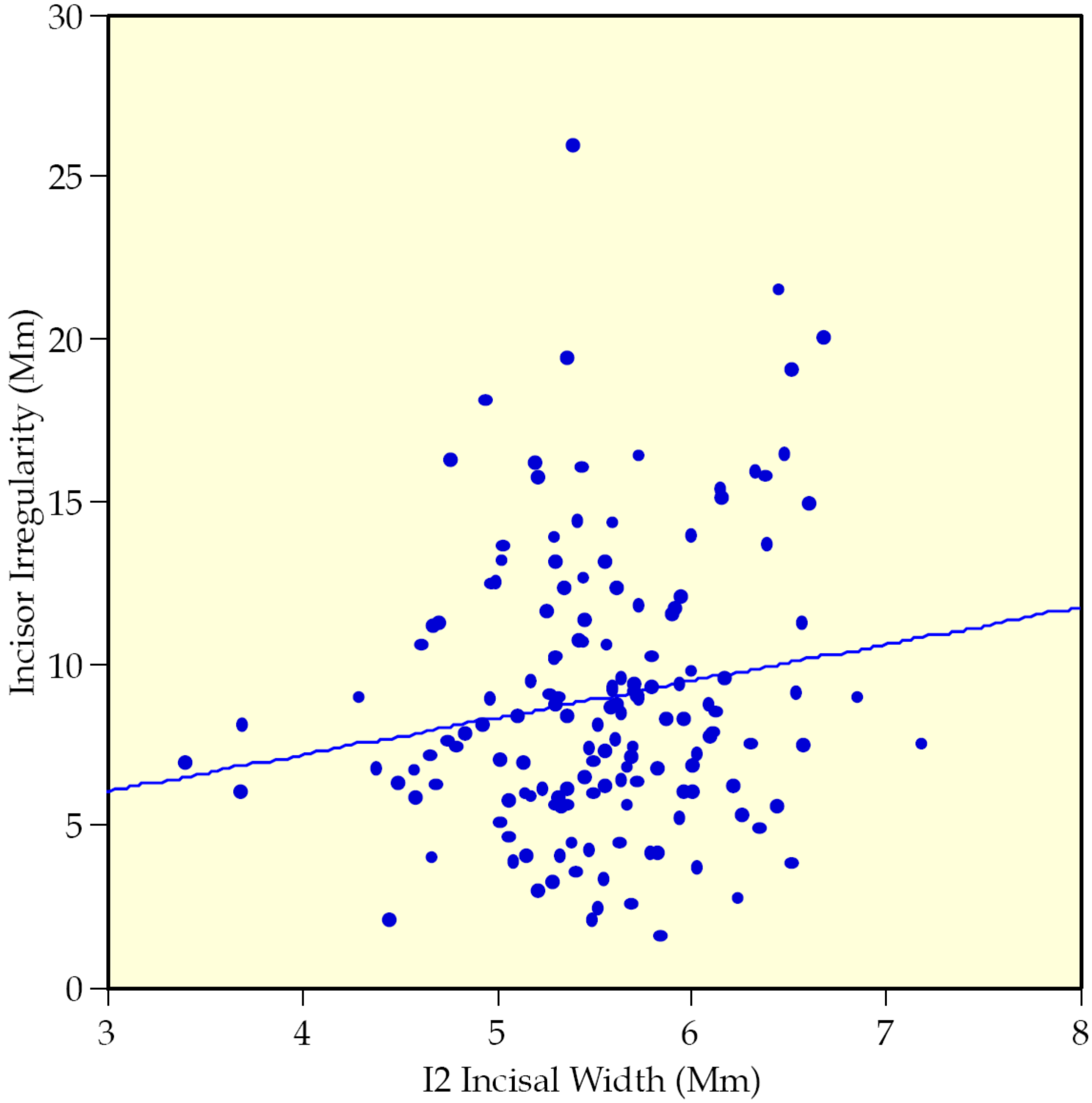


Figure 80. Scattergram showing the relationship between maxillary lateral incisor incisal MD width and incisor irregularity. The best fit regression line is shown.

Incisor Irregularity

There are 15 measures of crown and root size from which incisor irregularity might be predicted. Results at step 0 for the central incisor are shown in Table 10 (top). Just one variable, maximum crown width, achieved significance ($P = 0.0010$). Of note, once this variable was accounted for, none of the others achieved an F-ratio sufficient to be entered.

Six variables were significant at step 0 for the maxillary lateral incisor (Table 11). Mesiodistal width at the CEJ had the highest F-ratio, and the other predictors were only marginally significant ($0.10 > P > 0.05$). At step 1, lateral incisor width at the CEJ was entered ($P = 0.0003$), and the P-values for all other variables fell well below 0.05.

Tooth Size Arch Size Discrepancy

Prediction of TSASD by the central-incisor variables (Table 12) shows that there are five variables significant at an alpha of 0.05 at step 0, with maximum mesiodistal width exhibiting the largest F-ratio. When maximum crown width is entered at step 1 ($P = 0.0010$), none of the other variables possessed an F-ratio large enough for entry, so the procedure stopped.

For the upper lateral incisor (Table 13), three variables were significant at step 0; maximum mesiodistal crown width had the largest F-ratio. At step 1, the P-value for maximum width was 0.0015, and none of the other independent variables was large enough to be entered.

In overview, maximum crown width was the single significant predictor in three of these four models. The exception was the high predictive value of width at the CEJ for the lateral incisor. Parenthetically, when CEJ width is removed from this model, then maximum mesiodistal width is the one significant predictor as in the other three cases. The inference, then, is that the greater the mesiodistal width—which is the mediolateral space required to properly align the tooth in the arch—the greater the typical anterior crowding, either measured as Little's incisor irregularity or as TSASD. These relationships are graphed in Figures 81 through 84. Because of the measurement schemes, greater incisor widths are associated with greater incisor irregularity (positive associations) and with greater crowding (negative associations).

One supposition not controlled in these regression analyses is that the patient's sex (and sexual dimorphism in tooth size) could account for the variation. That is, if females, with smaller tooth sizes, exhibited less anterior

Table 10. Results of stepwise multiple linear regression predicting incisor irregularity from dimensions of the maxillary central incisor.

Variable	df	F Ratio	P Value
	Step 0		
Root Height	1	0.01	0.9076
Crown Height	1	0.91	0.3428
MD Width at the CEJ	1	0.13	0.7169
Maximum MD Width	1	11.22	**0.0010**
Incisal MD Width	1	0.38	0.5392
Lateral Crown Height	1	0.18	0.6705
Medial Crown Height	1	0.26	0.6127
Tooth Length	1	0.08	0.7785
Crown-Root Ratio	1	0.50	0.4810
Length-Width Ratio	1	0.13	0.7146
Width-Height Ratio	1	1.16	0.2842
Flare 1	1	0.18	0.6761
Flare 2	1	0.43	0.5134
Flare 3	1	0.01	0.9366
Crown Eccentricity	1	0.05	0.8261
	Step 1		
Root Height	1	0.01	0.9076
Crown Height	1	0.91	0.3428
MD Width at the CEJ	1	0.13	0.7169
Maximum MD Width	1	11.22	**0.0010**
Incisal MD Width	1	0.38	0.5392
Lateral Crown Height	1	0.18	0.6705
Medial Crown Height	1	0.26	0.6127
Tooth Length	1	0.08	0.7785
Crown-Root Ratio	1	0.50	0.4810
Length-Width Ratio	1	0.13	0.7146
Width-Height Ratio	1	1.16	0.2842
Flare 1	1	0.18	0.6761
Flare 2	1	0.43	0.5134
Flare 3	1	0.01	0.9366
Crown Eccentricity	1	0.05	0.8261

Table 11. Results of stepwise multiple linear regression predicting incisor irregularity from dimensions of the maxillary lateral incisor.

Variable	df	F Ratio	P Value
Step 0			
Root Height	1	0.86	0.3560
Crown Height	1	6.56	**0.0114**
MD Width at the CEJ	1	13.67	**0.0003**
Maximum MD Width	1	7.13	**0.0084**
Incisal MD Width	1	4.02	**0.0469**
Lateral Crown Height	1	4.08	**0.0452**
Medial Crown Height	1	4.07	**0.0454**
Tooth Length	1	3.12	0.0795
Crown-Root Ratio	1	1.77	0.1856
Length-Width Ratio	1	0.33	0.5682
Width-Height Ratio	1	0.12	0.7297
Flare 1	1	2.38	0.1247
Flare 2	1	0.28	0.5979
Flare 3	1	2.32	0.1296
Crown Eccentricity	1	0.03	0.8568
Step 1			
Root Height	1	0.81	0.3696
Crown Height	1	0.02	0.8839
MD Width at the CEJ	1	13.67	**0.0003**
Maximum MD Width	1	0.10	0.7515
Incisal MD Width	1	0.47	0.4949
Lateral Crown Height	1	0.06	0.8037
Medial Crown Height	1	0.03	0.8702
Tooth Length	1	0.40	0.5285
Crown-Root Ratio	1	0.57	0.4523
Length-Width Ratio	1	0.12	0.7333
Width-Height Ratio	1	0.02	0.8828
Flare 1	1	0.01	0.9304
Flare 2	1	0.32	0.5731
Flare 3	1	0.18	0.6728
Crown Eccentricity	1	0.00	0.9917

Table 12. Results of stepwise multiple linear regression predicting TSASD (tooth size arch size discrepancy) from dimensions of the maxillary central incisor.

Variable	df	F Ratio	P Value
Step 0			
Root Height	1	0.49	0.4832
Crown Height	1	0.20	0.6580
MD Width at the CEJ	1	0.70	0.4036
Maximum MD Width	1	11.19	**0.0010**
Incisal MD Width	1	11.10	**0.0011**
Lateral Crown Height	1	0.17	0.6848
Medial Crown Height	1	0.27	0.6027
Tooth Length	1	0.54	0.4654
Crown-Root Ratio	1	0.25	0.6202
Length-Width Ratio	1	2.53	0.1140
Width-Height Ratio	1	5.28	**0.0229**
Flare 1	1	5.44	**0.0210**
Flare 2	1	1.20	0.2758
Flare 3	1	5.72	**0.0180**
Crown Eccentricity	1	1.84	0.1774
Step 1			
Root Height	1	0.01	0.9171
Crown Height	1	1.55	0.2145
MD Width at the CEJ	1	2.84	0.0940
Maximum MD Width	1	11.19	**0.0010**
Incisal MD Width	1	1.07	0.3031
Lateral Crown Height	1	3.25	0.0733
Medial Crown Height	1	0.44	0.5065
Tooth Length	1	0.17	0.6846
Crown-Root Ratio	1	0.89	0.3466
Length-Width Ratio	1	0.39	0.5317
Width-Height Ratio	1	2.48	0.1178
Flare 1	1	3.18	0.0766
Flare 2	1	1.09	0.2974
Flare 3	1	3.69	0.0566
Crown Eccentricity	1	2.20	0.1398

Table 13. Results of stepwise multiple linear regression predicting TSASD (tooth size arch size discrepancy) from dimensions of the maxillary lateral incisor.

