ASSESSMENT OF THE APPARENT CONTACT DIMENSION AND CO-VARIATES IN NON-TREATED AND ORTHODONTICALLY TREATED DENTITIONS

Vishnu Raj

A thesis submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Master of Sciences in the School Of Dentistry

Chapel Hill
2008

Approved by

Advisor: Harald O. Heymann, D.D.S, M.Ed.

Reader: H. Garland Hershey, Jr. D.D.S., M.S.

Reader: André V. Ritter, D.D.S., M.S.

Reader: Edward J. Swift Jr., D.M.D, M.S.

ABSTRACT

VISHNU RAJ: Assessment of the Apparent Contact Dimension and Co-Variates in Untreated and Orthodontically Treated Dentitions

(Under the direction of Harald O. Heymann, DDS, M.Ed.)

This study assessed the existence of the Apparent Contact Dimension, a determinant of dental esthetics, using casts of orthodontically treated (n=40) and non-treated (n=27) subjects deemed to possess excellent occlusion. Co-variates studied included tooth size, tooth shape, tip and torque. The average ACD proportions in this study, relative to the height of an ipsilateral central incisor, were found to be 49, 38 and 27 % between the central incisors, central and lateral incisor, and the lateral incisor and canine, respectively. The ACD exhibited a positive correlation ($p<0.05$) with the height of the clinical crown and a negative correlation ($p<0.05$) with W/H ratios of the corresponding teeth. No statistically significant correlations were evident between the ACD with the shape of the clinical crown, the tip, and torque. This study is the first to validate the existence and proportions of the ACD.

ACKNOWLEDGEMENTS

I would like to express my gratitude and appreciation to my mentor and committee chair, Dr. Harald Heymann, for accepting me as a mentee, as well as encouraging and supporting this enterprise. Dr. Garland Hershey has been an indispensable part of this project, and I am very grateful to him for his steady guidance and perspicacity, in addition to facilitating access to the study models. I would like to acknowledge and thank Dr. Andre Ritter and Dr. Ed Swift for their introspective critique and assistance in designing this study. Dr. John S Casko, from the University of Iowa, Department of Orthodontics, deserves special mention for graciously allowing the use of his collection of non-treated study models. I'd like to recognize and thank Marie Roberts, Judith Laferriere, and my fellow residents especially Dr. Georgia Macedo and Dr. Gustavo Oliveira for their assistance and camaraderie. And last but not least, I'd like to acknowledge my indebtedness to my parents for their persistence and belief in me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF GRAPHS

BACKGROUND

Esthetics in dentistry has gained increasing attention and prominence over the years, leading to an almost histological approach to the elucidation of the components that determine dental attractiveness. Tooth shape, size and alignment relationships are integral to the attainment of optimal function and esthetics. An esthetic smile is one in which the size, shape, position and color of the teeth are in harmony, proportion and relative symmetry to each other and the elements that frame them.[1] Another determinant of esthetics that has only recently been identified in the dental literature is the so-called "connector zone" in the maxillary anterior sextant.[2,3] The first apparent reference to the term "connector zone" was in a 2001 refereed publication by *Morley* and *Eubank* in which they delineated the connector zone from proximal contact points, by stating that "***The connector is a larger, broader area that can be defined as the zone in which two adjacent teeth appear to touch. The contact points between the anterior teeth are generally smaller areas (about 2 x 2 millimeters) that can be marked by passing articulating ribbon between the teeth***." [2]

A source of concern is that the existing nomenclature (i.e. "Connector Zone") is descriptively ambiguous, in that the adjacent teeth do not actually "connect" or touch throughout the connector zone. Another potential source of confusion is due to the fact that "connectors" are widely defined and well known as components of removable and fixed prosthodontic appliances. Due to these concerns, it is recommended that the perceived area of contact between adjacent teeth be termed the *Apparent Contact Dimension* (ACD), which is a more precise and quantifiable description of the "connector zone". Based on evaluating the illustration of the "connector zone" (**Fig. 1**) in the literature and as a result of a pilot study, it was concluded that for accuracy and reproducibility, ACD measurements be made at 90° to each proximal contact area. Therefore, based on our pilot study, it is proposed that the ACD ***be defined as the area where the teeth appear to be in contact, when viewed from the facial aspect at 90 degrees to each interproximal area.*** For example, the ACD between the central incisors is clearly evident in **Figure 2**.

Dentistry is rife with several purported paradigms to guide the treatment planning process as part of creating or enhancing esthetics. For decades, the prevalent philosophy has been to restore or replace teeth based on vague concepts such as sex, personality, and age.[4] However, in this era of evidence based health care, it is imperative to incorporate the tenets of modern interdisciplinary research into the dental treatment planning process. Several investigators have attempted to provide other guidelines to facilitate esthetic excellence. *Magne et al.* (2003) mentioned the use of certain subjective and objective criteria including tooth form, relative tooth dimensions, smile symmetry, color, tooth axis and gingival health.[5] *Rufenacht* proposed a more dynamic approach, where subjects are provided with orthodontic elements as a part of esthetic reconstruction.[6] Nevertheless, the presence of a quantifiable "ideal" reference is integral to the application of these esoteric concepts in dentistry.

Harmony in proportion has been defined as an esthetic principle, and the golden proportion is often cited as an exemplar for dental esthetics. The concept of the golden proportion was first used in ancient Greek architecture, and its basic premise is that for two related objects to appear natural and harmonious, the larger to the smaller should form a ratio of 1.6181:1.[7] In dentistry, the golden proportion represents a 62% regression from the mesial to the distal, with the implication that if the perceived width of a maxillary anterior tooth is approximately 62% the size of its adjacent mesial tooth, it is considered esthetically pleasing.[4] As stated by *Levin* (1998), when viewed from the facial "The width of the central incisor should be in golden proportion to the width of the lateral incisor, and the width of the lateral incisor should be golden to the canine and the canine width should be golden to the first premolar." [8]

Other reports have attributed less validity to the golden proportion, and some studies have found that the majority of smiles deemed to be esthetically pleasing clearly did not coincide with the golden proportion. [4,7, and 9] A recent study on dentists' preferences of anterior tooth proportions found that the golden proportion was preferable only with very tall teeth. [10] In addition, excessive narrowness of the maxillary arch and compression of lateral segments have been observed in cases of strict adherence to the golden proportion.[5] In an attempt to assess the prevalence of the golden proportion in the natural dentition, *Preston* (1993) measured the perceived widths of the maxillary central and lateral incisors on 58 imaged casts, and found that only 17% (10) had a perceived central: lateral incisor width ratio in the range of 1.59 and 1.65:1.[9] The mean perceived central: lateral incisor width ratio was 1.51:1. *Preston* also failed to find any diagnostic cast with a perceived maxillary lateral: canine width ratio within the range of the golden proportion.[9]

The ACD of the maxillary anterior teeth in an esthetic smile has itself been alleged to exhibit a proportional relationship, which Morley & Eubank quantified as the 50:40:30 rule (**Fig.1**).[2] This "rule" defined the ideal ACD between the central incisors as 50% the height of the central incisors, the ideal ACD between a maxillary lateral incisor and central incisor as 40% the height of a central incisor, and the ideal ACD between a lateral incisor and a canine as 30% the height of a central incisor. No data were provided to corroborate these proportions, and it appears that the prevalence of this "ideal" proportion of 50:40:30 has not been formally investigated. In addition, it is unclear if these proportions of the ACD are evident only when viewed from the facial aspect, or individually and at 90° to each corresponding inter-dental area.

The proportions of the ACD may be influenced by variations in tooth shape and size. For example, a triangular-shaped tooth would likely exhibit a shorter ACD compared to a more parallel shaped tooth and longer teeth could ostensibly exhibit a greater ACD than shorter teeth. A recent study assessed the relative hierarchy of various dental features that contribute to overall dental attractiveness and found that tooth shape was the feature most strongly associated with overall dental attractiveness. [11] However, it is important to note that the precise quantification of specific tooth shapes and their esthetic import has not been assessed.

