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Crown-Root Shape of the Permanent Maxillary Central Incisor

Grant T. McIntyre, BDS, FDS, MOrth, PhD;[a] Declan T. Millett, BDSc, DDS, FDS, MOrth[b]

ABSTRACT

This study aimed to determine whether the lateral cephalometric crown-root shape differs among the permanent maxillary central incisor in Class I, Class II division 1, Class II division 2 and Class III malocclusions and to identify the nature of any differences. Of the 499 lateral cephalograms recorded at a university orthodontic clinic during 2001, 361 satisfied the inclusion criteria. Sixty cephalograms were selected from the four malocclusion groups and were digitized in random order. The configurations of the 10 landmarks characterizing the crown-root shape of the permanent maxillary central incisor were then optimally superimposed using Procrustes algorithms. Discriminant analysis of the principal components of shape determined the incisor shape differences between the malocclusion groups. The crown-root shape of the permanent maxillary central incisor did not differ significantly among the Class I, Class II division 1, and Class III groups ($P > .05$); however, the crown-root shape of the Class II division 2 permanent maxillary central incisor was significantly different ($P < .001$) from that of the Class 1, Class II division 1 and Class III. The shape discrimination involved axial bending of the Class II division 2 incisors. Principal components 1, 2, and 3 accounted for 63% of the Class II division 2 incisor shape variance, encompassing a shorter root, a longer crown, and axial bending of the incisor, in addition to a reduced labiopalatal thickness. These shape features could precipitate the development of a deep overbite in Class II division 2 malocclusion and may limit the amount of palatal root torque during fixed appliance therapy.

KEY WORDS: Incisor shape, Malocclusion, Cephalometry, Morphometry.

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INTRODUCTION Return to TOC

The variability in tooth morphology is an important factor in achieving an aesthetic, functional, and stable Class I incisor relationship with orthodontic treatment.[1] The morphology of the permanent maxillary central incisors has been investigated in different malocclusion groups.[1–7] The angle formed by the intersection of the long axes of the crown and root (the crown-root angulation or collum angle) has been investigated most frequently using lateral cephalometric radiographs.[1,2,4–7] The labial surface angle and the lingual surface curvature of the permanent maxillary central incisor have also been measured on the lateral cephalogram,[1] whereas the labiopalatal thickness has been measured on study models.[3]

Previous cephalometric studies, however, have failed to completely characterize the morphologic features of the permanent maxillary central incisor in each of the different malocclusion groups. This is because nonrandom sampling techniques have been used, producing biased experimental groupings and relatively small numbers of subjects representing each malocclusion (Table 1). Furthermore, only two studies have sought to compare the crown-root angulation among *all* the incisor groups.[1,5]

The traditional method of measuring crown-root form on cephalometric radiographs involves measuring linear distances or angles (Table 1). These do not provide an assessment of the permanent maxillary central incisor shape because shape cannot be determined from measurement data.[8] Moreover, despite the lateral cephalogram being a standardized image, natural dental variation influences maxillary central incisor thickness, crown-root length, and the crown-root angulation. Intergroup comparisons of these measurements using parametric statistical techniques further compounds the "shape-from-size" problem because incisors with more deviant morphology may skew the data.

Morphometric techniques offer an opportunity to overcome the limitations of traditional cephalometric measurements because they integrate geometric location and biologic homology.[9] In addition, because size-standardization of all the landmark configurations is an essential step in shape-analysis, the effect of natural dental variation in traditional cephalometric analyses is eliminated.

The aims of this study were

- To determine whether the lateral cephalometric crown-root shape differs among the permanent maxillary central incisors in Class I, Class II division 1, Class II division 2, and Class III malocclusions.
- To identify the nature of any permanent maxillary central incisor shape differences among the malocclusion groups.

The null hypothesis tested was that there was no difference in the morphology of the permanent maxillary central incisor among Class I, Class II division 1, Class II division 2, and Class III malocclusions when assessed using the lateral cephalogram.

MATERIALS AND METHODS Return to TOC

From 499 lateral cephalograms recorded at a university orthodontic clinic during 2001, 135 were excluded for factors that would influence the permanent maxillary central incisor form or its visiospatial localization on a lateral cephalogram (Table 2). Furthermore, the records of three patients could not be located. Thus, 361 lateral cephalograms were available for this study. These were stratified into Class I (n = 71), Class II division 1 (n = 139), Class II division 2 (n = 60), and Class III (n = 91) groups by the incisor relationship[10] recorded in the clinical records by experienced orthodontists.