Variable	df	F Ratio	P Value
Step 0			
Root Height	1	1.23	0.2693
Crown Height	1	6.68	**0.0107**
MD Width at the CEJ	1	3.88	0.0507
Maximum MD Width	1	10.44	**0.0015**
Incisal MD Width	1	9.25	**0.0028**
Lateral Crown Height	1	0.65	0.4222
Medial Crown Height	1	1.98	0.1613
Tooth Length	1	3.62	0.0589
Crown-Root Ratio	1	1.00	0.3191
Length-Width Ratio	1	0.79	0.3761
Width-Height Ratio	1	0.10	0.7487
Flare 1	1	2.90	0.0907
Flare 2	1	0.14	0.7071
Flare 3	1	2.86	0.0930
Crown Eccentricity	1	1.12	0.2928
Step 1			
Root Height	1	0.09	0.7704
Crown Height	1	0.38	0.5368
MD Width at the CEJ	1	0.78	0.3799
Maximum MD Width	1	10.44	**0.0015**
Incisal MD Width	1	0.37	0.5468
Lateral Crown Height	1	0.60	0.4412
Medial Crown Height	1	0.05	0.8324
Tooth Length	1	0.00	0.9746
Crown-Root Ratio	1	0.13	0.7204
Length-Width Ratio	1	0.02	0.9022
Width-Height Ratio	1	0.06	0.8018
Flare 1	1	1.05	0.3062
Flare 2	1	0.32	0.5737
Flare 3	1	1.69	0.1957
Crown Eccentricity	1	0.72	0.3966

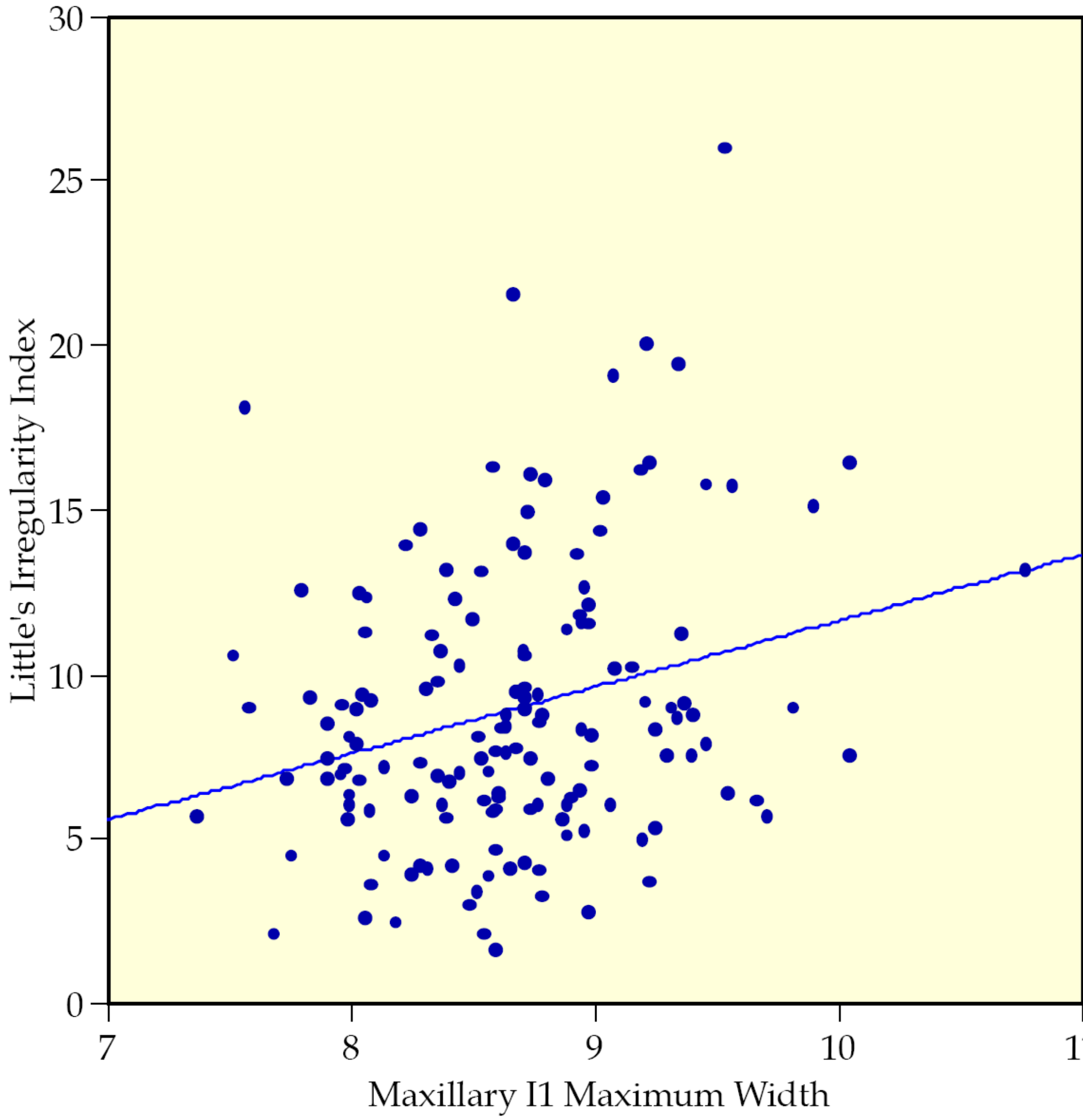


Figure 81. Bivariate plot showing the significant, positive association between the maximum MD crown width of the maxillary central incisor and the extent of Little's Irregularity Index.

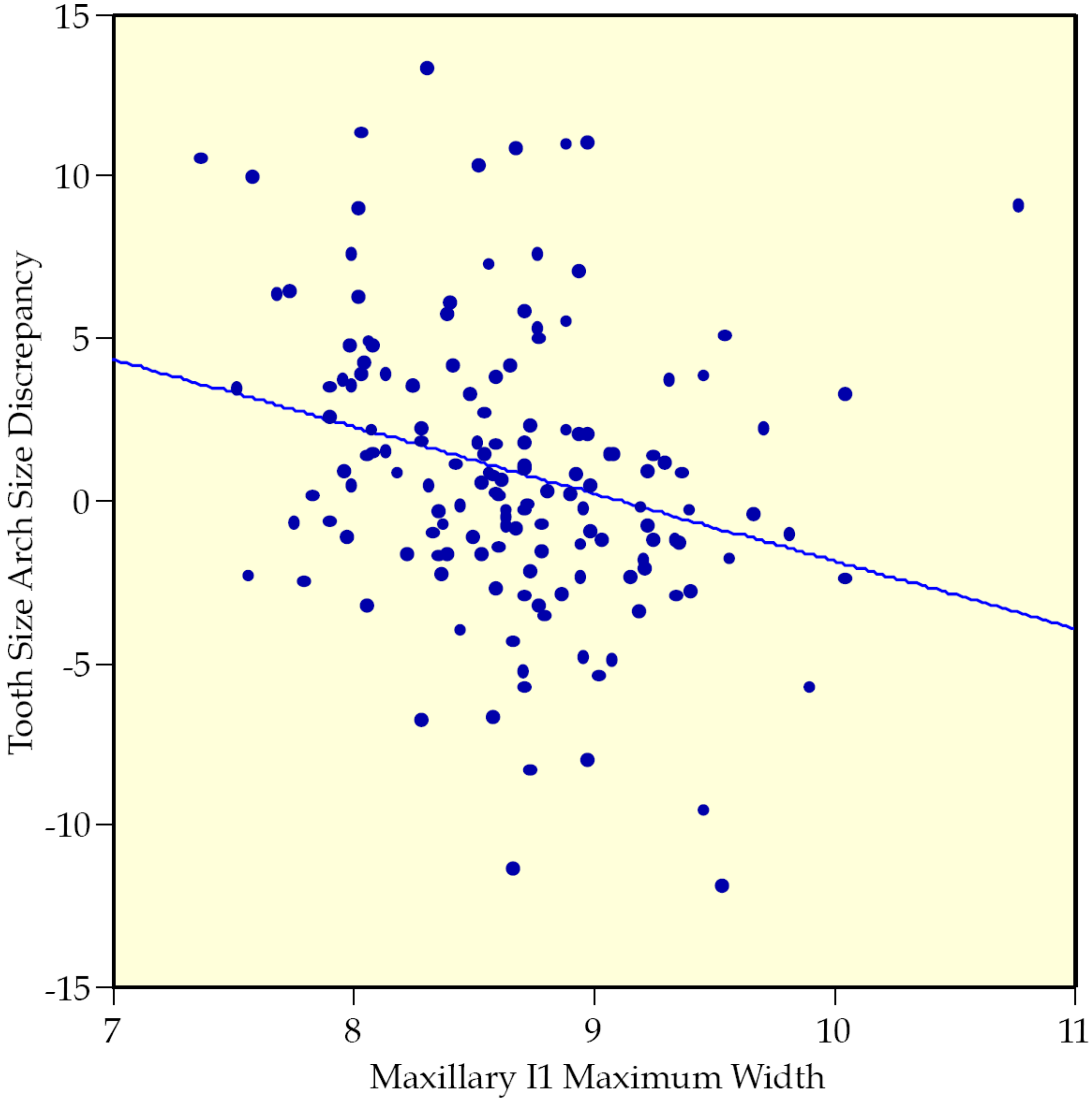


Figure 82. Bivariate plot showing the significant, negative association between maximum MD crown width of the maxillary central incisor and the extent of TSASD.