Two additional parameters that influence the perception of the ACD are the mesiodistal crown angulation (tip) and the labiolingual crown inclination (torque), both of which clearly contribute to the esthetics of the maxillary anterior dentition. Axial inclinations of maxillary teeth are perceived relative to the vertical axis of the face and the maxillary midline, both of which are usually parallel in an esthetic smile. When the maxillary anterior teeth tip medially (sic), the overall esthetic impact is harmonious with the lower lip (***Morley cites Lombardi***).[2] However, when teeth incline significantly toward the midline, the smile appears narrow and visually discordant.[1] In the natural dentition there is a progressive increase of anterior crown angulations mesially, or a mesial tip, as the smile line continues distally from the central incisors to the canines. Aberrations in angulation are usually perceptively tolerable to a minor degree, beyond which they appear disharmonic and unaesthetic. Kokich et al. evaluated perceptions of alterations in incisor crown angulation and found that even minor deviations from ideal were considered unattractive.[12]

In a landmark publication, Andrews (1972) measured diagnostic models of 120 untreated ideal occlusion subjects in an attempt to identify the characteristics consistently present in naturally optimal occlusion.[13] He then recorded the average values or norms for these parameters including antero-posterior and vertical molar relationships, tooth tip, torque, rotations, spaces and the depth of the occlusal plane. Andrews observed that in a dentition with excellent occlusion, nearly every tooth type had a discrete amount of crown angulation and inclination; but the amounts for each tooth type were similar among optimal dentitions.[14]Andrews' so-called six keys to ideal occlusion were incorporated into commercially available orthodontic brackets, and represented the first pre-programmed or straight wire appliance in orthodontics,[14] a concept that facilitated tooth movement into desirable positions based on carefully documented "ideal" occlusions. Average mesiodistal angulations obtained by *Andrews* from non-orthodontically treated normal models were 5º, 9º and 11º for the maxillary central incisor, lateral incisor and canine, respectively.[13] Other researchers have reported similar or comparable values of tip and torque,[15, 16] and although some disparities were evident in the angulation and inclination of individual tooth groups, this may be reflective of the ethnic diversity apparent in the different populations studied [i.e. Caucasian, Asian and Indian].

Tip and torque discrepancies may have significant associated functional and esthetic ramifications. The correlation between variations in angulation and inclination and the arch height has been reported by *Tuverson* (1980).[17] The esthetic import of angulation was further emphasized in a study by W*olfart* and colleagues, who assessed dental appearance following changes in incisor angulation, and concluded that symmetric teeth with ideal axes as well as minor variations in the mesial or distal angulation of the lateral incisors had the greatest influence on attractive appearance.[18] Brunzel et al. (2006) corroborated the significance of symmetry and axial inclination, specifically variations in the mesial angulation of the lateral incisors (up to 9°).[19] An interesting observation is the confluence of esthetic and functional ideals; the average lateral incisor angulation assessed by Andrews in ideal occlusion cases and the lateral incisor angulation cited by Brunzel et al. to be esthetic are both in the range of 9°**.**

Labiolingual inclination or torque was defined by Andrews as the angle between the tangent to the middle of the clinical crown and a perpendicular line dropped on the occlusal plane.[15] According to Rufenacht, the labial surface of the maxillary central incisors should be perpendicular to the occlusal plane, thus enhancing their esthetic appearance by facilitating maximum light reflection from the labial surface.[6] In a group of non-orthodontically treated normal models, *Andrews* reported mean torque values for the maxillary central incisor, lateral incisor and canine as 7º, 3º and -7º respectively.[13] The esthetic significance of torque was also delineated by *Mackley* (1993) in a study on post orthodontic smile evaluation, in which he found that one of the characteristics that distinguished the best judged orthodontist was the degree of improvement in the torque of the upper incisors.[20]

Esthetics in dentistry is contingent on principles of symmetry and proportion, and the inclusion of congruent elements may enhance the ability to achieve a natural appearance. Although each of the afore-mentioned components including the ACD, tooth size, shape, tip and torque has a contributory influence on esthetics, the interaction of these variables has not been studied. Therefore, the Specific Aims of the present study are to:

1. Assess the ACD from diagnostic models of untreated and treated subjects deemed to possess excellent occlusions in order to confirm or refute the existence of the proportion known as the “50:40:30 rule”.

2. Evaluate and quantify the relationship between the ACD and the co-variates of tooth shape, size, tip and torque.

PART 1: The Proportions of the Apparent Contact Dimension Among Orthodontically Treated And Non-Treated Subjects

INTRODUCTION

Esthetics in dentistry has gained increasing attention and prominence over the years, leading to an almost histological approach to the elucidation of the components that determine dental attractiveness. An esthetic smile is one in which the size, shape, position and color of the teeth are in harmony, proportion and relative symmetry to each other and the elements that frame them.[1] Another determinant of esthetics that has only recently been identified in the dental literature is the so-called "connector zone" in the maxillary anterior sextant.[2,3] The first apparent reference to the term "connector zone" was in a 2001 publication by *Morley* and *Eubank* in which they delineated the connector zone from proximal contact points, by stating that "***The connector is a larger, broader area that can be defined as the zone in which two adjacent teeth appear to touch. The contact points between the anterior teeth are generally smaller areas (about 2 x 2 millimeters) that can be marked by passing articulating ribbon between the teeth***."[2]

A source of concern is that the existing nomenclature (i.e. "Connector Zone") is descriptively ambiguous, in that the adjacent teeth do not actually "connect" or touch throughout the connector zone. Another potential source of confusion is due to the fact that "connectors" are widely defined and well known as components of removable and fixed prosthodontic appliances. Due to these concerns, it is recommended that the perceived area of contact between adjacent teeth be termed the *Apparent Contact Dimension* (ACD), which is a more precise and quantifiable description of the "connector zone". Based on evaluating the illustration of the "connector zone" (**Fig. 1**) in the literature and as a result of a pilot study, it was concluded that for accuracy and reproducibility, ACD measurements be made at 90° to each proximal contact area. Therefore, based on our pilot study, it is proposed that the ACD ***be defined as the area where the teeth appear to be in contact, when viewed from the facial aspect at 90 degrees to each interproximal area.*** For example, the ACD between the central incisors is clearly evident in **Figure 2**.

Dentistry is rife with several purported paradigms to guide the treatment planning process as part of creating or enhancing esthetics. For decades, the prevalent philosophy has been to restore or replace teeth based on vague concepts such as sex, personality, and age.[4] However, in this era of evidence based health care, it is imperative to incorporate the tenets of modern interdisciplinary research into the dental treatment planning process. Several investigators have attempted to provide other guidelines to facilitate esthetic excellence. *Magne et al.* (2003) mentioned the use of certain subjective and objective criteria including tooth form, relative tooth dimensions, smile symmetry, color, tooth axis and gingival health.[5] *Rufenacht* proposed a more dynamic approach, where subjects are provided with orthodontic elements as a part of esthetic reconstruction.[6] Nevertheless, the presence of a quantifiable "ideal" reference is integral to the application of these esoteric concepts in dentistry.

Harmony in proportion has been defined as an esthetic principle, and the golden proportion is often cited as an exemplar for dental esthetics. The concept of the golden proportion was first used in ancient Greek architecture, and its basic premise is that for two related objects to appear natural and harmonious, the larger to the smaller should form a ratio of 1.6181:1.[7] In dentistry, the golden proportion represents a 62% regression from the mesial to the distal, with the implication that if the perceived width of a maxillary anterior tooth is approximately 62% the size of its adjacent mesial tooth, it is considered esthetically pleasing.[4] As stated by *Levin* (1998), when viewed from the facial "The width of the central incisor should be in golden proportion to the width of the lateral incisor, and the width of the lateral incisor should be golden to the canine and the canine width should be golden to the first premolar." [8]

Other reports have attributed less validity to the golden proportion, and some studies have found that the majority of smiles deemed to be esthetically pleasing clearly did not coincide with the golden proportion. [4,7, and 9] A recent study on dentists' preferences of anterior tooth proportions found that the golden proportion was preferable only with very tall teeth. [10] In addition, excessive narrowness of the maxillary arch and compression of lateral segments have been observed in cases of strict adherence to the golden proportion.[5] In an attempt to assess the prevalence of the golden proportion in the natural dentition, *Preston* (1993) measured the perceived widths of the maxillary central and lateral incisors on 58 imaged casts, and found that only 17% (10) had a perceived central: lateral incisor width ratio in the range of 1.59 and 1.65:1.[9] The mean perceived central: lateral incisor width ratio was 1.51:1. *Preston* also failed to find any diagnostic cast with a perceived maxillary lateral: canine width ratio within the range of the golden proportion.[9]

The ACD of the maxillary anterior teeth in an esthetic smile has itself been alleged to exhibit a proportional relationship, which Morley & Eubank quantified as the 50:40:30

rule (**Fig.1**).[2] This "rule" defined the ideal ACD between the central incisors as 50% the height of the central incisors, the ideal ACD between a maxillary lateral incisor and central incisor as 40% the height of a central incisor, and the ideal ACD between a lateral incisor and a canine as 30% the height of a central incisor. No data were provided to corroborate these proportions, and it appears that the prevalence of this "ideal" proportion of 50:40:30 has not been formally investigated. In addition, it is unclear if these proportions of the ACD are evident only when viewed from the facial aspect, or individually and at 90° to each corresponding inter-dental area.

