The Apparent Contact Dimension and Covariates among Orthodontically Treated and Nontreated Subjects

VISHNU RAJ, BDS, MSFS*
HARALD O. HEYMANN, DDS, M.ED†
H. GARLAND HERSHEY, DDS, MS‡
ANDRE V. RITTER, DDS, MS§
JOHN S. CASKO, DDS, MS, PHD¶

ABSTRACT
The apparent contact dimension (ACD), a determinant of dental esthetics, has been purported to exhibit an esthetic relationship termed the "50:40:30" rule, implying that in an esthetic smile, the ACD between the central incisors, central and lateral incisors, and lateral incisor and canine would be 50, 40, and 30% of the height of a central incisor, respectively. This study assessed the existence of this proportion using casts of orthodontically treated ($N = 40$) and nontreated ($N = 27$) subjects deemed to possess excellent occlusion. Covariates 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 incisors, 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 the width/height ratios of the corresponding teeth. No statistically significant correlations were evident between the ACD with the shape of the clinical crown, tip, and torque. However, the tip and torque did exhibit a statistically significant ($p < 0.05$) correlation with the height of the clinical crown. This study is the first to validate the existence and proportions of the ACD.

CLINICAL SIGNIFICANCE
This study validates the existence of the ACD and quantifies the relationship of the ACD with tooth size, tooth shape, mesiodistal crown angulation (tip), and labiolingual crown inclination (torque) among subjects deemed to possess excellent occlusion and alignment. This quantifiable "ideal" and its correlation with the other determinants of dental esthetics may be used in conjunction with various evidence-based paradigms in the esthetic appraisal of the maxillary anterior teeth.

(*J Esthet Restor Dent* 21:96–112, 2009)

*Resident, Graduate Orthodontics, School of Dentistry, University of Texas Health Sciences Center at San Antonio
†Professor and graduate program director, Department of Operative Dentistry, School of Dentistry, University of North Carolina at Chapel Hill
‡Professor, Department of Orthodontics, School of Dentistry, University of North Carolina at Chapel Hill
§Associate professor, Department of Operative Dentistry, School of Dentistry, University of North Carolina at Chapel Hill
¶Professor, B.F. and Helen E. Dewel Endowed Chair, Department of Orthodontics, College of Dentistry, University of Iowa, Iowa City

DOI 10.1111/j.1708-8240.2009.00240.x

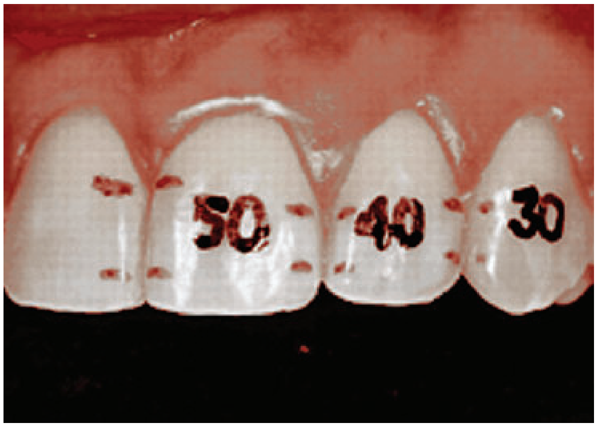


Figure 1. Connector zone (reprinted with permission from the Journal of the American Dental Association *2001;132(1):39–45).*

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. 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 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 2×2 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 derives from the fact that "connectors" are widely defined and well known as components of removable and fixed prosthodontic appliances. Because of 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 an evaluation of the illustration of the "connector zone" (Figure 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 degrees to each proximal contact area. Therefore, based on the 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.* As an 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 and colleagues mentioned the use of certain

Figure 2. Apparent contact dimension.