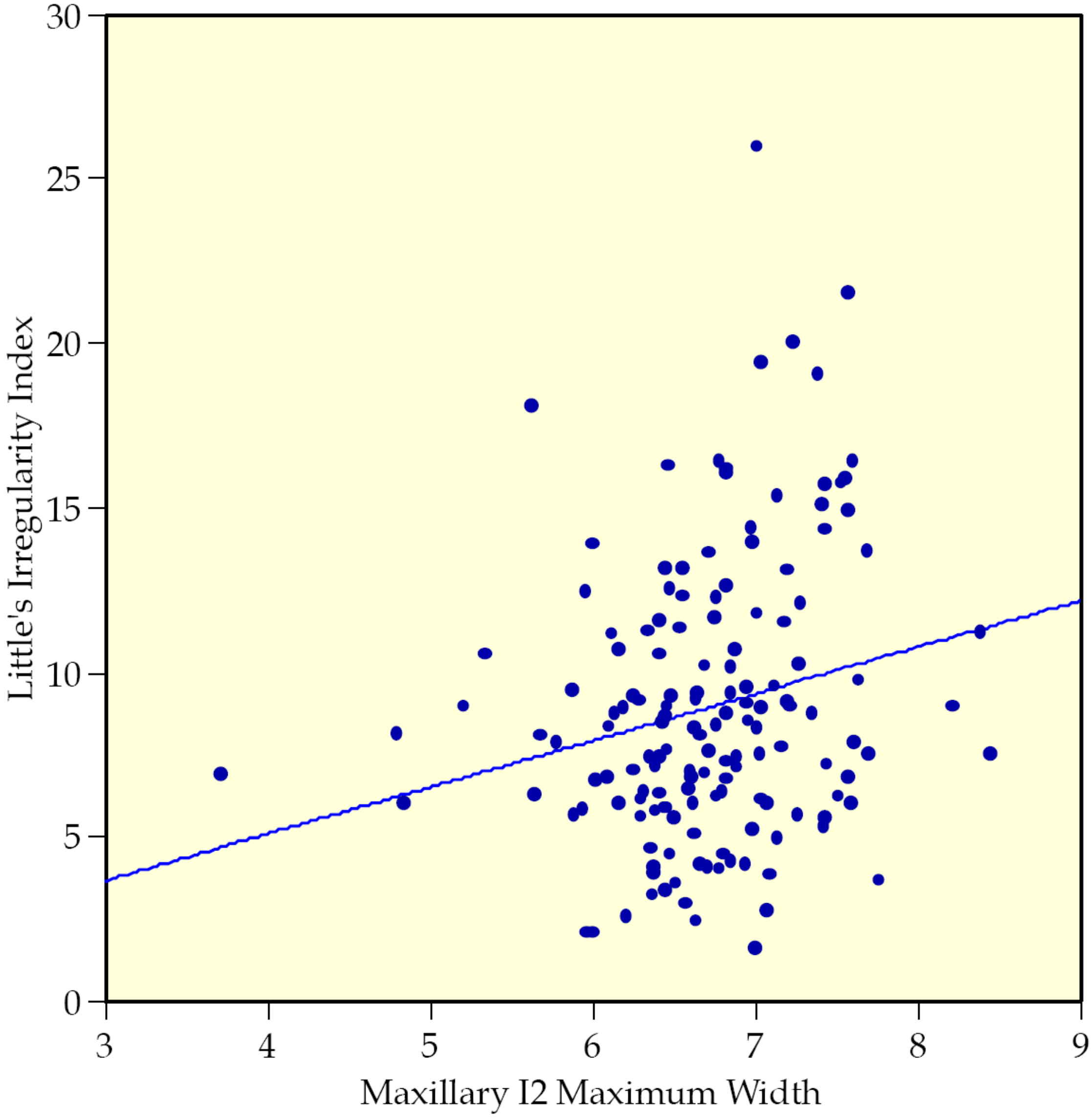


Figure 83. Bivariate plot showing the significant, positive association between the maximum MD crown width of the maxillary lateral incisor and the extent of Little’s Irregularity Index.

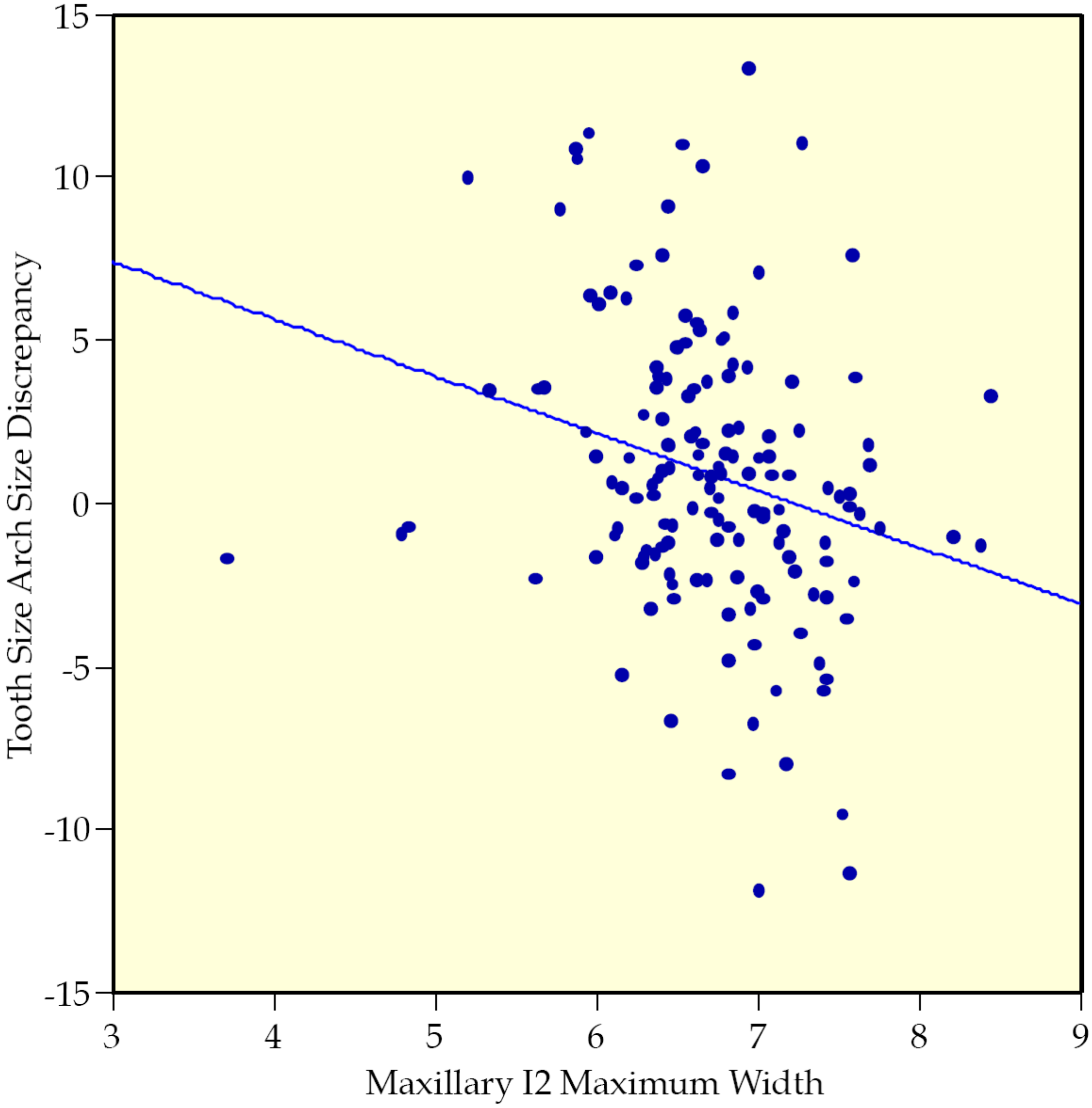


Figure 84. Bivariate plot showing the significant, negative association between maximum MD crown width of the maxillary lateral incisor and the extent of TSASD.

crowding, and males with larger teeth exhibited more crowding, then the association between crown size and crowding could be confounded by sexual dimorphism. The four ANCOVA analyses in Table 14 show that this is not the case. While males have larger teeth, sexual dimorphism is additively related to the tooth size-crowding relationships. This is evident from inspection of the interaction terms, none of which approaches statistical significance. In other words, while there is significant sexual dimorphism in some variables (*i.e.*, the two measures of irregularity), the interaction effects are not significant, showing that sex has only an additive effect (and is reasonable removed by the ANCOVA design).

Table 14. Results of ANCOVA tests assessing for a significant sex effect.

A. I1 crown size and irregularity, holding sex constant.

Source	df	SSQ	F Ratio	P Value
Maximum MD of I1	1	133.06	8.00	0.0053
Sex	1	103.86	6.25	0.0136
Sex-x-MD Size	1	0.06	0.00	0.9521

B. I1 crown size and TSASD, holding sex constant.

Source	df	SSQ	F Ratio	P Value
Maximum MD of I1	1	204.32	11.10	0.0011
Sex	1	1.37	0.07	0.7857
Sex-x-MD Size	1	3.37	0.18	0.6696

C. I2 crown size and irregularity, holding sex constant.

Source	df	SSQ	F Ratio	P Value
Maximum MD of I2	1	104.52	6.23	0.0137
Sex	1	148.88	8.88	0.0034
Sex-x-MD Size	1	0.65	0.04	0.8437

D. I2 crown size and TSASD, holding sex constant.

Source	df	SSQ	F Ratio	P Value
Maximum MD of I2	1	179.02	9.66	0.0023
Sex	1	0.87	0.05	0.8291
Sex-x-MD Size	1	0.52	0.03	0.8675

CHAPTER V

DISCUSSION

Anterior dental crowding is an esthetic concern that causes many people to seek orthodontic treatment (Little 1975; Destang and Kerr 2003). Much orthodontic research has been aimed at determining the etiologies of malocclusion. Several studies have looked at tooth *size* as it relates to malocclusion (Howe *et al*. 1983; McCann and Burden 1996; Sterrett *et al*. 1999; Poosti and Jalali 2007), others have categorized incisor crown forms (Williams 1914; Frush and Fisher 1956; Ibrahimagić 2001a), the present study tested whether maxillary incisor crown *form* is predictive of anterior crowding.

In the present study, periapical radiographs of the maxillary incisors allowed for measurements to be made from scanned radiographic images of *anatomical* crown form, rather than clinical measurements of tooth size (clinical crown height or width) from dental casts. By identifying several landmarks (Figure 18) on the periapical radiographs of the maxillary central and lateral incisors, linear distances were obtained (Figure 19). From these linear distances, width ratios, height ratios, and width-to-height ratios were derived to numerically describe anatomical crown *form*. The width ratios quantify the flare (or taper) of the incisal crown form, which has been thought to correlate with incisor irregularity (Rhee and Nahm 2000).

Tooth Size, Shape, and Crowding in the Anterior Segment

The central question in this study was whether maxillary incisor size and/or shape were predictive of the extent of malocclusion of the maxillary anterior segment. Malocclusion of the anterior segment was measured in two complementary manners, namely (1) maxillary incisor irregularity (Little 1976) and (2) TSASD (tooth size arch size discrepancy) as described by Merrifield (1978). These two variables reflect different but complementary aspects of anterior crowding. The irregularity index is a measure of irregularity alone and makes no statement as to whether enough room exists in the arch to properly align the teeth. The space analysis is more sensitive to the amount of space actually needed to align the teeth, while disregarding axioversions of the anterior teeth (Harris, Vaden and Williams 1987).