Esthetics in dentistry is contingent on principles of symmetry and proportion, and the inclusion of congruent elements may enhance the ability to achieve a natural appearance. Therefore, the present study assessed the ACD from diagnostic models of untreated and treated subjects deemed to possess excellent occlusions in order to confirm or refute the existence of the proportion known as the "50:40:30 rule".

MATERIALS AND METHODS

Clinical Pilot Study:

An IRB-approved pilot study was conducted to validate the accuracy of measuring the ACD on the diagnostic models compared to intraoral measurements. Ten subjects with intact maxillary anterior teeth comprised the pilot study sample. Subjects with incisal/proximal wear, crowding, rotations, poor alignment, and/or diastemas were excluded. The maxillary occlusal plane was used as the horizontal reference to facilitate measurement of the ACD at an angulation of 90° to the interdental area between the central incisors, central incisor and lateral incisor, and lateral incisor and canine. Although esthetics is not always perceived at 90° to each interdental area, this orientation was selected in order to facilitate measurement accuracy and reproducibility.

Vertical positioning of the subjects was standardized by using a Fox plane to orient the maxillary occlusal plane parallel to the floor. The same vertical head position was maintained throughout the measuring sequence and the cheek was reflected using cheek retractors. With subjects seated in this position, the investigator was positioned at eye level and at 90° to the interdental area of interest. The fine tips of an electronic Boley gauge were inserted to engage the incisal convergence of the gingival embrasure and the gingival convergence of the incisal embrasure (**Fig. 3**). This dimension is analogous to the distance between the incisal tip of the papilla and the incisal termination of the proximal contact. Readings were obtained and the measuring process repeated to obtain a second reading of the same area. The measuring protocol was repeated to measure all interdental areas between 6/7, 7/8, 8/9, 9/10 and 10/11. The clinical crown height of #8 and #9 were measured (**Fig. 4),** and recorded in duplicate. The Apparent Contact Dimension was established as a percentage of the height of the ipsilateral central. Next, a PVS impression of the maxillary arch was made, disinfected and poured with Type III dental stone. ACD measurements were performed on the casts (**Fig.5)** and converted to % ACD. The average intraoral and extraoral percent ACD was calculated by tooth type and Pearson's correlation was used to establish the strength of the association between Intraoral and Extraoral measurements. Paired T-tests were used to assess existence of systematic measurement differences.

Results of Pilot Study

Table 1 shows the average ACD measurements for each interdental area in vivo (intraoral) and in vitro (casts). Pearson correlation indicated excellent correlation between intraoral and extraoral ACDs of the maxillary anterior teeth, with correlation coefficients (r) ranging from 0.77 to 0.94 (Table 1). Results of the paired T-tests did not indicate the existence of any clinically significant differences between intraoral and extraoral ACD measurements (Table 2).

Cast Evaluation

Based on the results of the pilot study, there were no significant differences between direct intraoral and plaster cast measurements of the ACDs of the six maxillary anterior teeth. For the main study, the inclusion criteria for the casts were the presence of all six un-restored and well aligned maxillary anterior teeth. Casts with noticeable incisal wear, gingival conditions (recession, inflammations), under-sized teeth, anterior diastemas, rotations, black triangles and restorations/crowns were excluded from the study. Using these criteria, 27 of approximately 90 casts of non-treated, excellent occlusion subjects, compiled by Dr John S. Casko at the Department of Orthodontics, University of Iowa

College of Dentistry, were selected for the study. Employing the afore-mentioned criteria, additional casts (n=40) representing treated subjects with excellent occlusion, were selected from the Department of Orthodontics, University of North Carolina School of Dentistry.

ACD Measurements

The cast was hand positioned with the maxillary occlusal plane parallel to the floor. The investigator was positioned at 90° to the interdental area of interest, and the fine tips of an electronic Boley gauge were inserted to engage the incisal convergence of the gingival embrasure and the gingival convergence of the incisal embrasure (**Fig. 5**). Readings were obtained and the measuring process repeated to obtain a second reading of the same area. The measuring protocol was repeated to measure all interdental areas between 6/7, 7/8, 8/9, 9/10 and 10/11. The clinical crown height of #8 and #9 were measured and recorded in duplicate to reduce measurement error. The Apparent Contact Dimension was established as a percentage of the height of the ipsilateral central incisor using the following equation:

% ACD = (Measured ACD/Height of Ipsilateral Central Incisor) X 100

Statistical Analyses

Paired T-tests were run to evaluate differences between the ACD measurements for the right and left ACD locations. Differences between the treated and non-treated groups were assessed using unpaired T-tests.

RESULTS

The Average ACD in mm and the %ACD for the orthodontically treated and non-treated groups are listed in Table 3. Because the differences between the treated and non-treated ACD measurements were not clinically significant, [i.e. a few tenths of a millimeter] the two groups were pooled by location. Results of paired T-tests did not reveal statistically significant differences between the ACD measurements for the right and left ACD locations i.e. between 6/7 & 10/11 (p=0.916) and 7/8 & 9/10 (p=0.268). Therefore, the %ACD values were averaged between the right and left locations, to obtain a single average ACD per location (Table 3). The average %ACD between the central incisors was 49%, between the central and lateral incisor was 38% and between the lateral incisor and the canine was 27%.

DISCUSSION

Symmetry and proportionality clearly affect the perception of esthetics, especially in the maxillary anterior region. Various esthetic “ideals” such as the golden proportion, width: height ratios and the RED proportion have been proposed. [8, 10, 24] However, in this era of evidence-based dentistry, it is important that the validity of these “proportions” be substantiated by research based data. Although the proportions of the “Connector Space” have been reported and cited in the literature, there were no data presented to validate the existence of this proportion.[2]

This study attempted to define and establish the proportions of the ACD using casts of non-treated and orthodontically treated individuals deemed to possess excellent occlusion [Six keys]. With respect to method validation to assess the accuracy of measurement on diagnostic models, Lundstrom (as cited by Abdullah et al.), recorded the dimensions of six anterior teeth intraorally and on casts, and did not find significant differences between the two sets of measurements. [25] However, with respect to the actual and perceived widths, there appears to be a difference between diagnostic models and images. *Hasanreisoglu* et al. (2005) compared the mesiodistal width of the maxillary anterior teeth measured on casts to the perceived widths measured on the corresponding images, and found that the actual and perceived sizes of the anterior teeth when viewed from the facial differed due to the curvature of the arch and angulation of the teeth in relation to the frontal plane of the photograph.[4] The selection criteria for this study were aimed at precluding casts with mal-aligned teeth, rotations, diastemas, and significant incisal wear. Other exclusionary criteria included maxillary anterior teeth with restorations and evidence of gingival inflammation or recession, all of which may alter the mesio-distal or inciso-cervical tooth dimensions. The ACD mm measurements were expressed as a percentage of the height of the ipsilateral central incisor. The average ACD proportions established by this study were 49: 38: 27, between the central incisors, the central and lateral incisor, and the lateral incisor and canine, respectively. This proportion was very similar to the 50:40:30 ratio proposed by Morley and Eubank and was also consistent with the progressive increase in incisal embrasure dimensions from the midline to the canine, evident in the well-aligned and unworn maxillary anterior sextant. The ACD proportions exhibited excellent symmetry with minor and clinically insignificant differences between the left and right sides (Table 3).

The age of subjects in this study ranged from the late teens to the late twenties. Although age was not evaluated during this study, one should remain cognizant of the potential for age-related variations in ACD proportions due to increased incisal and proximal wear and gingival recession, both of which are associated with increasing age. Future research using digitally manipulated images to assess the esthetic importance of different ACD proportions, may prove beneficial.

CONCLUSIONS

Within the limitations of this study, it is possible to conclude that the average ACD proportions between the central incisors, the central/ lateral incisor and the lateral incisor and canine, were 49: 38:27 percent of the height of an ipsilateral central incisor, respectively. Additionally, the ACD proportions exhibited bilateral symmetry and were consistent with the ideal proportion of 50:40:30, as proposed by Morley and Eubank.

