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Morphometric analysis of the maxillary root apex positions according to crowding severity

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Abstract

Objectives—To determine differences in arch forms derived from the root apices locations between individuals with <2 mm maxillary crowding and controls.

Setting and Sample Population—The Department of Orthodontics, Pusan National University. Cone-beam computed tomography (CBCT) images of 102 patients in the control group and 95 patients in the crowding group.

Materials and Methods—*X*, *Y* and *Z* coordinates of the tip of the crowns and the apex of the root of the maxillary teeth (except second molars) were determined on the CBCT images. The acquired three-dimensional (3D) coordinates were converted into two-dimensional (2D) coordinates via projection on the palatal plane, and the Procrustes analysis was employed to process the converted 2D coordinates. The mean shape of the arch form derived from the location of the tip of the crowns and the apex of the root was compared between groups using the statistical shape analysis.

Results—There was a statistically significant difference ($P = .046$) between the groups for the mean shape of the root apex arch form, but the difference was small and clinically irrelevant as it is minor compared to the degree of crowding.

Conclusions—Maxillary arch form at the level of the maxillary apices only shows minor differences between crowded and non-crowded dentitions.

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CONFLICT OF INTEREST

None declared.

Keywords

cone-beam computed tomography; crowding; dental arch; procrustes superimposition

1 | INTRODUCTION

Dental arch form is one of the most important factors not only in dental stability, occlusion and aesthetics but also in orthodontic diagnosis and establishment of a treatment plan. It is also assumed that during levelling and alignment, there is no change in arch form at the level of the apices of the roots (root apex arch form) despite the displacement of the tooth crowns due to crowding.¹ Until now, most research on the dental arch form has concerned arch form at the level of the crowns of the teeth (crown arch form) or basal bone arch form; studies on the root apex arch form have been very rare.^{2–5} Recent progress in cone-beam computed tomography (CBCT) has made root apex studies possible in living individuals.⁶ The research considering crown arch forms includes the use of facial axis points (FA); the research considering the basal bone arch form includes the use of mucogingival junction points or root centre points.^{2–5} However, the arch form constructed from these points is measured from two-dimensional models. As the positions of root apices are three-dimensional, root apex points should be measured three-dimensionally and projected onto the reference plane (eg, palatal plane, occlusal plane) to construct the arch form accurately.

Tooth eruption can be classified into four stages: pre-eruptive movement, intraosseous movement, mucosal penetration and pre-occlusal movement.⁷ Tooth location is influenced by multiple factors in different stages of tooth eruption. The location of the tooth germ, where the growth of the tooth starts, is thought to be genetically determined.⁸ Fukase reported that according to the species-specific size balance of available space, the tooth crypt had a relative position during growth.⁹ Also, Scott reported that alignment of the dental lamina and the tooth germ during the embryonic period is maintained in a form of catenary curve.¹⁰ However, the prenatal shape of the dental arch is progressively changed. Variability of location can easily occur due to multiple factors. During intraosseous movement, factors such as the existence of proximal teeth, root resorption and/or premature loss of deciduous teeth, local lesions and growth of alveolar bone influence the location of teeth after eruption.^{11,12} The location of the root apex, considered to be the location of the tooth germ, does not vary to the extent that the position of tooth crowns may. In this regard, Proffit et al. asserted that “In nearly every patient with mal-aligned teeth, the root apices are closer to the normal position than the crowns, because malalignment almost always develops as the eruption paths of teeth are deflected. Putting it another way, a tooth bud occasionally develops in the wrong place, but the root apices are likely to be reasonably close to their correct positions even though the crowns have been displaced as the teeth erupted”.¹ To summarize, although complex dental crowding may occur, the location of root apices is speculated to have a regular arch form. However, there is no research supporting that assumption.

The purpose of this study was to examine differences in root apex and crown tip maxillary arch forms in dentitions with and without maxillary crowding using CBCT.

2 | MATERIALS AND METHODS

2.1 | Sample

This study was a retrospective comparative study and was reviewed and approved by the Institutional Review Board of Pusan National University Dental Hospital (PNUDH-2015-028).

The sample was selected from a group of adult patients who visited the Department of Orthodontics in Pusan National University Dental Hospital and who had a CBCT for a non-orthodontic reason and a plaster model for diagnosis. Exclusion criteria were a history of impacted teeth, supernumerary teeth, cleft lip and palate, trauma history or any syndrome.

We measured the degree of maxillary crowding by tooth size-arch length discrepancy calculations which were performed on each plaster model by manual methods using callipers. Selected patients were classified according to the observed degree of maxillary crowding.^{2,5,13} An overview of the sample is given in Table 1.