Mesiodistal Tooth Widths and TSASD

Bernabé and Flores-Mir (2006) examined tooth shape from the incisal aspect by comparing the maximum mesiodistal tooth width to the buccolingual width to examine MD/BL ratios for all maxillary and mandibular teeth separated into three defined groups of crowding as described by the TSASD. In the present study, we looked at crowding as a continuum using methods of TSASD and Little's irregularity index. Bernabé and Flores-Mir (2006) found that dental arches with moderate, mild or no crowding differed most of the time significantly in their MD tooth widths but not in their BL tooth sizes. For the maxillary teeth examined in the Bernabé and Flores-Mir study, differences in MD tooth width existed in all upper teeth among the different groups of crowding (Figure 85). The average mean MD tooth width for the maxillary lateral and central incisor was larger in the mild crowding group than the no crowding group, and larger still in the moderate crowding group than in the mild crowding group. Bernabé and Flores-Mir (2006) found that larger tooth *size* (MD width) not tooth *shape* (MD/FL index) was associated with greater TDASD

In the present study, tooth *shape* (flare) did not correlate with crowding, measured as TSASD or as irregularity. However, like Bernabé and Flores-Mir (2006), the present study found tooth *size* (maximum MD width and maximum incisal MD width) did correlate with both TSASD and Little's irregularity index. Subjects with wider teeth (mesiodistally), require more arch space, and therefore presented with larger (more negative) TSASD.

Crown Width-to-Height Ratio and TSASD

Another significant predictor of TSASD in the present study was the I1 width-to-height crown index. The width-to-height ratio includes the maximum mesiodistal crown dimension as the numerator. Since larger crown widths (maximum MD width and incisal MD width) were associated with crowding (TSASD), it is more likely that increased MD crown widths rather than decreased crown heights contributed to the statistically significant correlation seen between width-to-height ratio and decreased TSASD (crowding).

The bottom line to a dentist is that smaller teeth (mesiodistally) take up less space in the dental arch. An accepted range of normal relationships exists between crown height and crown width. As crown width-to-height ratio becomes larger, either the crown is shorter relative to the width or the crown is wider relative to the height. Regardless of sex, or Angle's molar classification, wider crowns take up more space in the dental arch and are frequently associated with a space deficit, or a more negative TSASD.

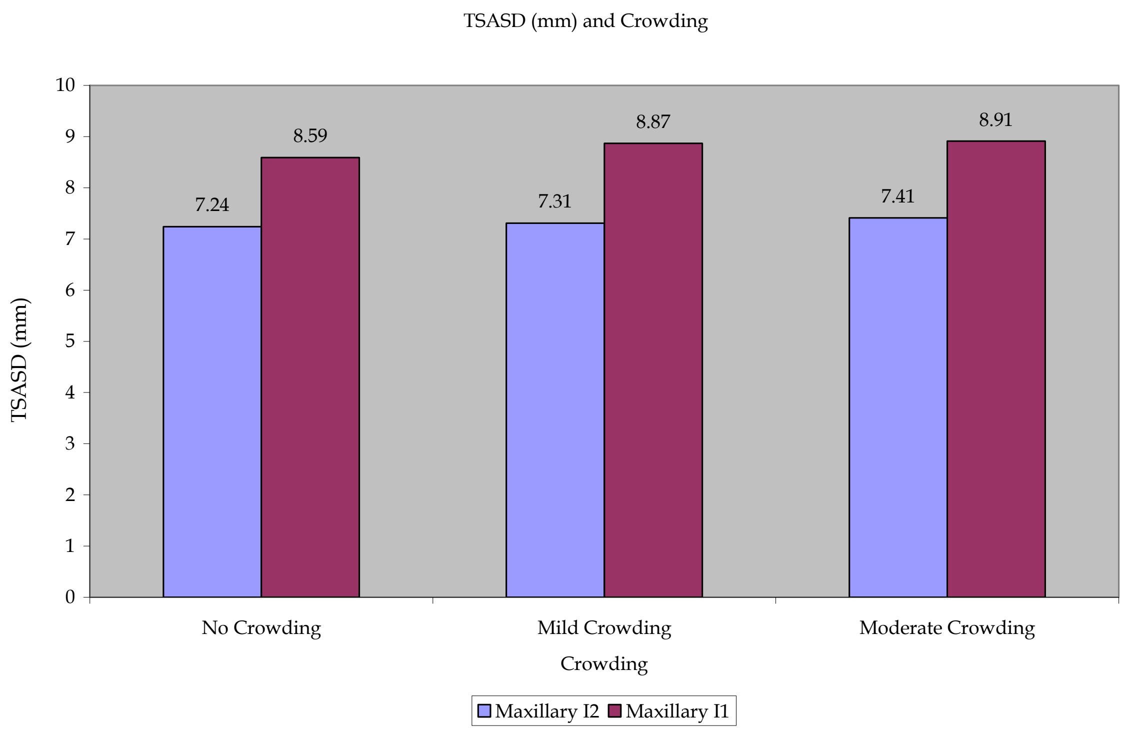


Figure 85: Graphic representation of the results reported by Bernabé and Flores-Mir (2006) of TSASD (mm) and average tooth widths for the maxillary central (I1) and lateral (I2) incisors. The group labeled "no crowding" had 0 mm TSASD, the "mild crowding" group had a space deficit between 0.1 and 5 mm, and the moderate crowding group had space deficit of 5.1 mm or greater.

Created with data from Bernabé E, Flores-Mir C. Dental morphology and crowding: a multivariate approach. Angle Orthod 2006;76:20-5.

Crown Form and Incisor Irregularity

Rhee and Nahm (2000) measured dental casts of orthodontically untreated Koreans to study the flare of the *clinical* crowns of the incisors. Rhee and Nahm (2000) hypothesized that the larger the contact area, the more stable the position of the tooth and the less likely it would be to slip under pressure or tension. Triangular (more flared) incisor forms have small anatomic contact areas and would have less stable contacts, which, Rhee and Nahm conjectured, would be reflected clinically as increased incisor irregularity. In their study measuring clinical crowns from dental casts, Rhee and Nahm found that patients with more incisor irregularity had greater mesiodistal widths at the incisal-most aspect (termed IMD) relative to the maximum mesiodistal width at the cervical-most measurement (termed CMD, width measured at one fourth the clinical crown height from the most apical point on the gingival margin). Larger width ratios (IMD:CMD) (Figure 12) were found in the crowded group. Crowding, measured as incisor irregularity, was more common in individuals with triangularly shaped incisors (*i.e.*, those with a larger IMD:CMD ratio).

In the study by Rhee and Nahm (2000), where flared or triangular shaped incisors were correlated with larger irregularity indices, the authors conjectured that triangularly shaped crowns would have smaller proximal contacts and thus be more likely to slip contact under pressure, displaying greater incisor irregularity. In their study, broadness or area of proximal contact was not actually measured, and looking at mesiodistal tooth widths does not provide information as to contact size. In cases where clinical contact points are small and mesiodistal widths are wide, one can create a broader contact point and narrower tooth width by judicious removal of tooth structure at the level of the contact point. Interproximal reduction creates a larger, broader contact point and buys mesiodistal arch space.

Clinical Crown Measurements *vs.* Anatomical Crown Measurements

The present study looked at three different mesiodistal widths: the cervical mesiodistal width (measured between the medial and lateral CEJ landmarks), the maximum mesiodistal width, and the incisal mesiodistal width (measured between the medial-occlusal and lateral-occlusal landmarks) as opposed to the two mesiodistal widths (IMD and CMD) in the study by Rhee and Nahm (2000). The measurements in the present study were made from periapical radiographs, and describe anatomical crown form. In the study by Rhee and Nahm (2000), the CEJ would not have been visible on the dental casts (the gingiva would cover a portion of the cervical part of the crown), so the CMD measurements in Rhee and Nahm's study would be smaller than the cervical mesiodistal width measured at the level of the CEJ in our study (Figure 86). In a healthy patient the interdental papilla fills interdental space and covers a portion of the cervical third of the crown (Ash 1993; Carranza and Newman 1996). A healthy gingival sulcus varies from 0.5 to 3.0 mm with an average depth of 1.8 mm (Carranza and Newman 1996;Ten Cate 1998). In a study by Smith *et al.* (1996), the average probing depths of maxillary lateral incisors recorded over a 20 week period were 1.4 mm (sd = 0.49) at the buccocervical aspect and 2.1 mm (sd = 0.53) at the mesiobuccal aspect.

Continuous eruption, as described by Gottlieb and Orban (1933), continues throughout life. Eruption does not cease when teeth meet their functional antagonist and consists of two stages: active and passive (Carranza and Newman 1996). Active eruption is the movement of the teeth in the direction of the occlusal plane. Passive eruption is the continuous exposure of the teeth by apical migration of the gingiva and can be described as a series of 4 stages. The first stage occurs when the teeth reach the line of occlusion. In the first stage of passive eruption the junctional epithelium and base of the gingival sulcus are on the enamel (at this stage the clinical crown is approximately two thirds of the anatomic crown). In stage two, the base of the gingival sulcus is still on enamel and part of the junctional epithelium is on the root. In stage three, the base of the gingival sulcus is at the CEJ, and by stage four both the base of the gingival sulcus and the junctional epithelium are on the root (Carranza and Newman 1996) (Figure 87).

In the present study, the average subject age was 13.7 years. In a young patient with a healthy periodontium, and assuming stage one, two or three of passive eruption, the average base of the gingival sulcus would be at the level of the CEJ or located more coronally. With an average probing depth of 1.8 mm (Carranza and Newman 1996;Ten Cate 1998), a significant portion of the anatomic crown would be covered by gingival tissue (Figure 86). Smaller CMD measurements of clinical crown form entered into the IMD:CMD equation would yield a higher ratio and describe a more flared incisor than the anatomic crown measurement of the MD width at the CEJ, which is hidden under gingival tissue.

With sexes pooled, the clinical crowns of the maxillary central and lateral incisors of the crowded group in the study by Rhee and Nahm (2000) had smaller average CMD measurements and larger IMD measurements when compared to their “normal” group. This led to more triangularly shaped incisors (larger IMD:CMD ratio) in the crowded group, which also had an average irregularity index of 11.5 mm as compared to the average index of 1.95 mm in their “normal” group.