PART 2: Correlation Between The Apparent Contact Dimension Tooth Size, Tooth Shape, Tip and Torque

INTRODUCTION

Tooth shape, size and alignment relationships are integral to the attainment of optimal function and esthetics. An esthetic smile is one in which the size, shape, position and color of the teeth are in harmony, proportion and relative symmetry to each other and the elements that frame them.[1] Another determinant of esthetics that has only recently been identified in the dental literature is the so-called "connector zone" in the maxillary anterior sextant.[2,3] As described in Chapter 1, for the purposes of this study, the "connector zone" has been redefined as the Apparent Contact Dimension (ACD). The ACD of the maxillary anterior teeth in an esthetic smile has been reported to exhibit a proportional relationship, which Morley & Eubank quantified as the 50:40:30 rule (**Fig.1).**[2] This "rule" defined the ideal ACD between the central incisors as 50% the height of the central incisors, the ideal ACD between a maxillary lateral incisor and central incisor as 40% the height of a central incisor, and the ideal ACD between a lateral incisor and a canine as 30% the height of a central incisor.

The proportions of the ACD may be influenced by variations in tooth shape and size. For example, a triangular-shaped tooth would likely exhibit a shorter ACD compared to a more parallel shaped tooth and longer teeth could ostensibly exhibit a greater ACD than shorter teeth. A recent study assessed the relative hierarchy of various dental features that contribute to overall dental attractiveness and found that tooth shape was the feature most strongly associated with overall dental attractiveness. [11] However, it is important to note that the precise quantification of specific tooth shapes and their esthetic import has not been assessed.

Two additional parameters that influence the perception of the ACD are the mesiodistal crown angulation (tip) and the labiolingual crown inclination (torque), both of which clearly contribute to the esthetics of the maxillary anterior dentition. Axial inclinations of maxillary teeth are perceived relative to the vertical axis of the face and the maxillary midline, both of which are usually parallel in an esthetic smile. When the maxillary anterior teeth tip medially (sic), the overall esthetic impact is harmonious with the lower lip (***Morley cites Lombardi***).[2] However, when teeth incline significantly toward the midline, the smile appears narrow and visually discordant.[1] In the natural dentition there is a progressive increase of anterior crown angulations mesially, or a mesial tip, as the smile line continues distally from the central incisors to the canines. Aberrations in angulation are usually perceptively tolerable to a minor degree, beyond which they appear disharmonic and unaesthetic. Kokich et al. evaluated perceptions of alterations in incisor crown angulation and found that even minor deviations from ideal were considered unattractive.[12]

In a landmark publication, Andrews (1972) measured diagnostic models of 120 untreated ideal occlusion subjects in an attempt to identify the characteristics consistently present in naturally optimal occlusion.[13] He then recorded the average values or norms for these parameters including antero-posterior and vertical molar relationships, tooth tip, torque, rotations, spaces and the depth of the occlusal plane. Andrews observed that in a dentition with excellent occlusion, nearly every tooth type had a discrete amount of crown angulation and inclination; but the amounts for each tooth type were similar among optimal dentitions.[14]Andrews' so-called six keys to ideal occlusion were incorporated into commercially available orthodontic brackets, and represented the first pre-programmed or straight wire appliance in orthodontics,[14] a concept that facilitated tooth movement into desirable positions based on carefully documented "ideal" occlusions. Average mesiodistal angulations obtained by *Andrews* from non-orthodontically treated normal models were 5º, 9º and 11º for the maxillary central incisor, lateral incisor and canine, respectively.[13] Other researchers have reported similar or comparable values of tip and torque,[15, 16] and although some disparities were evident in the angulation and inclination of individual tooth groups, this may be reflective of the ethnic diversity apparent in the different populations studied [i.e. Caucasian, Asian and Indian].

Tip and torque discrepancies may have significant associated functional and esthetic ramifications. The correlation between variations in angulation and inclination and the arch height has been reported by *Tuverson* (1980).[17] The esthetic import of angulation was further emphasized in a study by W*olfart* and colleagues, who assessed dental appearance following changes in incisor angulation, and concluded that symmetric teeth with ideal axes as well as minor variations in the mesial or distal angulation of the lateral incisors had the greatest influence on attractive appearance.[18] Brunzel et al. (2006) corroborated the significance of symmetry and axial inclination, specifically variations in the mesial angulation of the lateral incisors (up to 9°).[19] An interesting observation is the confluence of esthetic and functional ideals; the average lateral incisor angulation assessed by Andrews in ideal occlusion cases and the lateral incisor angulation cited by Brunzel et al. to be esthetic are both in the range of 9°.

Labiolingual inclination or torque was defined by Andrews as the angle between the tangent to the middle of the clinical crown and a perpendicular line dropped on the occlusal plane.[15] According to Rufenacht, the labial surface of the maxillary central incisors should be perpendicular to the occlusal plane, thus enhancing their esthetic appearance by facilitating maximum light reflection from the labial surface.[6] In a group of non-orthodontically treated normal models, *Andrews* reported mean torque values for the maxillary central incisor, lateral incisor and canine as 7º, 3º and -7º respectively.[13] The esthetic significance of torque was also delineated by *Mackley* (1993) in a study on post orthodontic smile evaluation, in which he found that one of the characteristics that distinguished the best judged orthodontist was the degree of improvement in the torque of the upper incisors.[20]

Esthetics in dentistry is contingent on principles of symmetry and proportion, and the inclusion of congruent elements may enhance the ability to achieve a natural appearance. Although each of the afore-mentioned components including the ACD, tooth size, shape, tip and torque has a contributory influence on esthetics, the interaction of these variables has not been studied. Therefore, the Specific Aims of the present study are to evaluate and quantify the relationship between the ACD and the co-variates of tooth shape, size, tip and torque using diagnostic casts of Non-treated and Orthodontically treated subjects.

MATERIALS AND METHODS

Cast Evaluations

The inclusion criteria for the casts were the presence of all six un-restored and well aligned maxillary anterior teeth. Casts with noticeable incisal wear, gingival conditions (recession, inflammations), under-sized teeth, anterior diastemas, rotations, black triangles and restorations/crowns were excluded from the study. Using these criteria, 27 of approximately 90 casts of non-treated, excellent occlusion subjects, compiled by Dr John S. Casko at the Department of Orthodontics, University of Iowa College of Dentistry, were selected for the study. Employing the afore-mentioned criteria, additional casts (n=40) representing treated subjects with excellent occlusion, were selected from the Department of Orthodontics, University of North Carolina School of Dentistry.

Tooth Size

Tooth size measurements comprising the mesio-distal width and the clinical crown height, were measured in duplicate using a Boley gauge. The clinical crown height was defined as the distance from the most apical concavity of the gingival margin to the incisal edge/occlusal surface of a tooth. Width: height ratios were calculated.

Tooth Shape

Although tooth shape is not a readily quantifiable variable, it has the potential to substantially affect the ACD. For the purposes of this study, teeth were classified as parallel shaped (**Fig. 6A**), barrel shaped (**Fig. 6B**) or triangular shaped (**Fig. 6C**),[21] based on the degree of cervico-incisal divergence.

Facial Axis of the Clinical Crown (FACC)

As originally proposed by Andrews, the facial (long) axis of the clinical crown (FACC) is judged to be the mid-developmental ridge which represents the most prominent and centermost portion of the facial central lobe of all teeth except molars. [14] Clinically, the FACC for all teeth except molars, can he high-lighted with the side of a pencil lead. The midpoint of the FACC is referred to as the FA point. [14] *Andrews* reported that when the teeth in an arch are correctly positioned, their FA points fall on a plane that closely corresponds to the occlusal plane.[14] In this study, the tip and torque were measured at the FACC.

Tooth Inclination Protractor

Richmond et al. described a disposable device – the Tooth Inclination Protractor (TIP) which they used to measure the inclination of the labial surface of the maxillary and mandibular incisors to their respective occlusal planes.[21] The TIP consists of an acrylic platform (corresponding to the occlusal plane) with a 180° protractor suspended below it. The perforated platform receives a stainless steel wire, which can be cut to lie against the labial surface of the incisor, allowing for anatomical variations in crown height. Below the platform, the other end of the wire rests against the graduated scale of the protractor. [21,22] The wire pointer is placed against the labial surface of the incisor crown at its maximum convexity (FA Point), so that the angles above and below the contact are equal. The reading on the scale reflects the inclination of the labial surface of the maxillary teeth to their respective occlusal planes.

Tip

The tip represents the mesiodistal angle formed by the FACC and a line perpendicular to the occlusal plane.[14] The tip was considered positive when the occlusal portion of the FACC was mesial to the gingival portion, and negative when it was distal.[14] The tip was measured by orienting the cast with the occlusal plane seated on the TIP platform, and the needle aligned at the FACC (**Fig. 7**). Crown angulation was estimated at 2.5 ° degree intervals.