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 1.6,181 : 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% of the size of its adjacent mesial tooth, it is considered esthetically pleasing.[4] As stated by Levin, 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.[4,7,9] A recent study on dentists' preferences of anterior tooth proportions found that the golden proportion was preferable only for 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 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 and Eubank quantified as the 50 : 40 : 30 rule (Figure 1).[2] This "rule" defined the ideal ACD between the central incisors as 50% of the height of the central incisors, the ideal ACD between a maxillary lateral incisor and central incisor as 40% of the height of a central incisor, and the ideal ACD between a lateral incisor and a canine as 30% of 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 degrees to each corresponding interdental 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 with 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.[13] 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 unesthetic. Kokich and colleagues evaluated perceptions of alterations in incisor crown angulation and found that even minor deviations from the ideal were considered unattractive.[14]

In a landmark publication, Andrews measured diagnostic models of 120 untreated ideal occlusion subjects in an attempt to identify the characteristics consistently present in naturally optimal occlusion.[15] He then recorded the average values or norms for these parameters, including anteroposterior 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.[16] Andrews's so-called six keys to ideal occlusion were incorporated into commercially available orthodontic brackets and represented the first preprogrammed or straight wire appliance in orthodontics,[16] a concept that facilitated tooth movement into desirable positions based on carefully documented "ideal" occlusions. Average mesiodistal angulations obtained by Andrews from nonorthodontically treated normal models were 5, 9, and 11 degrees for the maxillary central incisor, lateral incisor, and canine, respectively.[15] Other researchers have reported similar or comparable values of tip and torque,[17,18] 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.[19] The esthetic import of angulation was further emphasized in a study by Wolfart 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.[20] Brunzel and colleagues corroborated the significance of symmetry and axial inclination, specifically variations in the mesial angulation of the lateral incisors (up to 9 degrees).[21] 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 and colleagues to be esthetic are both in the range of 9 degrees.

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.[17] 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 nonorthodontically treated normal models, Andrews reported mean torque values for the maxillary central incisor, lateral incisor, and canine as 7, 3, and –7 degrees, respectively.[15] The esthetic significance of torque was also delineated by Mackley in a study on postorthodontic 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.[22]

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 aforementioned 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 were to establish the proportions of the ACD and to quantify the relationship between the ACD and the covariates of tooth shape, size, tip, and torque using diagnostic casts of nontreated and orthodontically treated subjects.

MATERIALS AND METHODS

Clinical Pilot Study

A pilot study approved by the Institutional Review Board was conducted to validate the accuracy of measuring the ACD on the diagnostic models compared with 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 degrees to the interdental area between the central incisors, central and lateral incisors, and lateral incisor and canine. Although esthetics is not always perceived at 90 degrees 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 degrees 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 (Figure 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

Figure 3. Intraoral apparent contact dimension measurement.

Figure 4. Measurement of clinical crown height.

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 teeth #8 and 9 were measured (Figure 4) and recorded in duplicate. The ACD was established as a percentage of the height of the ipsilateral central incisor. Next, a PolyVinyl Siloxane (PVS) impression of the maxillary arch was made, disinfected, and poured with Type III dental stone. ACD measurements were performed on the casts (Figure 5) and converted to %ACD. The average intraoral and extraoral %ACD was calculated by tooth type, and Pearson correlation was used to establish the strength of the association between intraoral and extraoral measurements. Paired *t*-tests were used to assess the existence of systematic measurement differences.

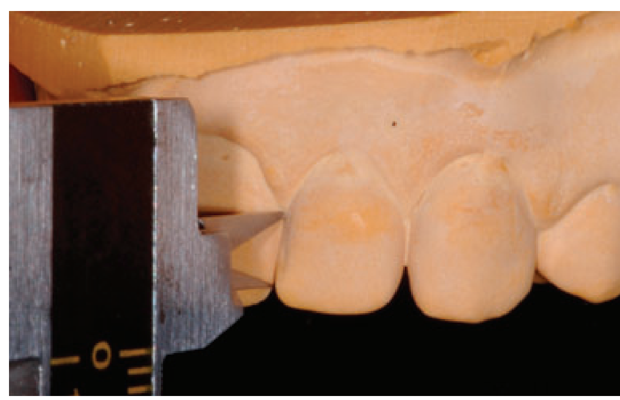


Figure 5. Apparent contact dimension measurement on casts.

Results of the 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

TABLE 1. AVERAGE %ACD (RELATIVE TO HEIGHT OF THE IPSILATERAL CENTRAL INCISOR) AND CORRELATION BETWEEN INTRA- AND EXTRAORAL %ACD.