2.2 | Data acquisition

The CBCT (Pax-Zenith3D, Vatech Co., Seoul, Korea) settings were as follows: tube voltage, 90 kVp; scan time, 24 seconds; tube current, 4 mA; voxel size, 0.3 mm; and FOV, 20 cm × 19 cm. CBCT data were converted and saved as DICOM files, and the relevant *X*, *Y*, *Z* coordinates to locate the maxillary teeth's root apices and crown tip were obtained in the multiplanar reformation (MPR) mode of Ondemand3D (Cybermed Inc., Tustin, CA, USA) program.

2.3 | *X*, *Y*, *Z* coordinates for landmarks

We defined Nasion, which was the reference-point origin (0, 0, 0), as the most anterior limit of the frontonasal suture on the frontal bone in the facial midline and the CBCT scan was oriented with the palatal plane horizontal. We identified the palatal plane by 3 landmarks (ANS and the centre of the greater palatine foramen on the right and left sides).

The acquired coordinates of maxillary crown tips and root apices for analysis are as follows (Figure 1).

2.3.1 | Crown tip (C followed by tooth number)—C11, C12, C21, C22 (teeth 11, 12, 21, 22's middle point of the incisal edge of the crown), C13, C23 (tooth 13, 23's crown tip), C14B, C15B, C24B, C25B (buccal cusp tip of the crown of tooth 14,15,24,25), C16 MB, C26 MB (mesiobuccal cusp tip of the crown of tooth 16,26)), C16DB, C26DB (distobuccal cusp tip of the crown of tooth 16, 26).

2.3.2 | Root apex (A followed by tooth number)—A11, A12, A13, A21, A22, A23 (root apex of tooth 11, 12, 13, 21, 22, 23); A14B, A24B (buccal root apex of tooth 14, 24); A14P, A24P (palatal root apex of tooth 14, 24); A15, A25 (root apex of tooth 15, 25); A16 MB, A26 MB (mesiobuccal root apex of tooth 16, 26); A16DB, A26DB (distobuccal root apex of tooth 16, 26); A16P, A26P (palatal root apex of tooth 16, 26).

The second molars were excluded from the analysis because of the inability to ensure complete eruption in patients of all ages.

All measurements were performed by one observer. Landmarks of forty randomly selected cases were re-assessed after an interval of at least 1 month to determine the intra-examiner reliability. Differences were tested with the paired *t* test.

2.4 | Arch form for crown tip and root apex

Arch forms for crown tips were constructed using C11, C12, C13, C14B, C15B, the mid-point of C16 MB and C16DB, C21, C22, C23, C24B, C25B, and the mid-point of C26 MB and C26DB (Figure 2).

Arch forms for root apices were constructed using A11, A12, A13, the mid-point of A14B and A14P, A15, the mid-point of A16 MB, A16DB and A16P, A21, A22, A23, the mid-point of A24B and A24P, A25, the mid-point of A26 MB and A26DB, and A26P (Figure 3).

For maxillary premolars or molars, the number of roots can vary from two to three; thus, in those cases, the mid-point of root apices was used as the landmark point (see Figure 3).

2.5 | Comparison of crown tip and root apex arch forms between groups

Two-dimensional (2D) coordinates were converted from acquired three-dimensional (3D) coordinates via projection on the palatal plane. To convert 3D coordinates to 2D coordinates, the Matlab software (version 2014b, MathWorks Inc., MA, USA) was used. Thereafter, the Procrustes superimposition was used to process the converted two-dimensional coordinates and derive the mean shapes of crown tip and root apex arch forms; the centroids of each sample were translated and scaled, then rotated and superimposed.¹⁴ The comparison of mean shapes between the two groups uses the shape comparison method of statistical shape analysis.¹⁴ The shape analysis uses an *F* test under the assumption of multivariate normal distribution. Multivariate normal distribution may be assumed for data from patients with normally spaced teeth, but that assumption may not be true for data from patients with crowded teeth. Therefore, this study used the bootstrap test proposed by Amaral et al. to compare mean arch form shapes between the two groups.¹⁵ A bootstrap test involved 10 000 resamplings with replacement from each sample; a *P*-value of <.05 was considered significant. All analyses were conducted using “shapes” package in the R language (Vienna, Austria).

We assessed the differences in arch form between the control and the crowding groups by calculating the average Procrustes and Euclidean distances of each corresponding landmark from acquired mean shapes of root apex arch forms of the two groups. The Mann-Whitney *U* test was used to compare each landmark between groups. All statistical analyses were performed with R language.