Sixty lateral cephalograms were randomly selected from the Class I, Class II division 1, and Class III groups. These and all 60 Class II division 2 lateral cephalograms were scanned at 300 dpi using a Heidelberg NewColor4000 flatbed scanner (Heidelberg CPS GmbH, Bad Homburg, Germany, www.hdcps.com/) attached to a DELL Dimension XPS T550 computer and DELL D1626HT (UltraScan 1600HS Series) 21-inch Color Graphics Display monitor (DELL, Round Rock, Tex, www.dell.com) to produce monitor-displayed digital cephalograms.

Each of the 240 lateral cephalograms was randomly selected and digitized using the on-screen package tpsDIG32 (ftp://life.bio.sunysb.edu/morphmet/tpsdigw32.exe) by one orthodontist with several years of experience in working with digital cephalograms. All images were digitized under identical conditions in the same room with all sources of extraneous background lighting eliminated. Digitization produced the x, y coordinates of 10 landmarks (Table 3) characterizing the form of the most labially placed maxillary central incisor. Where any concern existed as to incisor orientation, images were enlarged and the subject's study models were consulted. Magnification, however, was standardized during the recording, scanning, and digitizing of the cephalograms. Twenty-five percent of the images (n = 60) were redigitized one month later[11] to evaluate individual landmark intraoperator reproducibility.

Discriminant analysis of the principal components of shape

Before the shapes of the maxillary central incisors could be compared among the malocclusion groups, the landmark configurations were standardized using the APS software (version 2.4, www.cpod.com/monoweb/aps/aps.htm). This program uses Procrustes algorithms to scale the landmark configurations to uniform size, translating them to superimpose the centroids (the geometric midpoints), and iteratively rotating the configurations to minimize the squared differences between landmarks of the configurations.[12] This can be considered as the position of "best-fit" of the landmark configurations under consideration and allows shape information to be calculated precisely.

Statistical analysis

Quantifying random errors and systematic errors using the coefficient of reliability and a two-sample *t*-test, respectively, assessed landmark reproducibility. Following the Procrustes superimposition, the Procrustes mean (essentially the mean shape) was computed, and the displacement between each landmark and the Procrustes mean was calculated. This produced a matrix of Procrustes residuals for statistical analysis by a principal components of shape (PCS) analysis. The shape variance around the landmarks is shown in Figure 1, where the individual observations are plotted as vectors from the landmark-specific means.

Discriminant analysis of the PCS collated the structure of the data set as new variables—linear combinations of the original variables. Each new variable, a shape component, was a global movement of all the landmarks. The shape components were then sorted by order of decreasing magnitude with the null space being relegated to the trailing components. Multivariate regression and discriminant analysis were then applied to calculate the best linear combination of the PCs separating the experimental groups.

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Landmark reproducibility

All the landmarks were associated with random error values above 0.95, whilst none was associated with systematic errors with $P < .1$. These have previously been suggested as acceptable thresholds.[11,13]

Crown-root shape

The crown-root shape of the permanent maxillary central incisor in the Class II division 2 group was significantly different from that of the Class I, Class II division 1, and Class III groups (Table 4). The discrimination between the incisor shape of the Class II division 2 and the Class I, Class II division 1, and Class III groups is shown in Figure 2. In each of these three tests, the shape discrimination involved axial bending of the Class II division 2 maxillary central incisors, where the crown and root tip landmarks were displaced palatally, with the body of the incisor being displaced labially. There was no statistically significant difference in maxillary central incisor crown-root shape among the Class I, Class II division 1, or Class III groups ($P > .05$; Table 4).

In the Class II division 2 group, the first three PCs accounted for 63% of the shape variance (Figure 3). PC1 (27% of the variance) was characterized by a shorter root/longer crown, in addition to an element of axial bending. PC2 (22% of the variance) demonstrated marked axial bending of the incisor and a reduced labiopalatal thickness. PC3 (14% of the variance) was characterized by less marked axial bending of the Class II division 2 maxillary central incisor.

DISCUSSION Return to TOC

This study found that the crown-root shape of the permanent maxillary central incisor in Class II division 2 malocclusions differs from that of Class I, Class II division 1, and Class III malocclusions. The crown-root shape of the maxillary central incisor, however, was not significantly different among the Class I, Class II division 1, and Class III malocclusion groups.