ACD Location ($N = 10$)	Intraoral (%)	Extraoral (%)	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

ACD = apparent contact dimension.

TABLE 2. MEAN DIFFERENCE BETWEEN IO AND EO %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

ACD = apparent contact dimension; IO = intraoral; EO = extraoral.

were the presence of all six unrestored and well-aligned maxillary anterior teeth. Casts with noticeable incisal wear, gingival conditions (recession, inflammation), undersized teeth, anterior diastemas, rotations, black triangles, and restorations/crowns were excluded from the study. Using these criteria, 27 of approximately 90 casts of nontreated, 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. Using the same aforementioned 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 degrees 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 (Figure 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 teeth #8 and 9 were measured and recorded in duplicate to reduce measurement error. The ACD was established as a percentage of the height of the ipsilateral central incisor using the following equation:

$$\%\text{ACD} = (\text{Measured ACD}/\text{Height of ipsilateral central incisor}) \times 100$$

Tooth Size

Tooth size measurements comprising the mesiodistal 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 (W/H) ratios were calculated.

Tooth Shape

Although tooth shape is not a readily quantifiable variable, it has

Figure 6. Tooth shape classification: (A) Parallel, (B) Barrel shaped, and (C) Triangular.

the potential to substantially affect the ACD. For the purposes of this study, teeth were classified as parallel shaped (Figure 6A), barrel shaped (Figure 6B), or triangular shaped (Figure 6C),[14] based on the degree of cervicoincisal divergence.

Facial Axis of the Clinical Crown (FACC)

As originally proposed by Andrews, the facial (long) axis of the clinical crown 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.[16] Clinically, the FACC for all teeth, except molars, can be highlighted with the side of a pencil lead. The midpoint of the FACC is referred to as the FA point.[16] 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.[16] In this study, the tip and torque were measured at the FACC.

Tooth Inclination Protractor (TIP)

Richmond and colleagues described a disposable device—the TIP—which they used to measure the inclination of the labial surface of the maxillary and mandibular incisors to their respective occlusal planes.[24] The TIP consists of an acrylic platform (corresponding to the occlusal plane) with a 180-degree 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.[24,25] 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.[7] The tip was considered positive when the occlusal portion of the FACC was mesial to the gingival portion, and negative when it was distal.[7] The tip was measured by orienting the cast with the occlusal plane seated on the TIP platform and the needle aligned at the FA point (Figure 7). Crown angulation was estimated at 2.5-degree intervals.

Torque

Crown inclination or torque represents the labiolingual angle between a line perpendicular to the occlusal plane and a line that is parallel and tangent to the FACC at the FA point.[8] 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 Figure 8). Crown inclination is

Figure 7. Measurement of crown angulation (tip) using the tooth inclination protractor.

Figure 8. Measurement of crown inclination (torque) using the tooth inclination protractor.

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.[7]

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 nontreated groups were assessed using unpaired *t*-tests. Analysis of variance (ANOVA) was used to study variations in the ACD by tooth shape. W/H ratios were calculated for all maxillary anterior teeth, and the association between the W/H and the corresponding ACD (millimeters) was established using Pearson correlation analysis. Differences between the treated and nontreated 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 covariates were averaged across each tooth pair that 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

The average ACD in millimeters and the %ACD for the orthodontically treated and nontreated groups are listed in Table 3. As the differences between the treated and nontreated 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—that is, between 6/7 and 10/11 ($p = 0.916$) and between 7/8 and 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%.

A statistically significant and negative correlation was evident between the ACD (millimeter) and the W/H ratio of each tooth that comprised the corresponding ACD (Table 1). One-way ANOVA did

TABLE 3. ACD AMONG TREATED ($N = 40$) AND NONTREATED ($N = 27$) SUBJECTS AND CORRELATION WITH W/H RATIOS.

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

ACD = apparent contact dimension; W/H = width/height.
*$p < 0.05$; **$p < 0.01$.

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 nontreated and treated groups are provided in Table 2. For teeth #7, 10, and 11, the average clinical crown heights were significantly lower ($p < 0.05$) for the treated group compared with that for the nontreated group. The torque was significantly higher across all six tooth categories in the treated groups compared with that in the nontreated group. For tooth #11, the treated group exhibited a lower average degree of tip compared with the nontreated group (Table 4).