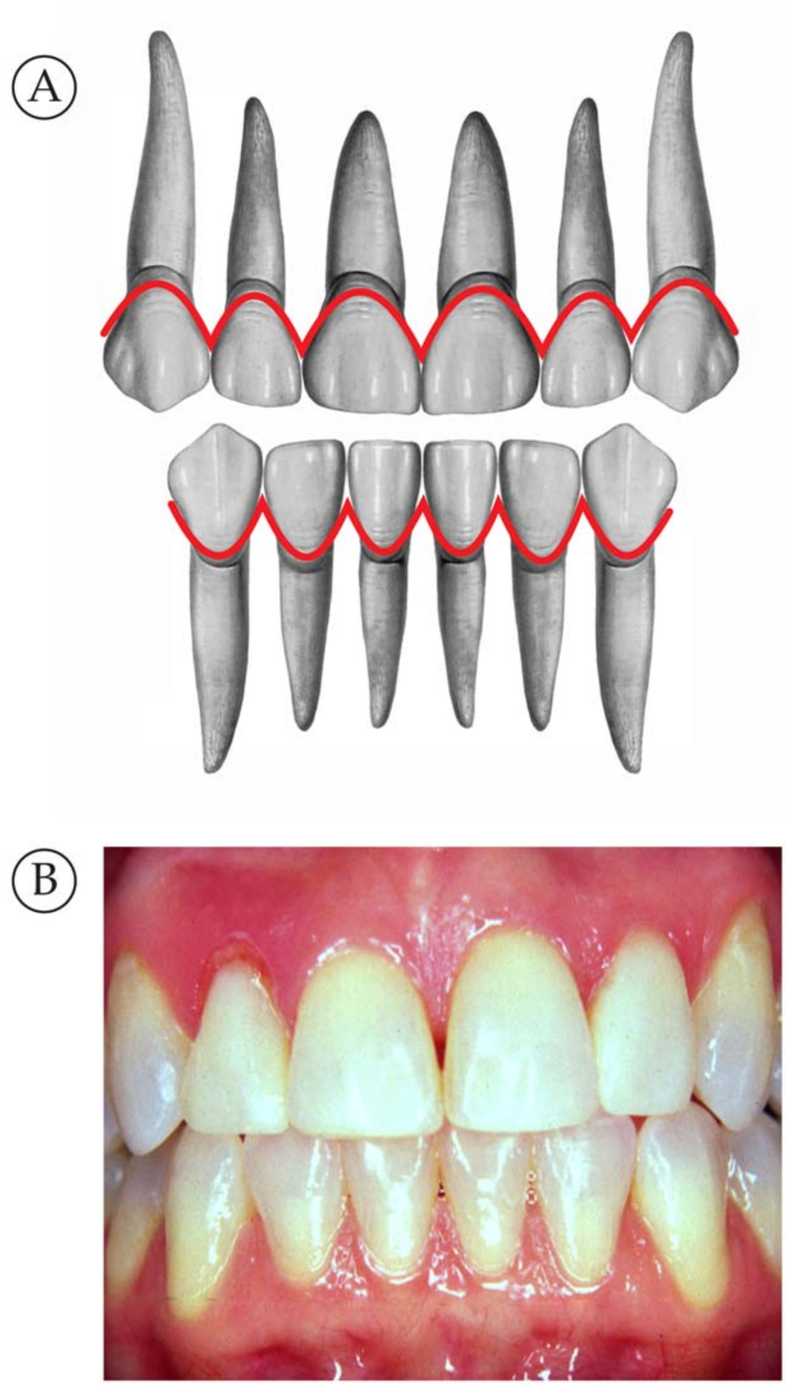


Figure 86. Labial views of the anterior teeth, showing the approximate coverage of the apical regions of the crowns by the gingiva.

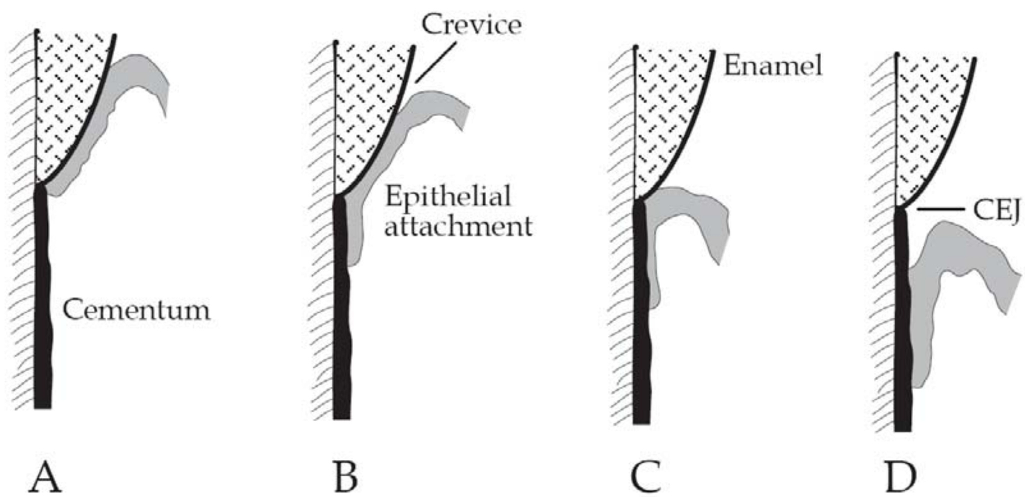


Figure 87. Illustration of the four stages of passive eruption as described by Gottlieb and Orban (1933). (A) The base of the gingival sulcus (crevice) and the junctional epithelium (epithelial attachment) are on the enamel. (2) The base of the gingival sulcus is on enamel and part of the junctional epithelium is on the root. (3) The base of the gingival sulcus is at the CEJ and the entire junctional epithelium is on the root. (4) The base of the gingival sulcus and the junctional epithelium are on the root.

Diagram supplied by E.F. Harris

Differences in Cervical Mesiodistal Measurement

The IMD:CMD ratio used to describe clinical crown form in the study by Rhee and Nahm (2000) most closely relates to the derived variable, Flare 3 (incisal mesiodistal width/mesiodistal width at the CEJ) in the present study. Rhee and Nahm found the ratios of IMD:CMD for both I1 and I2 to be statistically significantly correlated to the irregularity index. Our measurement for CMD was different from the measurement made in Rhee and Nahm's study. Figure 88 illustrates how measurements made from a dental cast have gingival tissue covering a portion of the anatomical crown. In most cases, the measurement used in the present study of the maximum mesiodistal width at the level of the CEJ yields a larger value than the mesiodistal measurement made at one fourth the distance of the height of the clinical crown from the gingival margin (CMD). The larger denominator in the present study produces a smaller IMD:CMD ratio (in our case Flare 3). The difference in measurement technique at the cervical most measurement between the present study and the study by Rhee and Nahm (2000) is likely why the present study did not find a statistically significant correlation between the ratio (Flare 3) and incisor irregularity as described by Little (1975).

Resolving TSASD and Incisor Irregularities

One solution for dental crowding is orthodontic tooth movement. Orthodontic alignment of the teeth may include extraction (decreases the sum of the tooth widths) or expansion (increases the arch perimeter), these solutions allow for natural crown form to be maintained in the anterior segment. In cases of minor crowding, another orthodontic technique frequently employed is interproximal reduction (IPR). By removing proximal tooth structure from one or more teeth, the sum of the tooth widths is decreased, and space is created for orthodontic alignment. Interproximal reduction does not preserve natural crown form, however it is believed that IPR creates broader contact points with larger surface areas. Broadening of the contact points is believed to lead to better long-term stability of the orthodontic correction (Rhee and Nahm 2000).

Another solution, gaining popularity is cosmetic correction of dental crowding through dental restorations. If an attempt is made to correct anterior crowding without the aid of orthodontic tooth movement, one would either have to make (1) the tooth-sizes narrower, or (2) the arch-size larger. This can be accomplished through crowns, bridges, veneers, dental implants, or other dental materials by (A) making the crowns proportionally narrower, (B) repositioning the new restorations more buccally to increase the arch length, (C) a combination

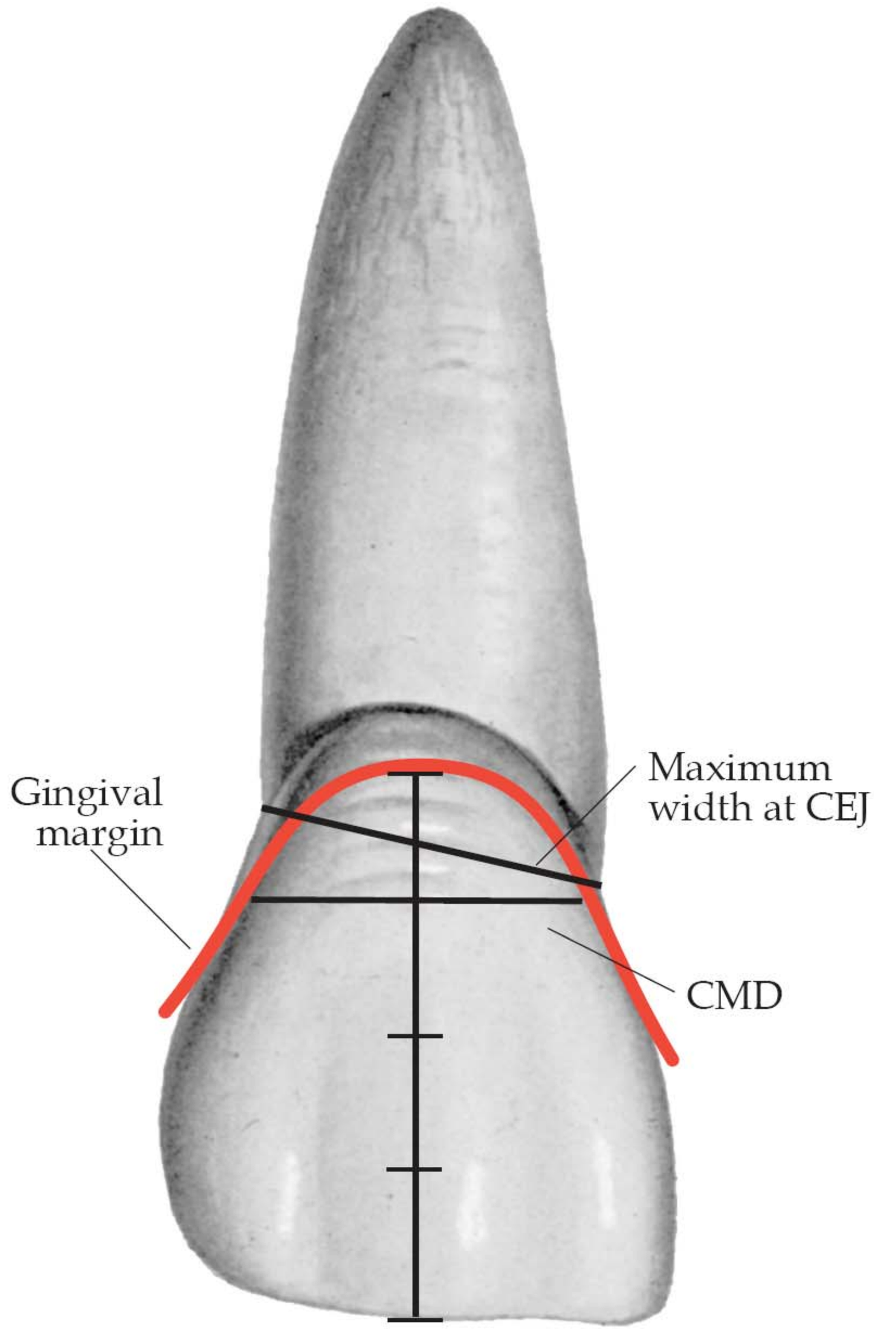


Figure 88. Illustration of the difference between measurements of CMD (Rhee and Nahm 2000) and maximum MD width at the CEJ.

of A and B, or (D) extracting displaced or crowded teeth and redistributing the space.