Torque

Crown inclination or torque represents the labio-lingual angle between a line perpendicular to the occlusal plane and a line that is parallel and tangent to the FACC at the FA point.[15] Crown inclination is determined from the mesial or distal, and the line representing the inclination of the FACC should be equidistant from each end of the clinical crown (cervical and incisal), while contacting the FACC (See **Fig. 8A and 8B**). Crown inclination is considered positive if the incisal portion of the crown, tangent line or FACC is facial to its gingival portion and is considered negative, if lingual to the gingival portion.[14]

Statistical Analyses

ANOVA was used to study variations in the ACD by tooth shape. Width/Height (W/H) ratios were calculated for all maxillary anterior teeth, and the association between the W/H and the corresponding ACD (mm) was established using Pearson's correlation analysis. Differences between the treated and non-treated groups were assessed using unpaired T-tests. In order to evaluate the relationship between the ACD measurements and tooth height, tip, and torque, the values for each of the co-variates were averaged across each tooth pair which comprised an ACD location. A fixed effects model was used to evaluate correlations between the ACD by clinical crown height, tip, torque and location.

RESULTS

A statistically significant and negative correlation was evident between the ACD (mm) and the Width/Height ratio of each tooth that comprised the corresponding ACD (Table 3). One-way ANOVA did not indicate statistically significant differences in ACD values by tooth shape. However, statistically significant differences in the clinical crown height of teeth # 8 ($p=0.016$) and 9 ($p=0.049$) were evident across the parallel ($n=47$) and the barrel shaped groups ($n=16$). Average values for clinical crown height, tip and torque for the non-treated and treated groups are provided in Table 4. For teeth #s7,10 and 11, the average clinical crown heights were significantly lower ($p<0.05$) for the treated group, compared to the non-treated group. The torque was significantly higher across all six tooth categories in the treated groups compared to the non-treated group. For tooth #11, the treated group exhibited a lower average degree of tip compared to the non-treated group.

The ACD measurements exhibited statistically significant correlations by location ($p<0.0001$) and by height ($p<0.0001$) of the clinical crown. Pearson correlation co-efficients between the ACD and clinical crown height were 0.297, 0.511 and 0.478 for the canine/lateral incisor, central/lateral incisor and midline, respectively. Graphs 1, 2 and 3 represent variations in ACD (mm) dimensions as a function of the clinical crown height of each tooth pair that represents an ACD location. Clinical crown height exhibited statistically significant correlations by tip ($p= 0.0216$), torque ($p=0.0015$) and location ($p<0.0001$).

DISCUSSION

This study assessed the effect of crown shape, clinical crown height, tip and torque on the ACD. Teeth were classified into three groups: parallel shaped (Fig 1a), barrel shaped (Fig 1b) and triangular (Fig 1c), based on the labial outline of the maxillary central incisor crowns, as described by O'Higgins and Kirschen.[21, 28] The average ACD dimensions did not vary across the three groups; however, the parallel and barrel shaped groups did exhibit statistically significant differences for the clinical crown heights of the maxillary central incisors. On an average, parallel shaped teeth had greater clinical crown height than barrel shaped teeth. The small number of triangular shaped teeth (n=4) precluded any useful extrapolation.

Since the ACD is a function of two adjacent teeth, in order to evaluate the relationship between the ACD measurements and the co-variates (height, tip and torque), the values for the co-variates were averaged across each tooth pair which comprised an ACD location. The use of paired adjacent teeth was considered acceptable, since there was no significant variation when the individual teeth were used to study the association between ACD and the co-variates. The height of the clinical crown was significantly associated with the corresponding ACD, thereby implying that taller teeth could have relatively higher ACD values compared to shorter teeth.

Interestingly, the orthodontically treated group exhibited statistically significant variations in the heights of the clinical crowns of #7,10 and 11. This finding may be attributable to passive eruption, and according to Morrow et al., passive eruption may cause an increase in the clinical crown length of the maxillary central incisors, lateral incisors and canines of subjects up to 18-19 years of age.[27] For the orthodontically treated group, age data were available for 31 of the 40 subjects, and 81% (i.e. 25 of the 31) of them were aged 18 or younger, at the time of debonding. Width/Height (W/H) ratios of the maxillary anterior teeth exhibited a negative correlation ($p < 0.05$) with their corresponding ACD locations (Table 3), thereby connoting increasing ACD dimensions with diminishing W/H ratios, or vice versa. This was consistent with the afore-mentioned positive association between the ACD and the height of the clinical crown.

Variations in the degree of tip and torque may influence the position of the proximal contacts. O'Higgins et al. suggested that increasing the torque of maxillary incisors will lead to a palatal movement of the proximal contacts.[21] However, according to the results of the present study, the tip and torque did not appear to influence the ACD proportions. This may be due to the fact that the selection criteria for the study were specifically set to incorporate casts of subjects with excellent occlusion and alignment, and this could therefore narrow the range of deviation in tip and torque. As a point of interest, the incisors in the orthodontically treated group had higher average torque values compared to the non-treated group. This observation was similar to the study by Ugur and Yukay, who compared the crown torque of treated and normal (untreated) occlusion subjects, and found that the maxillary incisors were inclined more labially in the treatment group.[28]

In this study, the Tooth Inclination Protractor (TIP) was used to measure the tip and torque of the clinical crown, with the maxillary occlusal plane as the horizontal reference. Richmond et al. measured crown inclination on dental casts using the TIP, and reported average intra-examiner errors ranging from 2.2 to 2.6 °, and inter-examiner reliability (intra class correlation) values to be above 0.9 for the maxillary central incisors[22]. A comparison of TIP scores with the upper incisor to the maxillary plane inclination angle, indicated that although the TIP scores were closely related to the upper incisor to maxillary plane angles, the TIP tended to record the upper incisor's axial inclination approximately 10.46 ° smaller than did the lateral cephalogram.[22] Ghahferokhi et al found a similar diminution of 14° between the tooth inclination scores when comparing the TIP to lateral cephalograms.[23]

Cephalometric assessment of incisor axial inclination is based on the premise that a line connecting the root apex and the incisal edge reflects the long axis of the tooth.[29] Andrews' method measures the labial surface inclination relative to the occlusal plane regardless of the inclination of the root or the long axis of the entire tooth, and consequently there might be lack of congruity between the two measured components that represent inclination i.e. the long axis of the tooth and the labial surface inclination. Fredericks measured the angle formed by a tangent to the labial surface and the long axis of the tooth (labial surface angle) and found a range of 17° to 38° in his sample of 30 maxillary central incisors.[30] Similarly, Bryant et al. reported a range of 7 to 24° for the labial surface angle of 198 central incisors.[31] This range of variation between the labial surface inclination and the long axis of the tooth might explain the reported differences in inclination between the TIP and lateral cephalograms.

Another factor to be cognizant of is the potential for angular variations (collum angle) between the long axis of the crown and the long axis of the root, for example in CL II Div II malocclusions.[31] Therefore, a tooth that appears to be proclined on the lateral cephalogram might show a retroclined crown on the dental cast.[29] More recently, Knosel et al (2007) compared incisor inclinations obtained using lateral cephalograms with the NA line as a reference, and inclination values obtained from direct cast measurements using the

TIP on corresponding dental casts of 67 subjects between 10 and 25 years of age.[29] They concluded that direct dental cast measurements appear to be more precise and more valuable than lateral radiographs. [29] It is important to note that all three afore-mentioned studies did not use subjects with excellent occlusion, thereby potentially affecting the range of discrepancy between lateral cephalograms and direct cast measurements. A potential limitation of this device (TIP) is that it is challenging to locate solely by visual means the FACC that is tangential to the FA point and equidistant from the occlusal and gingival extremities of the crown's facial surface. [15]

An additional finding of interest in this study was the association between the height of the clinical crown with the tip and torque. Andlin-Sobocki (1993) reported that when teeth are moved facially, the facial gingiva may recede thereby leading to a relative increase in the height of the clinical crown.[32] Wennstrom suggested that facial tooth movement led to a reduced bucco-lingual tissue thickness, reduced height of the free gingival margin, as well as an increase in the height of the clinical crown.[33] Similarly, Kornhauser et al. noted that labial tipping of teeth in cross-bite led to a statistically significant but clinically innocuous decrease in the width of the keratinized and attached gingiva.[34] Kandasamy et al. in a recent study, observed a decrease in papillary height, relative to the control, after labial movement of teeth.[35] Therefore, an increase in the labial inclination of the crown may be associated with a minor increase in the height of the clinical crown.