The ACD measurements exhibited statistically significant correlations by location ($p < 0.0001$) and by height ($p < 0.0001$) of the clinical crown. Pearson correlation coefficients between the ACD and clinical crown height were 0.297, 0.511, and 0.478 for the canine/lateral incisor, central/lateral incisors, and midline, respectively. Graphs 1 through 3 represent variations in ACD (millimeter) 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 ($p < 0.0001$).

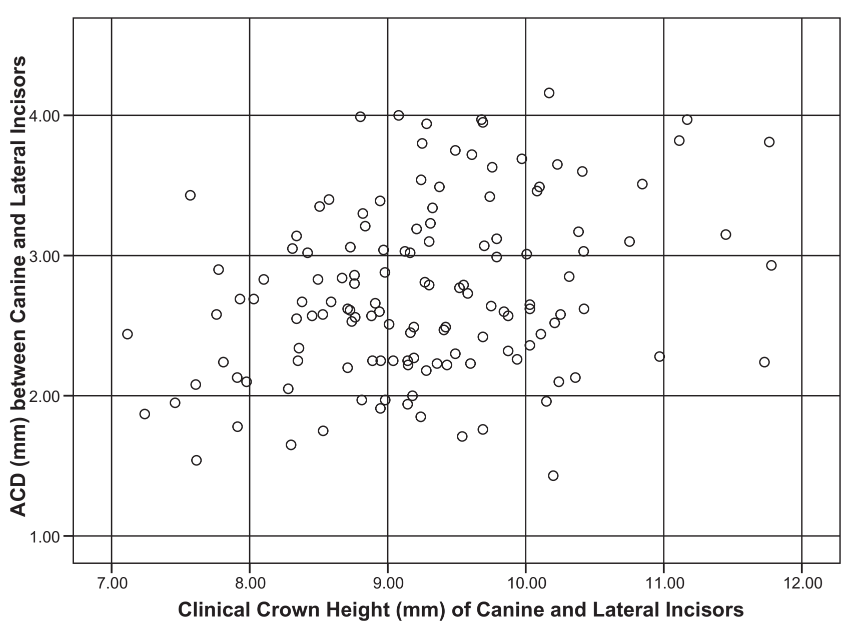
DISCUSSION

Symmetry and proportionality clearly affect the perception of esthetics, especially in the maxillary anterior region. Various esthetic "ideals," such as the golden proportion, W/H ratios, and the Recurring Esthetic Dental (RED) proportion, have been proposed.[8,10,11] 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 nontreated 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 and colleagues), recorded the dimensions

TABLE 4. CLINICAL CROWN HEIGHT, TIP, AND TORQUE FOR TREATED (N = 40) AND NONTREATED SUBJECTS (N = 27).

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

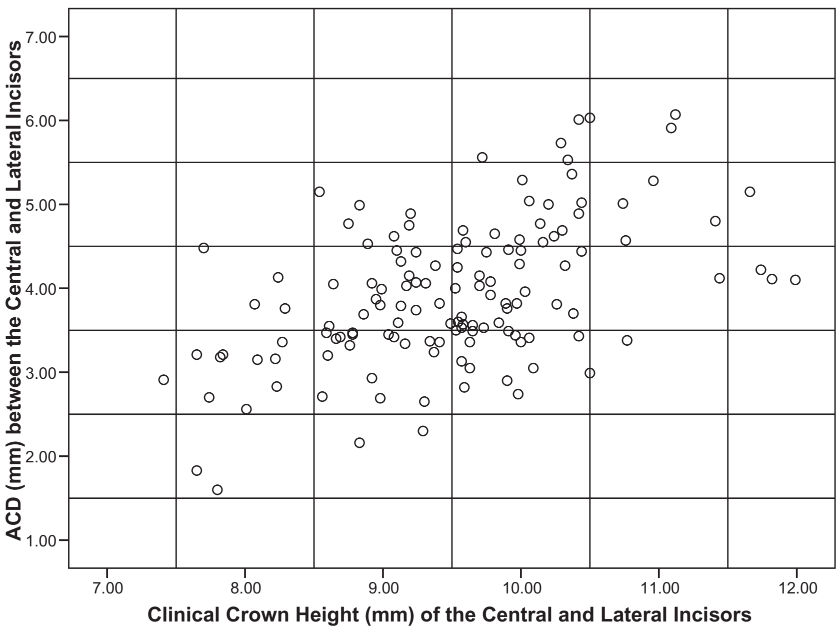
*Indicates $p < 0.05$ between treated and nontreated groups.