Intrinsic Error in Periapical Radiographs

It seems prudent to discuss the possible issue of image distortion associated with periapical radiographs. Image shape distortion can result from unequal magnification of different parts of the same object when not all parts of the object are in the same focal spot-to-object distance (White and Pharoah 2000). The long-cone paralleling technique is the preferred method for taking periapical radiographs and produces some magnification of the image, since the image must be projected across the distance between the object and the film. The present study controlled for the magnification inherent to periapical radiographs by calculating the magnification of each tooth in the study. The tooth width measured on the plaster cast was divided by the maximum mesiodistal crown width measured on the radiograph. All other linear distances recorded for the same tooth were multiplied by this magnification factor before any derived variables were calculated.

The common problems of foreshortening (image is shorter than the actual object) and elongation (image is longer than the actual object) are due to problems in paralleling the film and the object or having the x-ray beam at a right angle to the object or film. No matter how sophisticated the measuring system, how you know you are looking at the actual mesiodistal view of a tooth comes down to visual assessment. In the present study, each subject had, on average, four periapicals of the anterior teeth and the majority of incisors were present on more than one radiograph. If the radiographic image of a tooth appeared elongated, foreshortened, or distorted in anyway, or if the repeated images of the same tooth contradicted one another, the antimeric central or lateral incisor was measured, or the subject was discluded from the study.

It also is important to appreciate the effects of variably orienting the source, tooth, and film. Inconsistencies increase the measures of sample dispersion (*e.g.*, variance and standard deviation). Unless there is consistent bias within and among operators, the means (measures of central tendency) remain unaffected. Consequently, inconsistencies will make it more difficult to detect statistically-significant associations if they truly exist, but they will not alter the nature of the associations. That is, inconsistencies increase the noise-to-signal ratio by increasing the sample variances. The risk, then, is that true statistical associations might be missed, but this is countered by the large sample sizes available here (Houston 1983). Given the highly significant and internallyconsistant results achieved in this study, the effects of operator inconsistencies seem to be inconsequential.

One strength of the present study was that pretreatment periapical radiographs were available in a young orthodontic sample, allowing for the study of *anatomic* crown form. Through visual assessment and clinical judgement, images with any detectable distortions were discluded. This study could be improved upon by examining anatomic crown form from 3D cone-beam CT images, thus, eliminating the intrinsic error inherent to periapical radiographs.

Tooth Dimensions and Angle's Classification

There is some evidence that tooth sizes are tied statistically (and, by inference, developmentally) to the type of malocclusion and measured by Angle's molar classification. When looking at associations between dimensions of the *lateral* incisor with Angle's classification, five of the dimensions of the lateral incisor achieved significance. Root height did not differ by Angle's Class, but crown height did differ significantly among classes because crown height in the Class II, division 2 group was shorter. By itself, this might be argued away because of the diminished crown-root angulation (Harris *et al.* 1993) and, thus, the potentially altered crown-to-film angulation. However, the difference in collum angle does not account for the inter-Class differences seen in mesiodistal dimensions. The mesiodistal width at the CEJ, the widest mesiodistal width, and width at the incisal edge all were significantly narrower in the Class II, division 2 group. Of note, crown heights measured at the medial and lateral margins did not differ among groups, which suggest that the smaller dimensions seen for other dimensions of the Class II, division 2 sample are not due to foreshortening.

Total tooth length did not differ among Classes, but the crown-root ratio was significantly smaller in the Class II, division 2 sample. Since there was no statistically significant difference for the measurement of root length, or the derived tooth length between the Angle's classifications tested, the statistically significant difference in crown-to-root ratio seen in the Class II, division 2 malocclusion group was due to a difference in crown height (*i.e.*, Class II, division 2 malocclusions have shorter crowns). In overview, the upper central incisor shows no discernible statistical dependency among Angle's Classes; in contrast, shorter, narrower lateral incisor crowns characterize the present sample of Class II, division 2 malocclusions.

Angle's molar classification is based on the anteroposterior relationship of the first permanent molars, but the division for the Angle's Class II molar relationship depends on the anteroposterior relationship of the maxillary incisors. Division 1 is characterized by labioversion of the maxillary incisor teeth, whereas division 2 is characterized by linguoversion of the maxillary central incisors (Riolo and Avery 2003). With the anteroposterior position of the maxillary incisors being the diagnostic criteria for the division of a Class II malocclusion, perhaps there is something inherent in the crown form of shorter, narrower lateral incisors characteristic of the division 2 group that cause the relative labioversion of the adjacent central incisors. Since crown size and shape, as well as malocclusion have a heritable and genetic component, perhaps short, narrow lateral incisor crown form is an etiology of the Class II, division 2 malocclusion. If a particular I2 crown form is associated with large discrepancies between the central (linguoverted) relative to the lateral (labioverted) incisor, as in a Class II, division 2 malocclusion, this would be a good crown form not to attempt to replicate restoratively, assuming that crown form is predictive of irregularity.

The Multivariate Analysis

Despite statistically significant differences seen in various measurements of anatomical crown form in the present study, the reality is that after stepwise multiple linear regression to develop sets of tooth-size variables predictive of anterior crowding (TSASD or Little's irregularity index), in three out of four models, the maximum mesiodistal tooth width was the single significant predictor of TSASD and incisor irregularity. The exception was the high predictive value of the width measurement at the level of the CEJ for the lateral incisor for predicting the irregularity index. Statistically significant differences were seen between the sexes for lateral incisor crown shape; however, the most predictive variable of anterior crowding was the maximum mesiodistal tooth width (size) of the maxillary incisors. Larger teeth require more arch space to be well aligned. In the absence of additional arch space, individuals with larger teeth display greater TSASD and incisor irregularity.

Larger teeth presenting with tooth-size arch-size discrepancies or incisor irregularities present an age-old problem for orthodontists. The clinical solutions are few, (1) decrease the tooth size—through interproximal reapproximation or extraction, or (2) increase arch-size—through dental and/or orthopedic expansion or through distalization of posterior teeth.

Sexual Dimorphism

Crown Flare

There was a statistically significant difference found between sexes for the shape of the lateral incisor in the present study. The ratio of crown widths labeled Flare 1 (Figure 89) was significantly larger in females for the maxillary lateral incisor—I2 flared more occlusally from the CEJ in females than in males. Additionally, the CEJ width of females compared to the crown width at the incisal edge (*i.e.*, Flare 3) disclosed a highly significant difference (Figure 90). The statistically significant differences in crown shape described by Flare 1 and Flare 3 for I2 was due primarily to a smaller average mesiodistal width at the CEJ in females, with little difference in maximum mesiodistal width or incisal width between sexes. Rhee and Nahm (2000) also looked at crown form (IMD:CMD) between sexes. The difference between sexes found for the flare of the maxillary lateral incisor in the present study was due to a statistically smaller width measured at the level of the *anatomical* CEJ in females, whereas Rhee and Nahm (2000) found a statistically significantly larger MD width measured at the level of the incisal edge for both the maxillary central and lateral incisor in males. When Rhee and Nahm (2000) calculated width ratios for IMD and CMD of the maxillary incisors, the ratio was not sexually dimorphic. One major difference between the present study and the study by Rhee and Nahm was that our width measurement at the level of the CEJ was made at the radiographic CEJ, rather than the CMD width measured at "the level of the cementoenamel junction equal to one fourth of the labial crown length." In a healthy periodontium, the interdental papilla fills interdental space and covers a portion of the cervical third of the crown (Ash 1993) (Figure 21). A healthy gingival sulcus varies from 0.5 to 3.0 mm with an average depth of 1.8 mm (Ten Cate 1998). Unlike measurements of clinical crown form, measurements of the anatomical CEJ are unaffected and unchanged by variations in gingival tissue due to poor hygiene, delayed passive eruption, or periodontal disease.

Crown Form of Lateral Incisor

The average anatomical lateral incisor crown of the females in this study may best be described by Leon Williams' (1914b) Class III crown form (Figure 4), or the more currently used classification system of House and Loop (Engelmeier 1996) of ovoid (Figure 6). This finding may be useful in prosthetic and restorative dentistry when replacing or restoring maxillary lateral incisors with crowns, veneers, or prosthetic teeth for dentures. When selecting replacement maxillary lateral incisors, a smaller, more tapered incisor would reflect female

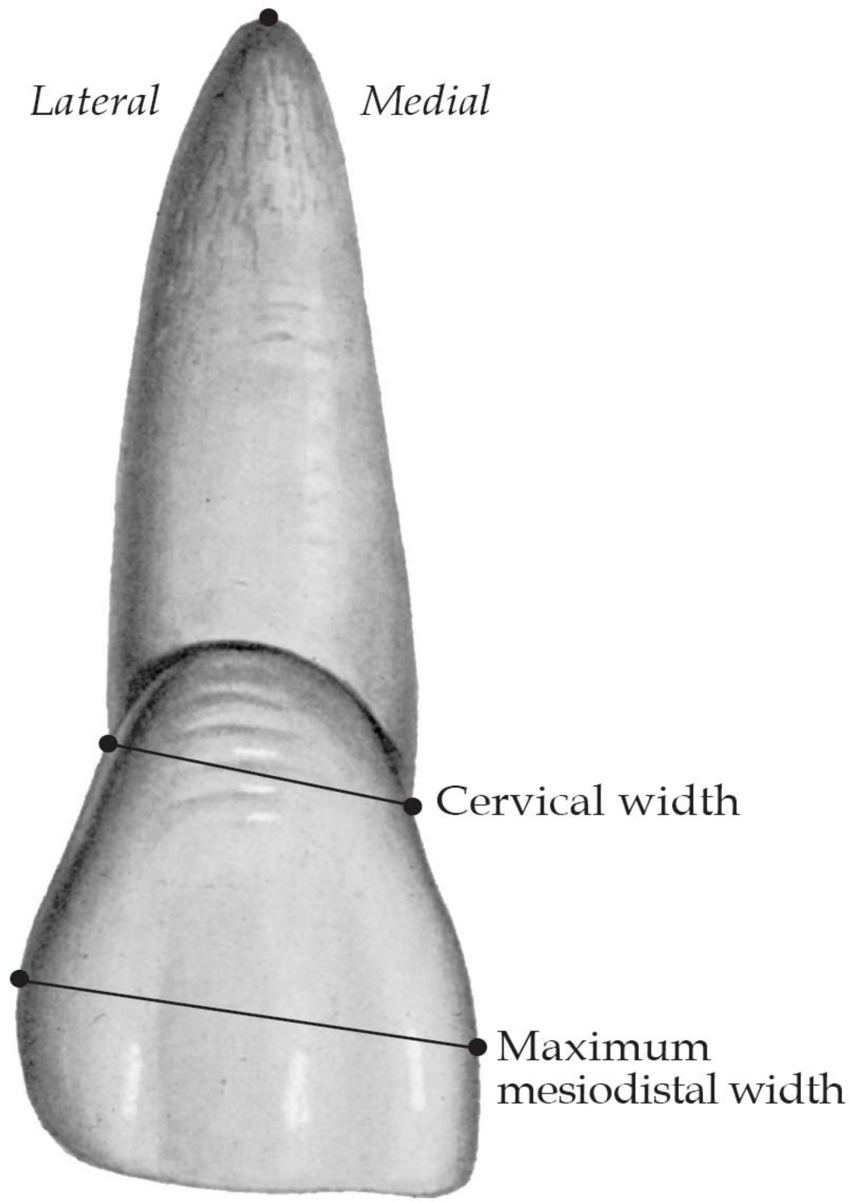


Figure 89: Illustration of the measurements from a maxillary right central incisor used to derive Flare 1. Flare 1 is a dimensionless ratio calculated by dividing the maximum MD width (in millimeters) by the CEJ width (in millimeters).