The age of subjects in this study ranged from the late teens to the late twenties. Although age was not evaluated during this study, one should remain cognizant of the potential for age-related variations in ACD proportions due to increased incisal and proximal wear and gingival recession, both of which are associated with increasing age

CONCLUSION

Within the limitations of this study, it is possible to conclude that the ACD exhibited a statistically significant and positive association with the height of the clinical crown. A statistically significant and negative correlation was evident between the ACD and W/H ratios of the corresponding teeth, thereby implying an inverse relationship between the two proportions. No statistically significant correlations were found between the ACD and shape of the clinical crown. However, the height of the clinical crown of the maxillary central incisors did exhibit statistically significant variations between parallel and barrel shaped teeth. No statistically significant correlations were found between the ACD with the tip and the torque. The orthodontically treated group exhibited a statistically significant ($p<0.05$) increase in labial crown inclination compared to the non-treated group. The tip and torque did exhibit a statistically significant ($p<0.05$) correlation with the height of the clinical crown, and this may be due to altered position of the gingival zeniths or margin, thereby leading to an increase in the height of the clinical crown.

CLINICAL SIGNIFICANCE

This study validates the existence of the proportions of the Apparent Contact Dimension among subjects deemed to possess excellent occlusion and alignment. This quantifiable "ideal" could be used in conjunction with other evidence based paradigms, in the esthetic appraisal of the maxillary anterior teeth, with the understanding that a case-by-case approach is decidedly prudent.

Table 1: Average ACD% (relative to height of the Ipsilateral Central Incisor) and correlation between Intra and Extraoral Percent ACD

ACD Location (n=10)	**Intra-Oral**	**Extra-Oral**	**Correlation coefficient (r)**	**P-value**
6,7	28.4%	26.2%	0.88	0.001
7,8	37.2%	36.3%	0.77	0.004
8,9	44.7%	41.6%	0.92	0.001
9,10	37.4%	36.9%	0.94	0.001
10,11	28.7%	28.1%	0.84	0.001

Table 2: Mean difference between Intra and Extraoral Percent ACD

ACD Location	Mean Difference (IO-EO)	P-value
6,7	2.2%	0.021
7,8	0.83%	0.489
8,9	3.1%	0.036
9,10	-0.2%	0.87
10,11	0.62%	0.55

Table 3: ACD among treated (n=40) and non-treated (n=27) subjects and Correlation with W/H ratios

Location	Group	Average ACD (mm)	Average %ACD	ACD (mm) Correlation with W/H ratios (R)
6,7	Non-Treated	2.76± 0.49	**27± 6.1**	-0.245*, -0.166
	Treated	2.73± 0.66		
10,11	Non-Treated	2.73± 0.59		-0.246*, -0.147
	Treated	2.74± 0.68		
7,8	Non-Treated	4.29± 0.75	**38± 7.5**	-0.293*, -0.243*
	Treated	3.76± 0.84		
9,10	Non-Treated	4.08± 0.80		-0.287*, -0.372‡
	Treated	3.75± 0.91		
8,9 (Midline)	Non-Treated	5.15± 0.63	**49± 6.7**	-0.404‡, -0.367‡
	Treated	4.89± 0.86		

*, ‡ **- Denote $p<0.05$ and 0.01, respectively.**

Table 4: Clinical crown height, tip and torque for treated (n=40) and non-treated subjects (n=27)

Tooth	Group	Average Height (mm)	Average Tip (Degrees)	Average Torque (Degrees)
6	Non-Treated	10.0± 1.08	5± 3.7	1± 2.7
	Treated	9.6± 0.96	5± 4.5	3± 3.3*
7	Non-Treated	8.9± 0.95	8± 3.5	9± 4.6
	Treated	8.4± 0.90*	8± 3.2	12± 5.0*
8	Non-Treated	10.3± 1.05	4± 2.1	8± 5.5
	Treated	10.3± 1.07	4± 2.0	13± 4.5*
9	Non-Treated	10.4± 0.97	5± 2.7	8± 4.8
	Treated	10.4± 1.08	4± 1.7	13± 4.8*
10	Non-Treated	9.2± 0.83	8± 3.5	6± 4.6
	Treated	8.4± 0.89*	8± 3.0	11± 5.3*
11	Non-Treated	10.3± 0.97	7± 4.3	-1± 3.9
	Treated	9.7± 1.02*	4± 4.1*	3± 3.9*

*** Indicates $p<0.05$ between Tx and Non-Tx groups**

Fig 1: Connector Zone –Morley , Eubank. J Am Dent Assoc. 2001 Jan;132(1):39-45.