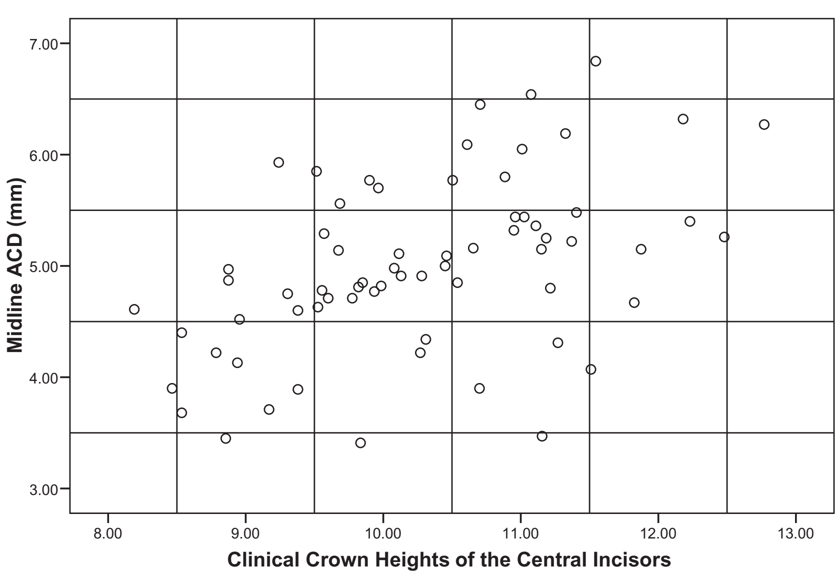
Graph 1. Association between apparent contact dimension (ACD) and clinical crown height—canine and lateral incisors.

of six anterior teeth intraorally and on casts, and did not find significant differences between the two sets of measurements.[12] However, with respect to the actual and perceived widths, there appears to be a difference between diagnostic models and images. Hasanreisoglu and colleagues 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 because of 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 malaligned 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 mesiodistal or incisocervical tooth dimensions. The ACD millimeter



Graph 2. Association between apparent contact dimension (ACD) and clinical crown height—central and lateral incisors.



Graph 3. Association between apparent contact dimension (ACD) and clinical crown height—midline.

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 incisors, 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).

A secondary aim of this study was to assess the effect of crown shape, clinical crown height, tip, and torque on the ACD. Teeth were classified into three groups—parallel shaped (Figure 6A), barrel shaped (Figure 6B), and triangular shaped (Figure 6C)—based on the labial outline of the maxillary central incisor crowns, as described by O'Higgins and Kirschen and colleagues.[23,26] 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 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.

As the ACD is a function of two adjacent teeth, in order to evaluate the relationship between the ACD measurements and the covariates (height, tip, and torque), the values for the covariates were averaged across each tooth pair that comprised an ACD location. The use of paired adjacent teeth was considered acceptable as there was no significant variation when the individual teeth were used to study the association between ACD and the covariates. 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 with shorter teeth.