3 | RESULTS

3.1 | Measurement error

The mean differences between the first and second assessments of the landmarks varied from 0.12 to 0.25 mm. The paired t test showed no significant difference ($P > .05$) between the two sets.

3.2 | Comparison of crown tip and root apex arch forms between the control and crowding groups

The mean shapes of crown tip and root apex arch forms were derived using projected two-dimensional coordinates utilizing the Procrustes analysis (Figure 4). Differences in arch forms derived from the crown locations between the control and crowding groups were shown ($P < .001$). The same holds true for differences in arch forms derived from the root apex locations ($P = .046$).

3.3 | Procrustes and Euclidean distances of root apex corresponding landmarks from mean root apex arch form

To clarify variability of corresponding landmarks from mean arch forms between the two groups, we calculated average Procrustes distances and Euclidean distances of each corresponding landmark from the mean shape and configuration (Table 2 and 3).

The average difference of Euclidean distance between the two groups was small ranging from 0.0113 to 0.3010 mm.

4 | DISCUSSION

Using arch forms, this study compares and analyses the location of the root apex and crown in a trajectory line of eruption, which is the process of tooth eruption that starts at the location of tooth germ. It has been reported that embryonic alignments of the dental lamina and tooth germ occur in a catenary curve.¹⁰ However, the dental arch is known to change continually before birth. After eruption, tooth location can alter due to extrinsic factors including muscular function of the lips, cheeks and tongue and pernicious oral habits, or due to loss of dental substance because of dental caries or tooth extraction. In the eruption stage of pre-occlusal movement, tooth location is determined by complex occluding forces. The shape and locations of the crowns that are expressed after tooth eruption are a result of complex influences of genetic and environmental factors.^{11,12,16}

For analysis, locations of the root apex and crown of each tooth were converted from three-dimensional coordinates to two-dimensional coordinates and their arch forms were expressed in mean shapes and comparatively analysed. For the comparison of mean shapes between the two groups, we used the shape comparison method of statistical shape analysis.¹⁴ Shape analysis is based on Procrustes analysis. Procrustes analysis is a form of statistical shape analysis used to analyse the distribution of a set of shapes. To compare the shapes of two or more objects, the objects must be first optimally superimposed. Procrustes superimposition is performed by optimally translating, rotating and uniformly scaling a given configuration of each object. We can estimate a mean shape of any group from

Procrustes superimposition of the objects in that group, but the statistical shape analysis is required to compare the mean shapes of different groups. That is, the statistical shape analysis is the comparing method of the mean shapes of two groups by utilizing the shape information without the influences of translating, scaling or rotating from a given configuration.¹⁴

We conducted adequate resampling with replacement (bootstrapping) from the provided samples for generalization of the test results because normal distribution may not be true for data from patients with crowded teeth. Bootstrapping is the estimating or testing method by measuring properties of an estimator when sampling from an approximate distribution and is an appropriate way to control and check the stability of the results.

There is a statistically significant difference in crown tip arch forms between the controls and the crowding group (Figure 4). This result is expected, as the two groups are classified based on the degree of dental crowding. Most studies of occlusal traits have reported that genetic variation is correlated with phenotypic variation for arch width and arch length. However, the size and shape of the dental arch are also more closely associated with environmental factors than with genetic factors.¹⁷ As many occlusal traits reflect combined variations of tooth eruption and alveolar growth, these crown tip arch forms may be more variable than the supporting structures involving root apex arch forms.¹⁸

As the P -value for root apex arch forms was $<.05$ ($P = .046$), there was a statistically significant difference in the mean shape of the root apex arch forms of the two groups. However, in Figure 4, the difference is hard to recognize. This is because means for variation in shape are presented. In this study, the distance between each corresponding landmark in mean shapes has been calculated to clarify the difference of root apex arch forms and the two groups have been compared. In conclusion, in both Procrustes distance and Euclidean distance, two groups have shown differences in the position of the right maxillary canine and first premolar ($P < .05$). The average difference of Euclidean distance between the two groups, however, was small, ranging from 0.0113 to 0.3010 mm. Also, considering that crowding in the normal group is -0.5 ± 1.3 mm compared to -6.3 ± 4.3 mm in the crowding group, the disparity of root apex arch form shape between the two groups can be considered as clinically irrelevant.

As tooth growth is dependent to some extent on genetics, the location of teeth changes due to different factors in different stages. Gomez-Robles and Polly asserted that despite common developmental and morphogenetic pathways, each tooth can be regarded on a small scale as a different developmental module because tooth germs develop independently.¹⁹ However, even though development and eruption of each tooth are independent, modern human teeth have been reported to display consistent relative anterior and posterior locations.⁹ As Proffit argues, this consistent location is the reason why levelling and alignment of orthodontic treatment have been relatively easy.¹ Although the crown is displaced as the teeth erupt, the root apex remains near the original correct location. As shown in this study, although the shape of the crown tip arch form of crowded teeth shows severe displacement, the overall shape of the root apex arch form of crowded teeth is little different from that of normally spaced teeth.