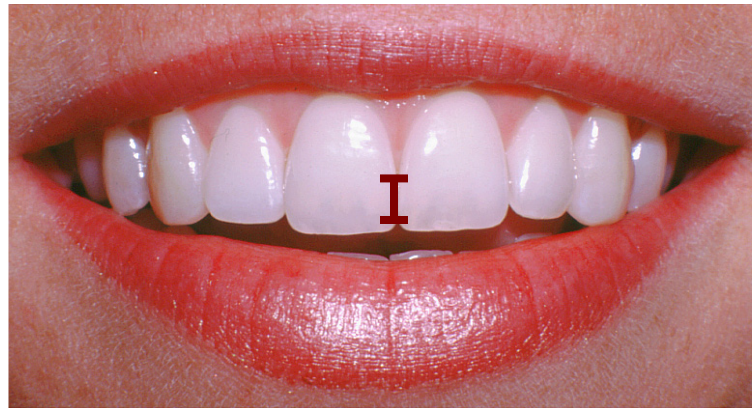


Fig 2: Apparent Contact Dimension

Fig 3: Intra-Oral ACD measurement

Fig 4: Measurement of clinical crown height

Fig 5: ACD measurement on Casts

Figure 6: Tooth Shape Classification

Fig. 6A

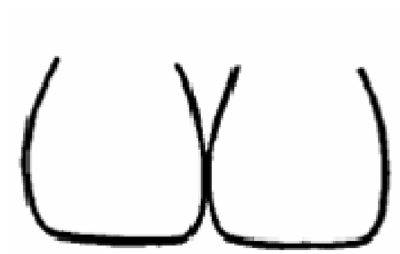


Fig. 6B

Fig. 6C

<u>Fig. 7 Measurement of crown angulation (tip) using the TIP</u>

A

<u>Fig. 8 Measurement of crown inclination (Torque) using the TIP</u>

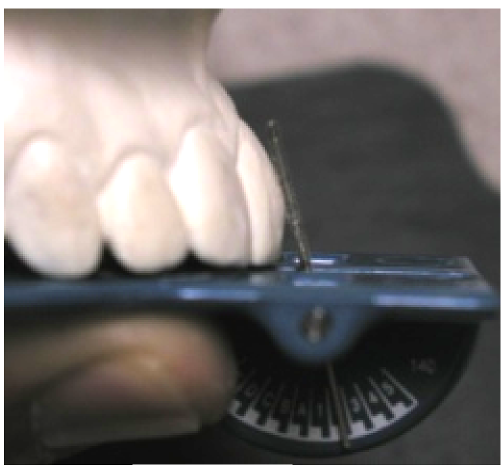


Fig 8A

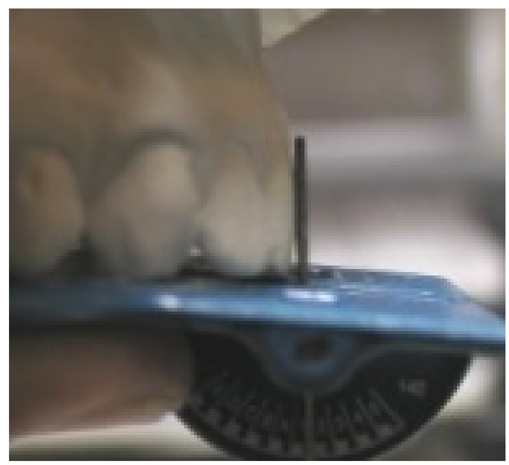
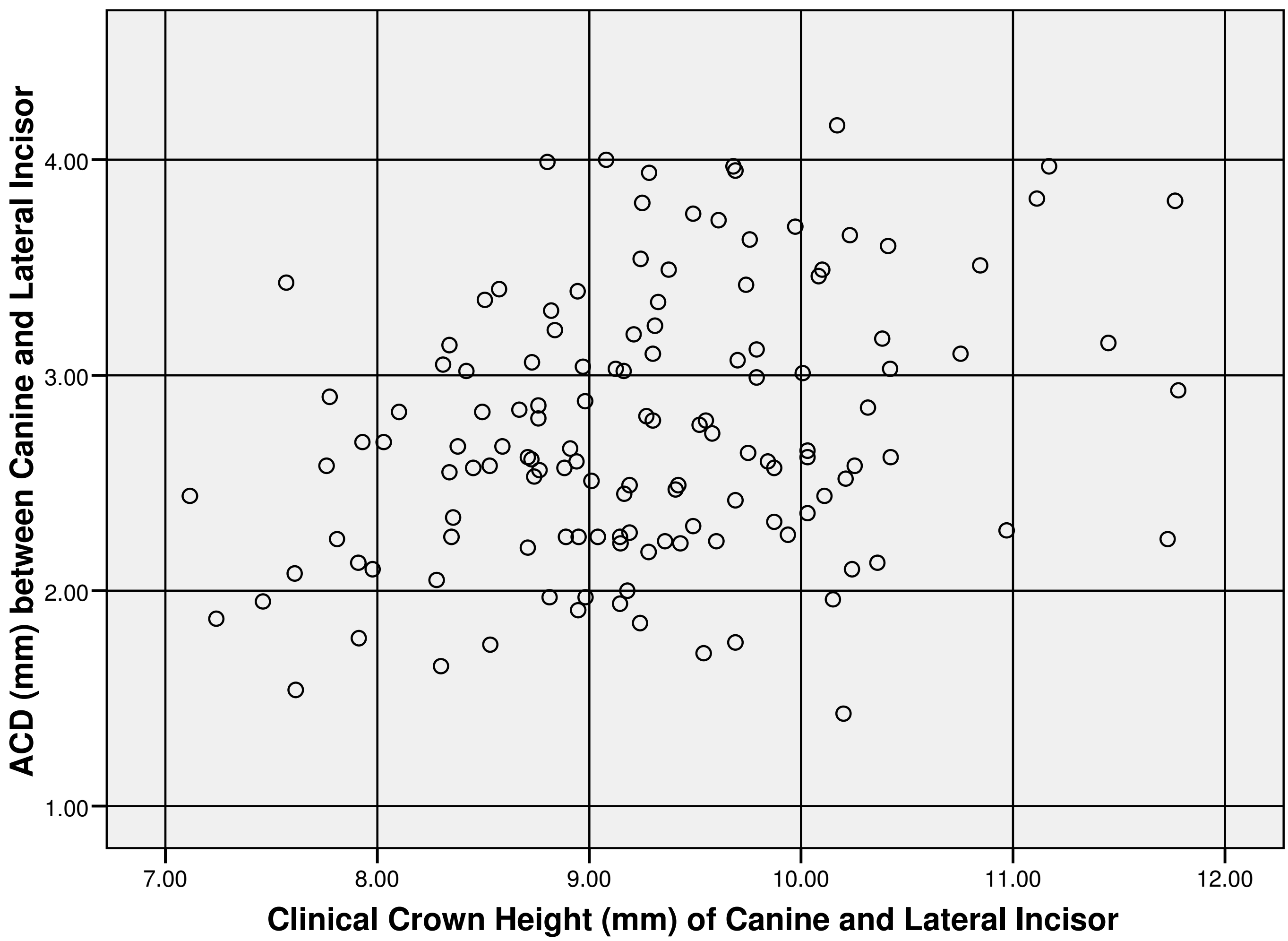
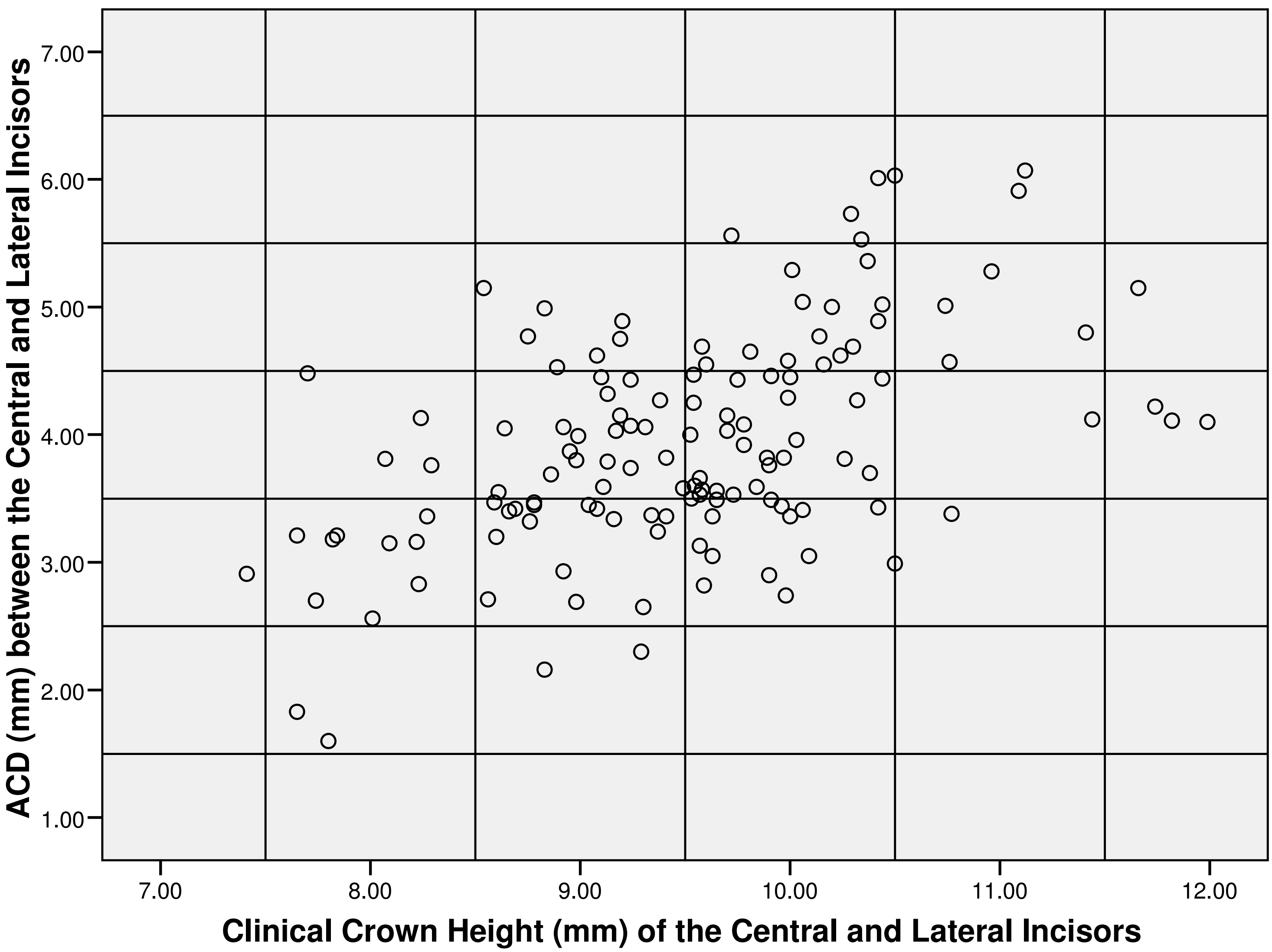