In a cephalometric study of incisor morphology, the most significant sources of bias originate from sample selection and digitization. In this study, we aimed to minimize the effect of these variables. Therefore, lateral cephalograms were randomly selected from each of the Class I, Class II division 1, and Class III groups. However, because of the lower prevalence of Class II division 2 malocclusion,[14] all the Class II division 2 lateral cephalograms that satisfied our inclusion criteria were included. Furthermore, unlike Delivanis and Kuftinec[4] and Bryant et al,[1] we did not specifically select severe cases of each malocclusion type. Nonetheless, marked central incisor rotations and subdivision malocclusions were present in six cases. Their exclusion is unlikely to have biased our results.

Where the lateral cephalometric image clarity was such that all 10 permanent maxillary central incisor landmarks were not clearly identifiable, the image was excluded from the study. Despite this, the ability to identify and digitize the central incisor and not the lateral incisor in typical Class II division 2 cases was of particular concern. Therefore, image magnification and study models assisted in the orientation of the incisors, where there was any uncertainty. None of the landmarks, however, were associated with significant systematic or random errors.

The shape characteristics of the Class II division 2 permanent maxillary central incisor involved axial bending and a reduced labiopalatal thickness. This is in accordance with previous studies.[1–5,7] Furthermore, a shorter root and a longer crown were also identified as important characteristics of the Class II division 2 permanent maxillary central incisor. No previous cephalometric study has investigated this crown-root relationship among all the incisal classes. This parameter could prove to be important in the etiology and management of Class II division 2 malocclusions. No significant incisor shape difference was found between our Class III group and any of the other malocclusion groups. This conflicts with the findings of Harris et al.[6] Despite excluding Class II division 2 cases from their sample, they detected a difference in the crown-root angulation of Class III maxillary central incisors in comparison with Class I and Class II division 1 incisor relationships.

The possible reasons for the differences between the results of the study reported here and those reported in previous studies are several. First, in the present study, equal numbers of cases were selected from each of the malocclusion groups. Second, cases were randomly selected and then randomly digitized. We also applied a morphometric analysis to assess the *shape* of the maxillary central incisor (the information independent of size, location, and orientation).

Despite the advantages of the morphometric technique used in this study, boundary outline techniques have been proposed as alternatives.[15] However, the use of elliptical Fourier function analysis (EFFA) would have precluded the two midpulpal points necessary to optimize the shape information on shape from the Procrustes superimposition. Furthermore, because EFFA operates using the outline of the object under consideration, this would have necessitated the inclusion of the peripheral landmarks used in this study. On the other hand, medial axis analysis would be even more limited, only providing information on the shape of the regions of directional change in the boundary outline.[16]

The Class II division 2 permanent maxillary central incisor shape features are of importance in the development of this malocclusion. The combination of crown retroclination, reduced labiopalatal thickness, and poorly developed cingulae[1,3] predispose to an increase in the interincisal angle and a deep overbite.[17] During root formation, the crown-root angulation of permanent maxillary central incisors may change.[18] However, two-thirds of the root is mineralized before the central incisor erupts.[19] Therefore, any alteration in the direction of the developing root would only influence the apical third. This would only produce a dilaceration rather than axial bending of the maxillary permanent central incisor. Consequently, attempts to correct the permanent maxillary central incisor crown retroclination during the mixed dentition will neither prevent nor reduce the severity of a potential crown-root axial deviation. More importantly, this may result in iatrogenic damage to the immature roots of these teeth.

The maxillary central incisor shape variance in our Class II division 2 group was greater than that in the other malocclusion groups. Williams and Woodhouse[5] found a 29° range in the crown-root angle of their Class II division 2 group, which was greater than that of their Class I, Class II division 1, and Class III groups. Sixty-three percent of our Class II division 2 group variance involved crown-root axial bending of the incisor. This factor limits the amount of third order movement required to achieve a normal interincisal angle of 135° and a normal relationship of the mandibular incisor tip to the maxillary central incisor centroid. These factors are important in promoting posttreatment stability.[17,20]

Furthermore, the relative inferior displacement of the Class II division 2 maxillary permanent central incisor, accounting for 27% of the variance in our study, indicates overeruption. Intrusion mechanics in combination with palatal root torque to correct the incisor relationship increase the likelihood of marked root resorption[21] and should be discussed with patients before commencing orthodontic treatment.

Where a marked crown-root displacement of the maxillary permanent central incisor is evident on a pretreatment lateral cephalogram, a prediction tracing should be conducted. This may be undertaken using a template of the incisor oriented in the predetermined end of treatment position to ascertain whether the intended tooth movement is feasible or whether the incisor apex would perforate the palatal cortex. Furthermore, where aberrant permanent maxillary central incisor morphology is identified on the pretreatment radiograph, a midtreatment radiograph should be evaluated to determine the amount of root movement possible within the limits of the alveolus.