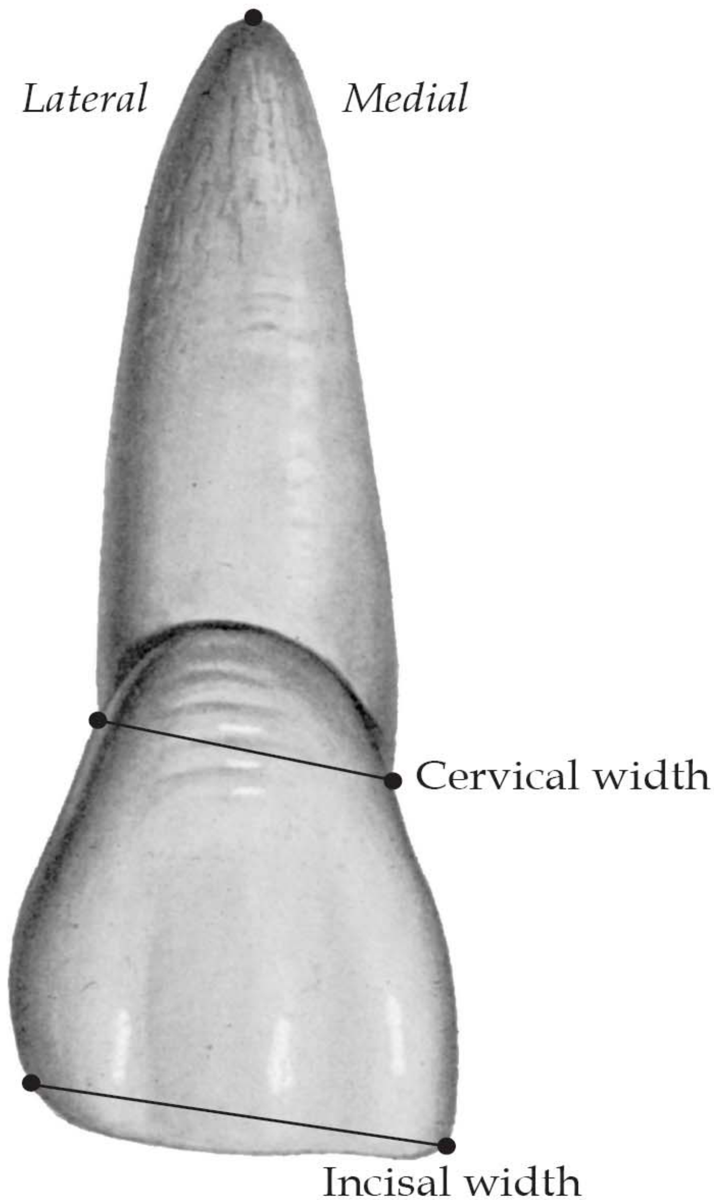


Figure 90: Illustration of the measurements from a maxillary right central incisor used to derive Flare 3. Flare 3 is a dimensionless ratio calculated by dividing the incisal MD width (in millimeters) by the CEJ width (in millimeters).

characteristics. Select larger teeth for males relative to females when choosing anterior denture teeth.

Identification of Sex from Maxillary Incisors

Wolfart *et al.* (2004) asked participants to identify the sex of each subject on the basis of tooth form from black-and-white photographs of the anterior dentition. The accuracy of sex prediction based on tooth form was only 55%, which is similar to the rate one would expect if the participants answered at random. Though the study by Wolfart *et al*. (2004) did not examine numerical measurements of the anatomical crown form, as in the present study, Wolfart *et al*. (2004) found that clinical crown form as judged from photographs was not a good predictor of sex. In the present study, the average anatomical crown form of the maxillary central incisor of males was an isometrically enlarged version of that of females, supporting their conclusion that crown form of the maxillary *central* incisor is not a good predictor of sex. However, the crown form of the maxillary *lateral* incisor, in the present study, did differ metrically between Caucasian males and females. One statistically significant difference for I2 was the width measured at the CEJ. The smaller width measured at the CEJ in females as compared to males made the derived variables Flare 1 and Flare 3 statistically significantly sexually dimorphic. Although we found these differences to be significant statistically, the actual average difference of the mean measurements at the CEJ between males and females was 0.2 mm. To the naked eye, the small average difference between the means of 0.2 mm, in combination with gingival tissue filling the embrasure and covering a portion of the anatomical crown (Ash 1993), would likely camouflage any distinguishable difference that might have been visible at the level of the CEJ. Probably of more importance, the present study evaluated a series of orthodontic patients, where (1) Bolton discrepancies (Bolton 1962) are more common than in the general population and (2) anomalies of tooth size and form are more common. Consequently, extrapolation of these results to the general population need to be made with caution. Relevantly, though, these data are likely to mirror those encountered in other orthodontic practices. If we had looked at intraoral photos of the clinical crowns of the patients, rather than anatomical crowns from radiographs, it is probable that the results would have supported the results found by Wolfart *et al.* (2004), that the sex of a patient cannot be determined from photographs of the teeth alone with more than about 50% accuracy.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Anterior dental crowding is one of the most obvious and most common characteristics of malocclusion (Little 1975; Cons and Jenny 1994). The etiology of malocclusion is generally termed multifactorial (*e.g.*, Mossey 1999; Proffit 2000; Graber 2005) involving both genetic and environmental components (Hartsfield 2005). Incisor crown form may be a factor contributing to dental crowding. There is appreciable variation in incisor crown form. Variation in tooth dimensions, taper, contact size, and contact location may all contribute to differences in incisor alignment.

Research has documented a positive statistical relationship between clinical crown width, arch length and incisor crowding. However, none of the studies has evaluated incisor crowding as it relates to the anatomical crown form. The present study had the opportunity to measure anatomical crown form from pretreatment periapical radiographs of the maxillary central and lateral incisors. Periapical radiographs allowed for anatomic measurements to be made at the cementoenamel junction, as opposed to clinical measurements between the dental papilla on orthodontic casts. In the present study, the anatomical crown measurements from the pretreatment periapical radiographs were compared to measurements of incisor irregularity and tooth-size arch-length discrepancy measured on orthodontic casts. The objective of the present study was to evaluate statistical associations between maxillary incisor crown form and the extent of incisor irregularity in adolescent boys and girls who sought comprehensive orthodontic treatment. Major findings were:

1. In the present study, the average maxillary *central* incisor of males was an isometrically enlarged version of the average maxillary central incisor of females. The average maxillary *lateral* incisor of females had a sexually dimorphic crown form characterized by a significantly smaller MD measurement at the level of the CEJ, which translated into more flared lateral incisor crowns.

2. Maxillary lateral incisors in Class II division 2 subjects had a distinctive crown form characterized by shorter and narrower crowns.

3. The maximum mesiodistal tooth width was the single significant predictor of TSASD and incisor irregularity. The exception was the high predictive value of the width measurement at the level of the CEJ for the lateral incisor for predicting the irregularity index. Larger teeth require more arch space to be

well aligned. In the absence of additional arch space, individuals with larger teeth display greater TSASD and incisor irregularity.

4. The present study did not evaluate the population at large, rather a series of orthodontic patients where (1) Bolton discrepancies (Bolton 1962) are more common than in the general population and (2) anomalies of tooth size and form are more common. Consequently, extrapolation of these results to the general population needs to be done with caution.

Larger teeth presenting with tooth-size arch-size discrepancies or incisor irregularities present an age-old problem for orthodontists. The clinical solutions are few, (1) decrease tooth size—through interproximal reapproximation or extraction, or (2) increase arch-size—through dental and/or orthopedic expansion, or through distalization of posterior teeth.

LIST OF REFERENCES

Anderson KM, Behrents RG, McKinney T, Buschang PH. Tooth shape preferences in an esthetic smile. Am J Orthod Dentofacial Orthop 2005;128:458-65.

Ash M. Wheeler's dental anatomy, physiology and occlusion, 7th ed. Philadelphia: WB Saunders; 1993.

Avery JK. Oral development and histology, 3rd ed. New York: Thieme Stuttgart; 2001.

Bernabé E, Flores-Mir C. Dental morphology and crowding: a multivariate approach. Angle Orthod 2006;76:20-5.

Björk A. Variations in the growth pattern of the human mandible. J Dent Res 1963;42:400-11.

Blair RN, Harris EF. Sex differences in esthetic treatment needs in American black and white adolescent orthodontic patients. Angle Orthod [In Press].

Boese LR. Fiberotomy and reproximation without lower retention 9 years in retrospect: Part I. Angle Orthod 1980;50:88-97.

Boese LR. Fiberotomy and reproximation without lower retention 9 years in retrospect: Part II. Angle Orthod 1980;50:169-78.

Bolton WA. The clinical application of a tooth-size analysis. Am J Orthod 1962;48:504-29.

Brook PH, Shaw WC. The development of an index of orthodontic treatment priority. Eur J Orthod 1989;11:309-20.

Burke SP, Silveria AM, Goldsmith LJ, Yancey JM, Van Stewart A, Scarge WC. A meta-analysis of mandibular intercanine width in treatment and postretention. Angle Orthod 1998;68:53-60.

Buschang PH, Shulman JD. Incisor crowding in untreated persons 15-50 years of age: United States, 1988-1994. Angle Orthod 2003;73:502-8.