Interestingly, the orthodontically treated group exhibited statistically significant variations in the heights of the clinical crowns of teeth #7, 10, and 11 compared with the nontreated group. This finding may be attributable to passive eruption, and according to Morrow and colleagues, 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 to 19 years of age.[27] Age data for the orthodontically treated group was available for 31 of the 40 subjects, and 81% (i.e., 25 of the 31) of the subjects were age 18 or younger at the time of debonding. W/H ratios of the maxillary anterior teeth exhibited a negative correlation ($p < 0.05$) with their corresponding ACD locations (Table 1), thereby connoting an increase in ACD dimensions with diminishing W/H ratios, or vice versa. This was consistent with the aforementioned 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 and colleagues suggested that increasing the torque of maxillary incisors will lead to a palatal movement of the proximal contacts.[23] However, according to the results of the present study, the tip and torque did not appear to influence the ACD proportions. This may be because of the fact that the selection criteria for the study were specifically set to incorporate casts of subjects with excellent occlusion and alignment, thereby narrowing the range of deviations in tip and torque. As a point of interest, the incisors in the orthodontically treated group had higher average torque values compared with that in the nontreated 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 TIP was used to measure the tip and torque of the clinical crown, with the maxillary occlusal plane as the horizontal reference. Richmond and colleagues measured crown inclination on dental casts using the TIP, and reported average intraexaminer errors ranging from 2.2 to 2.6 degrees, and interexaminer reliability (intraclass correlation) values above 0.9 for the maxillary central incisors.[24] 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 degrees smaller than did the lateral cephalogram.[15] Ghahferokhi and colleagues found a similar diminution of 14 degrees between the tooth inclination scores when comparing the TIP with lateral cephalograms.[25]

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.[20] Andrews's 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 and colleagues 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 Class II Div II malocclusions.[22] Therefore, a tooth that appears to be proclined on the lateral cephalogram might show a retroclined crown on the dental cast.[20] More recently, Knosel and colleagues 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 aforementioned 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.[6]

An additional finding that is of interest in this study was the association between the height of the clinical crown with the tip and torque. Andlin-Sobocki and Bodin 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] Wennström suggested that facial tooth movement led to a reduced buccolingual tissue thickness, reduced height of the free gingival margin, and an increase in the height of the clinical crown.[33] Similarly, Kornhauser and colleagues 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 and colleagues, in a recent study, observed a decrease in papillary height, relative to the control group, 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 20s. Although age was not evaluated during this study, one should remain cognizant of the potential for age-related variations in ACD proportions because of increased incisal and proximal wear and gingival recession, both of which are associated with increasing age. The present study did not assess other potential variables such as incisal embrasure dimensions and height of the gingival papilla. Inchoate ideas for future research could include the use of digitally manipulated images to assess the esthetic significance of different ACD proportions as well as the investigation of the relationship between the ACD, incisal embrasure dimensions, and the height of the gingival papilla (scallop depth).

CONCLUSIONS

Within the limitations of this study, it is possible to conclude that the average ACD proportions between the central incisors, the central/lateral incisors, and the lateral incisor and canine were 49 : 38 : 27% of the height of an ipsilateral central incisor, respectively. The ACD proportions exhibited bilateral symmetry and were consistent with the ideal proportion of 50 : 40 : 30, as proposed by Morley and Eubank. 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 with the nontreated 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 because of the altered position of the gingival zeniths or margin, thereby leading to an increase in the height of the clinical crown.

DISCLOSURE

The authors do not have any financial interest in the companies whose materials are included in this article.

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 (IL): 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. 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.
12. Abdullah MA. Inner canthal distance and geometric progression as a predictor of maxillary central incisor width. J Prosthet Dent 2002;88(1):16–20.
13. Ong E, Brown RA, Richmond S. Peer assessment of dental attractiveness. Am J Orthod Dentofacial Orthop 2006;130(2):163–9.
14. 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.
15. Andrews LF. The six keys to normal occlusion. Am J Orthod 1972;62(3):296–309.
16. Andrews LF. Straight wire: the concept and appliance. San Diego (CA): LA Wells Co.; 1989.
17. Watanabe K, Koga M. A morphometric study with setup models for bracket design. Angle Orthod 2001;71(6):499–511.
18. 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.
19. Tuverson DL. Anterior interocclusal relations. Part I. Am J Orthod 1980;78(4):361–70.
20. 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.
21. 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.
22. Mackley RJ. An evaluation of smiles before and after orthodontic treatment. Angle Orthod 1993;63(3):183–9.

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

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

25. Ghahferokhi AE, Elias L, Jonsson S, et al. Critical assessment of a device to measure incisor crown inclination. Am J Orthod Dentofacial Orthop 2002;121(2):185–91.

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. Ugur 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.

Reprint requests: Vishnu Raj, UHSCSA, Department of Orthodontics, 7703 Floyd Curl Drive, San Antonio, TX 78229-3900. Tel.: 919-259-2360; Fax: 210-567-2614; e-mail: rajv@uthscsa.edu