Fig 8B

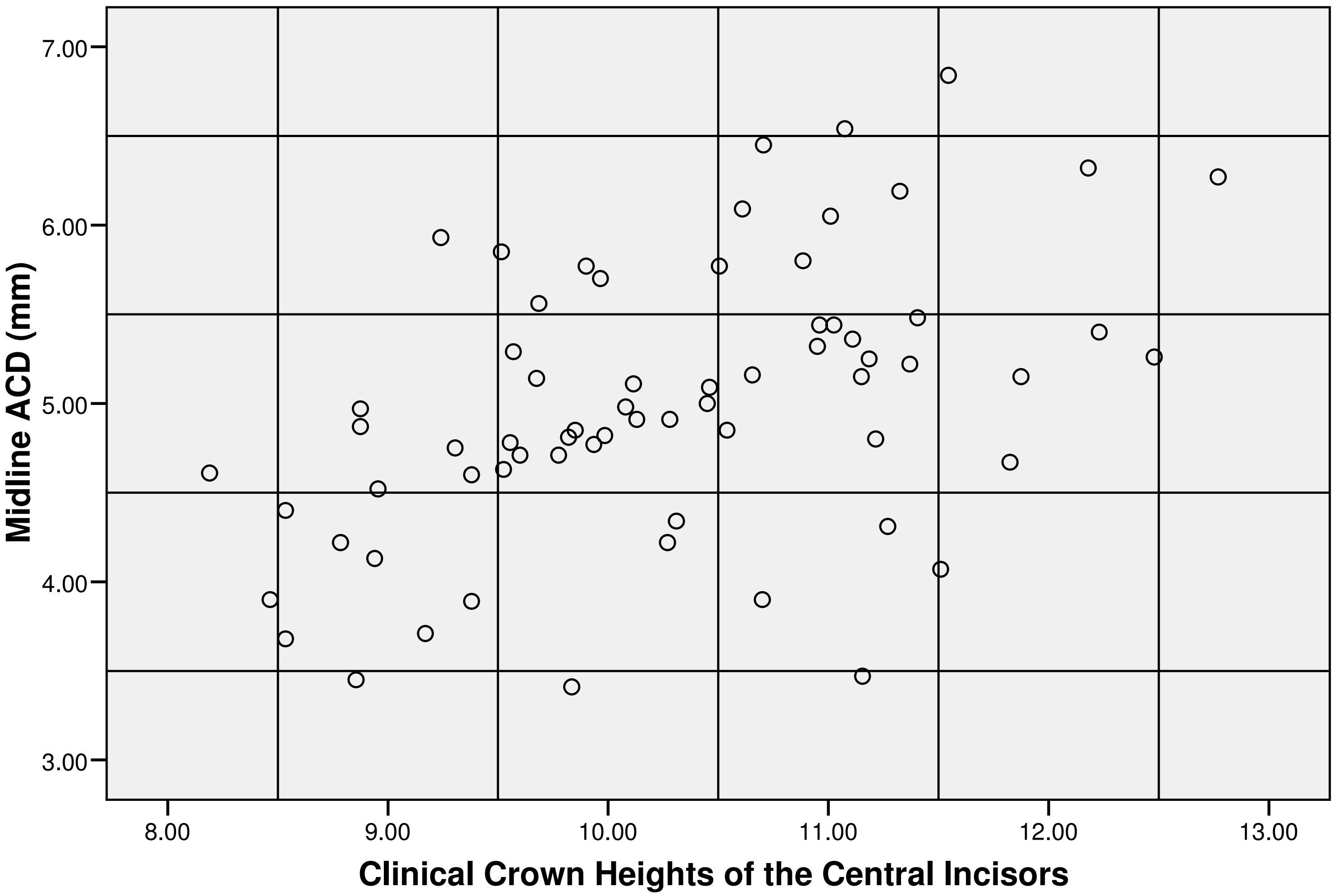
Graph 1: Effect of Clinical Crown Height on the ACD Between Canine and Lateral Incisor



Graph 2: Effect of Clinical Crown Height on the ACD Between Central and Lateral Incisor



Graph 3: Effect of Clinical Crown Height on Midline ACD



REFERENCES

1. Moskowitz ME, Nayyar A. Determinants of dental esthetics: a rationale for smile analysis and treatment. Compend Contin Educ Dent. 1995;16(12):1164-86.

2. Morley J, Eubank J. Macroesthetic elements of smile design. J Am Dent Assoc. 2001; 132(1):39-45.

3. Sarver DM. Principles of cosmetic dentistry in orthodontics: Part 1. Shape and proportionality of anterior teeth. Am J Orthod Dentofacial Orthop. 2004;126(6):749-53.

4. Hasanreisoglu U, Berksun S, Aras K, Arslan I. An analysis of maxillary anterior teeth: Facial and dental proportions. J Prosthet Dent. 2005;94(6):530-8.

5. Magne P, Gallucci GO, Belser UC. Anatomic crown width/length ratios of unworn and worn maxillary teeth in white subjects. J Prosthet Dent. 2003;89(5):453-61.

6. Rufenacht C. Fundamentals of Esthetics. Chicago: Quintessence; 1990

7. Gillen RJ, Schwartz RS, Hilton TJ, Evans DB. An analysis of selected normative tooth proportions. Int J Prosthodont. 1994;7(5):410-7

8. Levin EI. Dental esthetics and the golden proportion. J Prosthet Dent. 1978;40(3):244-52

9. Preston JD. The golden proportion revisited. J Esthet Dent. 1993;5(6):247-51.

10. Rosenstiel SF, Ward DH, Rashid RG. Dentists' preferences of anterior tooth proportion--a web-based study. J Prosthodont. 2000;9(3):123-36

11. Ong E, Brown RA, Richmond S. Peer assessment of dental attractiveness. Am J Orthod Dentofacial Orthop. 2006;130(2):163-9

12. Kokich VO Jr, Kiyak HA, Shapiro PA. Comparing the perception of dentists and lay people to altered dental esthetics. J Esthet Dent. 1999;11(6):311-24

13. Andrews LF. The six keys to normal occlusion. Am J Orthod. 1972; 62(3):296-309

14. Andrews LF. Straight Wire: The Concept and Appliance. San Diego: LA Wells Co; 1989.

15. Watanabe K, Koga M. A morphometric study with setup models for bracket design. Angle Orthod. 2001;71(6):499-511.

16. Currim S, Wadkar PV. Objective assessment of occlusal and coronal characteristics of untreated normals: a measurement study. Am J Orthod Dentofacial Orthop. 2004;125(5):582-8.

17. Tuverson DL. Anterior interocclusal relations. Am J Orthod. Part I. 1980;78(4):361-70.

18. Wolfart S, Brunzel S, Freitag S, Kern M. Assessment of dental appearance following changes in incisor angulation. Int J Prosthodont. 2004;17(2):150-4.

19. Brunzel S, Kern M, Freitag S, Wolfart S. Aesthetic effect of minor changes in incisor angulation: an internet evaluation. J Oral Rehabil. 2006;33(6):430-5

20. Mackley RJ. An evaluation of smiles before and after orthodontic treatment. Angle Orthod.1993;63(3):183-9.

21. O'Higgins EA, Kirschen RH, Lee RT. The influence of maxillary incisor inclination on arch length. Br J Orthod. 1999;26(2):97-102.

22. Richmond S, Klufas ML, Sywanyk M. Assessing incisor inclination: a non-invasive technique. Eur J Orthod. 1998;20(6):721-6.

23. Ghahferokhi AE, Elias L, Jonsson S, Rolfe B, Richmond S. Critical assessment of a device to measure incisor crown inclination. Am J Orthod Dentofacial Orthop. 2002 ;121(2):185-91.

24. Ward DH. A study of dentists' preferred maxillary anterior tooth width proportions: comparing the recurring esthetic dental proportion to other mathematical and naturally occurring proportions. J Esthet Restor Dent. 2007;19(6):324-37

25. Abdullah MA. Inner canthal distance and geometric progression as a predictor of maxillary central incisor width. J Prosthet Dent. 2002;88(1):16-20.

26. Kirschen RH, O'higgins EA, Lee RT. The Royal London Space Planning: an integration of space analysis and treatment planning: Part I: Assessing the space required to meet treatment objectives. Am J Orthod Dentofacial Orthop. 2000;118(4):448-55

27. Morrow LA, Robbins JW, Jones DL, Wilson NH. Clinical crown length changes from age 12-19 years: a longitudinal study. J Dent. 2000;28(7):469-73

28. Uğur T, Yukay F. Normal facio-lingual inclinations of tooth crowns compared with treatment groups of standard and pre-torqued brackets. Am J Orthod Dentofacial Orthop. 1997;112(1):50-7.

29. Knosel M, Kubein-Meesenburg D, Sadat-Khonsari R. The third-order angle and the maxillary incisor's inclination to the NA line. Angle Orthod. 2007;77(1):82-7

30. Fredericks CD. A method for determining the maxillary incisor inclination. Angle Orthod. 1974;44(4):341-5

31. Bryant RM, Sadowsky PL, Hazelrig JB. Variability in three morphologic features of the permanent maxillary centralincisor. Am J Orthod. 1984;86(1):25-32.

32. Andlin-Sobocki A, Bodin L. Dimensional alterations of the gingiva related to changes of facial/lingual tooth position in permanent anterior teeth of children. A 2-year longitudinal study. J Clin Periodontol. 1993;20(3):219-24.

33. Wennström JL. Mucogingival considerations in orthodontic treatment. Semin Orthod. 1996;2(1):46-54.

34. Kornhauser S, Schwartz Z, Bimstein E. Changes in the gingival structure of maxillary permanent teeth related to the orthodontic correction of simple anterior cross-bite. Am J Orthod Dentofacial Orthop. 1996;110(3):263-8

35. Kandasamy S, Goonewardene M, Tennant M. Changes in interdental papillae heights following alignment of anterior teeth. Aust Orthod J. 2007;23(1):16-23