Carranza FA, Newman MG. Clinical Periodontology, 8th ed. Philadelphia: WB Saunders; 1996.

Chung CS, Niswander JD. Genetic and epidemiologic studies of oral characteristics in Hawaii's schoolchildren: V. Sibling correlations in occlusion traits. J Dent Res 1975;54:324-9.

Cons NC, Jenny J. Comparing perceptions of dental aesthetics in the USA with those in eleven ethnic groups. Int Dent J. 1994;44:489-94.

Couch WM. Root morphology and sexual dimorphism: size standards for crown and root dimensions in adolescents. M.D.S. thesis, University of Tennessee, Memphis, 2007.

Dempsey PJ, Townsend GC, Martin NG, Neale MC. Genetic covariance structure of incisor crown size in twins. J Dent Res 1995;74:1389-98.

Dempsey PJ, Townsend GC, Richards LC. Increased tooth crown size in females with twin brothers: evidence of hormonal diffusion between human twins in utero. Am J Hum Biol 1999;11:577-86.

Destang DL, Kerr WJS. Maxillary retention: is longer better? Eur J Orthod 2003;25:65-9.

Ditch LE, Rose JC. A multivariate dental sexing technique. Am J Phys Anthropol 1972;37:61-4.

Doris JM, Bernard BW, Kuftinec MN, Stom D. A biometric study of tooth size and dental crowding. Am J Orthod 1981;79:326-36.

Driscoll-Gilliland J, Buschang PH, Behrents RG. An evaluation of growth and stability in untreated and treated subjects. J Orthod Dentofacial Orthop 2001;120:588-97.

Engelmeier RL, ed. Complete dentures. Dent Clin No Am 40;1996:3,74-5.

Enlow DH. The human face. New York: Harper and Row; 1968.

Fastlicht J. Crowding of mandibular incisors. Am J Orthod 1970;58:156-63.

Freund RJ, Littell RC. SAS® system for regression, 2nd ed. Cary, NC: SAS Institute Inc; 1991.

Frush JP, Fisher RD. How dentogenic restorations interpret the sex factor. J Prosthet Dent 1956;6:160-72.

Glassell BE, Harris EF. Sex differences in the uptake of orthodontic services among U.S. adolescents. Am J Orthod Dentofacial Orthop [In Press].

Goldstein RE. Study of need for esthetics in dentistry. J Prosthet Dent 1969;21:589-98.

Gottlieb B, Orban B. Active and passive eruption of the teeth. J Dent Res 1993;13:214.

Graber TM, Vanarsdall RL, Vig KWL. Orthodontics: Current principles and techniques, 4th ed. St. Louis: Elsevier Mosby; 2005.

Harris EF, Clark LL. Hypodontia: an epidemiological study of American blacks and whites. Am J Orthod Dentofacial Orthop [In Press].

Harris EF, Hassankiadeh S, Harris JT. Maxillary incisor crown-root relationships in different Angle malocclusions. Am J Orthod Dentofacial Orthop 1993;103:48-53.

Harris EF, Rathbun TA. Ethnic differences in the apportionment of tooth sizes. In: Kelley MA, Larsen CS, editors. Advances in dental anthropology. New York: Alan R. Liss, Inc.; 1991; p 121-42.

Harris EF, Vaden JL, Williams RA. Lower incisor space analysis: a contrast of methodologies. Am J Orthod Dentofacial Orthop 1987;92:375-80.

Hartsfield JK. Genetics and orthodontics. In: Graber TM, Vanarsdall RL, Vig KWL, editors. Orthodontics: Current principles and techniques, 4th ed. St. Louis: Elsevier Mosby; 2005; 101-15.

Hasanreisoglu U, Berksun S, Aras K, Arslan I. An analysis of maxillary anterior teeth: facial and dental proportions. J Prosthet Dent 2005;94:530-8.

Houston WJ. The analysis of errors in orthodontic measurements. Am J Orthod 1983;83:382-90.

Howe RP, McNamara JA, O'Connor KA. An examination of dental crowding and its relationship to tooth size and arch dimension. Am J Orthod 1983;83:363-73.

Ibrahimagić L, Jerolimov V, Čelebić A. The choice of tooth form for removable dentures. Acta Stomatol Croat 2001a;35:237-44.

Ibrahimagić L, Jerolimov V, Čelebić A, Carek V, Baučić I, Knezović Zlatarić D. Relationship between the face and the tooth form. Coll Antropol 2001b;25:619-26.

Jenny J. A social perspective on need and demand for orthodontic treatment. Int Dent J 1975;25:248-56.

Khalaf K, Elcock C, Smith RN, Brook AH. Fluctuating dental asymmetry of multiple crown variables measured by an image analysis system. Arch Oral Biol 2005;50:249-53.

Kieser JA. Human adult odontometrics: the study of variation in adult tooth size. New York: Cambridge University Press; 1990.

Klages U, Bruckner A, Zentner A. Dental aesthetics, self-awareness, and oral health-related quality of life in young adults. Eur J Orthod 2004;26:507-14.

Lindemann HB, Knauer C, Pfeiffer P. Morphometric relationships between tooth and face shapes. J Oral Rehabil 2004;31:972-8.

Little RM. The irregularity index: a quantitative score of mandibular anterior alignment. Am J Orthod 1975;68:554-63.

Little RM, Riedel RA, Artun J. An evaluation of changes in mandibular anterior alignment from 10 to 20 years postretention. Am J Orthod 1988;93:423-8.

Mayers M, Firestone AR, Rashid R, Vig KWL. Comparison of peer assessment rating (PAR) index scores of plaster and computer-based digital models. Am J Orthod Dentofacial Orthop 2005;128:431-4.

McCann J, Burden DJ. An investigation of tooth size in Northern Irish people with bimaxillary dental protrusion. Eur J Orthod 1996;18:617-21.

McIntyre GT, Millett DT. Crown-root shape of the permanent maxillary central incisor. Angle Orthod 2003;73:710-15.

Merrifield LL. Differential diagnosis with total dentition space analysis. Bull CH Tweed Found 1978;VI:10-5.

Miller HP, Shaller N, Eger T, Heinecke A. Thickness of masticatory mucosa. J Clin Periodontol 2000;27:431-36.

Mossey PA. The heritability of malocclusion: Part 1 - Genetics, principles and terminology. Br J Orthod 1999;26:103-13.

Mossey PA. The heritability of malocclusion: Part 2 - The influence of genetics in malocclusion. Br J of Orthod 1999;26:195-203.

Peck H, Peck S. An index for assessing tooth shape deviations as applied to the mandibular incisors. Am J Orthod 1972;61:384-401.

Poosti M, Jalali T. Tooth size and arch dimension in uncrowded versus crowded Class I malocclusions. J Contemp Dent Pract 2007;8:45-52.

Proffit WR. Contemporary orthodontics, 3rd ed. St. Louis: CV Mosby; 2000.

Rhee SH, Nahm DS. Triangular-shaped incisor crowns and crowding. Am J Orthod Dentofacial Orthop 2000;118:624-28.

Riolo ML, Avery JK. Essentials for orthodontic practice, 1st ed. Grand Haven: EFOP Press; 2003.

Shah AA, Elcock C, Brook AH. Incisor crown shape and crowding. Am J Orthod Dentofacial Orthop 2003;123:562-7.

Shaw WC, Richmond S, Kenealy PM, Kingdon A, Worthington H. A 20-year cohort study of health gain from orthodontic treatment: psychological outcome. Am J Orthod Dentofacial Orthop 2007;132:146-57.

Smid JR, Rowland JE, Young WG, Coschigano KT, Kopchick JJ, Waters MJ. Mouse molar dentin size/shape is dependent on growth hormone status. J Dent Res 2006;86:463-8.

Smith RJ, Davidson WM, Gipe DP. Incisor shape and incisor crowding: A re-evaluation of the Peck and Peck ratio. Am J Orthod 1982;82:231-35.

Smith RG, Çakici S, Newcombe RG. Variations in the clinical sulcus depth of healthy human gingiva: a longitudinal study. J Periodont Res 1996;31:181-6.

Sokal RR, Rohlf FJ. Biometry: The Principles and Practice of Statistics in Biological Research. 3rd ed. San Francisco: WH Freeman and Company; 1995.

Solow B, Sonnesen L. Head posture and malocclusions. Eur J Orthod 1998;20:685-93.

Stenvik A, Espeland L, Linge BO, Ling L. Lay attitudes to dental appearance and need for orthodontic treatment. Eur J Orthod 1997;19:271-7.

Sterrett JD, Oliver T, Robinson F, Fortson W, Knaak B, Russell CM. Width/length ratios of normal clinical crowns of the maxillary anterior dentition in man. J Clin Periodontol 1999;26:153-7.

Tedesco LA, Albino JE, Cunat JJ, Green LJ, Lewis EA, Alakter MJ. A dental-facial attractiveness scale. Part I. Reliability and validity. Am J Orthod 1983;83:38-43.

Ten Cate AR. Oral histology: development, structure, and function, 5th ed. St. Louis: CV Mosby; 1998.

Tukey JW. Exploratory data analysis. Reading, Mass: Addision-Wesley; 1977.

Watson WG. Retention or the restriction of physiologic recovery. Am J Orthod 1979;76:226-30.

Wheeler RC. An atlas of tooth form, 3rd ed. Philadelphia: WD Saunders; 1963.

White SC, Pharoah MJ. Oral radiology: principles and interpretation. St. Louis: CV Mosby; 2000.

Williams JL. The tempermental selection of artificial teeth, a fallacy. Dent Digest 1914a;20:63-75.

Williams JL. The tempermental selection of artificial teeth, a fallacy. Dent Digest 1914b;20:125-34.

Williams JL. The tempermental selection of artificial teeth, a fallacy. Dent Digest 1914c;20:243-59.

Wolfart S, Menzel H, Kern M. Inability to relate tooth forms to face shape and gender. Eur J Oral Sci 2004;112:471-6.

Young WG. Growth hormone and insulin-like growth factor-I in odontogenesis. Int J Dev Biol 1995;39:263-72.

VITA

Kortne King Frederick was born in Flint, Michigan on August 22, 1979. She attended elementary school in Grand Blanc, Michigan and moved to Fenton, Michigan in the fall of 1990. She graduated from Fenton Senior High School in May of 1997. Kortne attended the University of Michigan, Ann Arbor and earned a Bachelor of Science in General Biology in May of 2001. She received the degree of Doctor of Dental Surgery from the University of Michigan School of Dentistry, Ann Arbor in May of 2005. In August of 2005, she entered The University of Tennessee's Orthodontic program. She is expected to receive a Master of Dental Science degree in May 2008.

Following graduation, Kortne will move to Seattle, Washington to start her career in orthodontics.