CONCLUSIONS Return to TOC

The crown-root shape of the permanent maxillary central incisor is similar in Class I, Class II division 1, and Class III malocclusions. However, the crown-root shape of the Class II division 2 permanent maxillary central incisor differs significantly from that of the other malocclusion groups. These shape features involve a shorter root, a longer crown, and axial bending of the incisor, in addition to a reduced labiopalatal thickness.

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TABLE 1

	n	Class I	Class II Division 1	Class II Division 2	Class III	Measurements	Comments
Bryant et al[1]	100	25	25	25	25	Crown/root angle, Labial surface angle	Only included "severe" cases Priority given to images with "optimal sharpness and clarity"
Nicol[2]	24	0	12	12	0	Lingual curvature	Only compared Class II division 1 with Class II division 2
Delivanis and Kuftinec[4]	106	17	27	53	9	Collum angle	Class I, Class II division 1, and Class III data pooled for comparison with "severe" Class II division 2 cases only
Williams and Woodhouse[5]	191	65	66	29	31	Crown/root angle	Cephalograms selected having "clarity of upper central incisors"
Harris et al[6]	79	24	34	0	21	Collum angle	Class II division 2 cases excluded
Korda et al[7]	43	0	16	27	0	Crown length, root length	Cephalograms recorded using two different cephalostats
						Ratio of root length/crown length and root/crown angle	Only compared Class II division 1 with Class II division 2

TABLE 2. Exclusion Criteria

Reason(s) for Exclusion	Number
Mixed dentition/supernumerary teeth	24
Hypodontia	4
Subdivision malocclusions	3
Orofacial clefting/craniofacial syndromes	16
Midorthodontic treatment cephalogram/previous orthodontic treatment	42
Edentulous (image obtained for implantology)	20
Previous restorative (including endodontic) treatment	2
Previous incisor trauma/dilacerated incisors	6
Digit-sucking/nail-biting/pen chewing habits	2
Poor incisor definition due to superimposed teeth, incisor rotations, or inferior image quality	16
Total images excluded	135

TABLE 3. Permanent Maxillary Central Incisor Cephalometric Landmarks

Landmark	Definition
1	Incisor crown tip
2	Incisor root apex
3	Palatal amelocemental junction
4	Labial amelocemental junction
5	Midpulpal point on the line between the labial and palatal amelocemental junction
6	Midroot point on the palatal surface
7	Midroot point on the labial surface
8	Midpulpal point on the line between the labial and palatal midroot points
9	Most concave aspect of the cingulum
10	Most convex aspect of the labial surface of the crown

TABLE 4. Comparative Discriminant Analysis of the Principal Components of Shape Between the Malocclusion Groups

Malocclusion groups compared	R^2 value	F value	P value
Class I/Class II division 1	.001	0.055	.982
Class I/Class II division 2	.247	12.513	***[a]
Class I/Class III	.043	0.747	.161
Class II division 1/Class II division 2	.359	18.377	***[a]
Class II division 1/Class III	.049	0.988	.120
Class II division 2/Class III	.310	17.115	***[a]

[a] *** $P < .001$.

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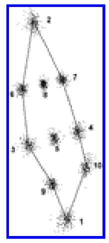
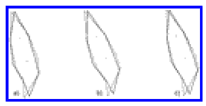


Click on thumbnail for full-sized image.

FIGURE 1. Shape variance.



Click on thumbnail for full-sized image.

FIGURE 2. Discrimination among malocclusion groups (solid line represents Class II division 2) (a) Class I/Class II division 2. (b) Class II division 1/Class II division 2. (c) Class III/Class II division 2.

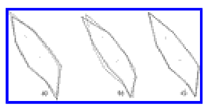


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FIGURE 3. Class II division 2 principal components (solid line represents PC under examination). (a) Principal component 1. (b) Principal component 2. (c) Principal component 3.

[a]Orthodontic Department, Unit of Orthodontics, Glasgow Dental Hospital and Dental School, 378 Sauchiehall Street, Glasgow, UK

[b]Senior Lecturer/Honorary Consultant in Orthodontics, Unit of Orthodontics, Glasgow Dental Hospital and Dental School, Glasgow, UK

Corresponding author: Grant T. McIntyre, BDS, FDS, MOrth, PhD, Orthodontic Department, Unit of Orthodontics, Glasgow Dental Hospital and Dental School, 378 Sauchiehall Street, Glasgow G2 3JZ, UK (E-mail: granttmcintyre@hotmail.com)