This study has some limitations. First, skeletal pattern was not taken into consideration. A second limitation of this study is its use of only the palatal plane of the maxilla as the reference plane for the root apices' arch forms; other planes (eg, the occlusal plane) should be considered as well. Finally, as data from patients with transposed or impacted teeth, which appeared to be a developmental anomaly with genetic determinant, were not included in this study, further research is required.

A11	A21	A22	A23	A24	A25	A26
0.015 ± 0.008	0.015 ± 0.008	0.015 ± 0.008	0.017 ± 0.008	0.012 ± 0.007	0.014 ± 0.008	0.013 ± 0.009
0.016 ± 0.011	0.016 ± 0.009	0.019 ± 0.014	0.019 ± 0.010	0.013 ± 0.008	0.017 ± 0.011	0.015 ± 0.009
0.001	0.001	0.005	0.002	0.001	0.004	0.002
.8738	.6886	.0430*	.1383	.2852	.0146	.1634

A11	A21	A22	A23	A24	A25	A26
1.521 ± 0.764	1.519 ± 0.810	1.471 ± 0.823	1.669 ± 0.845	1.214 ± 0.667	1.383 ± 0.796	1.347 ± 0.880
1.578 ± 1.066	1.530 ± 0.875	1.849 ± 1.322	1.819 ± 0.926	1.288 ± 0.756	1.657 ± 1.032	1.486 ± 0.880
0.058	0.0113	0.378	0.149	0.0741	0.2737	0.1395
.719	.838	.1199	.3510	.595	.055	.393

5 | CONCLUSIONS

We used CBCT data to acquire root apex coordinates of patients with >2 mm of maxillary crowding and compared the maxillary root apex arch forms with controls (<2 mm of crowding). Although there was a statistically significant difference between the mean shapes of the root apex arch form of both groups, the difference was small and clinically irrelevant as it is minor compared to the degree of crowding. Thus, even if a tooth crown shows severe displacement that results in tooth crowding, our study demonstrates that the root apices of crowded teeth are not in a crowded position.

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FIGURE 1.

CBCT image indicating crown tip and root apex of each tooth, as determined with Ondemand3D software. (A) Root apex, (B) crown tip [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 2.

Landmarks and arch form for crown tips. (A) Landmarks, (B) arch form [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 3.

Landmarks and arch form for root apex. (A) Landmarks, (B) arch form [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 4.

Mean shape of the maxillary arch constructed from locations of the crown tips and root apices. (A) Arch form derived from the crown tips, (B) arch form derived from the root apices [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1

Distribution of the sample

	Control group maxillary crowding < 2 mm	Crowding group maxillary crowding > 2 mm
N total	102	95
Male (N)	43	63
Female (N)	59	32
Mean age, SD (y)	23.2 ± 4.0	24.0 ± 5.1
Mean crowding, SD (mm)	-0.5 ± 1.3	-6.3 ± 4.3
Angle classification (N)		
Class I	20	24
Class II	7	5
Class III	75	66

TABLE 2

Procrustes distances for corresponding landmarks of the mean root apex arch form

Tooth	A16	A15	A14	A13	A12
Controls	0.014 ± 0.007	0.015 ± 0.009	0.011 ± 0.006	0.016 ± 0.008	0.015 ± 0.008
Crowding group	0.017 ± 0.009	0.017 ± 0.009	0.014 ± 0.007	0.020 ± 0.011	0.019 ± 0.011
Difference	0.003	0.002	0.003	0.004	0.004
<i>P</i> -value	.0116 *	.1841	.0025 *	.0091 *	.0205 *

* *P* < .05, Mann-Whitney *U* test.

TABLE 3
Euclidean distances for each corresponding landmark of the mean root apex arch form

	A16	A15	A14	A13	A12
Controls	1.434 ± 0.723	1.519 ± 0.917	1.147 ± 0.593	1.659 ± 0.780	1.486 ± 0.843
Crowding group	1.681 ± 0.851	1.618 ± 0.904	1.389 ± 0.697	1.953 ± 1.023	1.787 ± 1.064
Difference	0.247	0.099	0.243	0.294	0.301
<i>P</i> -value	.0520	.4228	.0140 *	.0432 *	.0768

* *P* < .05, Mann-Whitney *U* test.