Original Article

Morphometric and volumetric analysis of the proximity between the incisive canal and maxillary central incisors during anterior retraction: a retrospective cone-beam computed tomography study

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ABSTRACT

Objectives: To elucidate the relationships and factors affecting the proximity between the incisive canal (IC) and maxillary central incisors and to predict the probable outcomes after anterior tooth retraction using cone beam computed tomography (CBCT).

Materials and Methods: Retrospective CBCT data taken before and after maxillary anterior retraction in 36 patients were used in this study. The incisive canal length (ICL), maxillary central incisor length (TL), angles between the palatal plane and axes of the maxillary alveolar border (θ1), IC (θ2), and maxillary central incisor (θ3), retraction distance (TDE), distance from the maxillary central incisors to the IC (D), cross-sectional area of the IC (CSA), and volume of the IC were evaluated. Comparison of the parameters between contact and noncontact groups were examined. Logistic regression was performed to analyze the probable outcome prediction.

Results: All parameters significantly decreased after anterior retraction, except for the ICL. Eighteen roots in 12 patients contacted the IC. The θ1, θ2, θ3, and D values at all levels were significantly lower, whereas the TDE, midlevel and oral opening CSA, and volume were significantly higher in the contact group compared with the noncontact group. The larger the pretreatment θ1 and θ3 were, the higher was the chance of incisors not contacting the IC.

Conclusions: Maxillary central incisors not contacting the IC after anterior retraction was positively associated with larger degrees of pretreatment maxillary alveolar bone angle and maxillary central incisor angle. (*Angle Orthod.* 2023;93:159–167.)

KEY WORDS: Incisive canal; Anterior retraction; Cone beam computed tomography; Orthodontic tooth movement; Envelope of discrepancy

INTRODUCTION

The ideal goals of orthodontic treatment include achieving a harmonious smile, properly functional occlusion, and good facial esthetics.[1] Therefore, protrusion of maxillary incisors is a frequent chief complaint of patients in orthodontic practice. The three-dimensional

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integration of maxillary incisors and the surrounding structural examination is an essential procedure for orthodontic diagnosis and treatment planning.

The limits of orthodontic tooth movement were introduced by Ackerman and Proffit as a concept of "envelope of discrepancy," which presented a graphic illustration of the possible tooth movement range.[2,3] Regarding maxillary incisor retraction, when using orthodontic treatment alone, clinical guidelines recommend 7 mm as the maximum distance for retraction.

The incisive canal (IC) is an anatomic structure that runs parallel to and between the maxillary central incisors and palatal cortical plate on the median plane of the maxilla. It contains the nasopalatine nerve and vessels, branches of the trigeminal nerve, and the maxillary artery, surrounded by thick cortical bone.[4–6] Owing to its proximity to the maxillary incisors, care should be taken to prevent iatrogenic effects in the IC and maxillary incisors such as sensory impairment,[5,7] and root resorption.[8,9]

Generally, conventional two-dimensional radiographs have been performed for diagnosis and treatment planning. However, the IC, cortical plate, and alveolar bone housing on the premaxilla cannot be precisely examined with two-dimensional imaging alone. Cone beam computed tomography (CBCT) could dramatically facilitate craniofacial structure determination and precisely identify the IC position and configuration.[10] Several studies evaluated the maxillary incisors and surrounding structures by superimposition of pre- and postretraction CBCT images.[9,11,12] However, the analysis of morphometric and volumetric measurements of the proximity between the IC and maxillary central incisors after maxillary anterior tooth retraction remains inconclusive.

Currently, the prediction of treatment outcome after maxillary anterior tooth retraction is still limited. Pretreatment cephalometric analysis leading to a plausible, customized treatment plan for an individual patient would be beneficial and prevent adverse effects. Thus, this study aimed to elucidate the relationships and factors affecting the proximity between the IC and maxillary central incisors and to predict the probable outcomes after anterior tooth retraction using CBCT.

MATERIALS AND METHODS

This retrospective study was approved by the Institutional Ethical Committee of Tokyo Medical and Dental University (TMDU) (approval numbers: 1254 and D2015-619-04) and conducted in accordance with the tenets of the Declaration of Helsinki. Informed consent was obtained from all patients before the CBCT was taken.

First, retrospective screening was performed in the archive database for all patients older than 18 years who had pretreatment (T1) and posttreatment (T2) CBCT after maxillary anterior tooth retraction from May 2011 to March 2019. All the subjects had impacted mandibular third molars. The CBCTs were taken as follow-up for giving instruction to the patients regarding extraction of the impacted third molars at the Orthodontic Clinic at Tokyo Medical and Dental University Dental Hospital. The CBCT field of view included the area from the maxilla to mandible. This study included patients who underwent orthodontic treatment with upper premolar extraction and performance of en masse retraction of the anterior teeth. The exclusion criteria were: (1) previous history of orthodontic treatment, (2) missing or supernumerary maxillary incisors, (3) nasopalatine pathology, (4) trauma to maxillary incisors, (5) prosthodontic treatment of maxillary incisors, (6) maxillary dental midline deviation greater than or equal to 2 mm from facial midline, (7) congenital anomalies (eg, cleft lip and palate), and (8) severe distortion of CBCT images. In total, 36 patients with an overall mean age of 22.2 $\pm$ 5.3 years (age range: 18–38 years) were included. The CBCT images were taken at two different times (T1–T2). The mean difference between T1 and T2 was 16.6 $\pm$ 11.6 months.

CBCT (Finecube; Yoshida Dental Manufacturing, Tokyo, Japan) images were captured using normal mode (4.10 mGy, 90 kV, and 4 mA), scanning time of 16.8 s, slice thickness of 0.147 mm, field of view of 81 $\times$ 74 mm, and voxel size of 0.146 mm. Imaging was performed with Frankfort horizontal plane parallel to the floor. The obtained images were saved as Digital Imaging and Communication in Medicine (DICOM) files, then constructed and analyzed using analysis software (OsiriX; Pixmeo, Geneva, Switzerland). Three-reference plane registration (axial, sagittal, and coronal planes) was identified. Then, the reference planes were coordinated and maxillary superimposition was performed automatically by the software using the best-fit method to ensure that the CBCT images were consistently reoriented and reproducible regarding the different anatomical landmarks prior to measurement (Figure 1).[13,14]

In the midsagittal plane, linear and angular measurements were performed as described in a previous study[15] as follows: incisive canal length (ICL), defined as the distance from center of nasal to oral opening of IC; maxillary central incisor length (TL); and angles between the palatal plane and axes of the maxillary alveolar border (θ1), IC (θ2), and maxillary central incisor (θ3) (Figure 2A, 2B).

The CBCT regional maxillary superimposition between T1 and T2 images was registered on the maxilla,

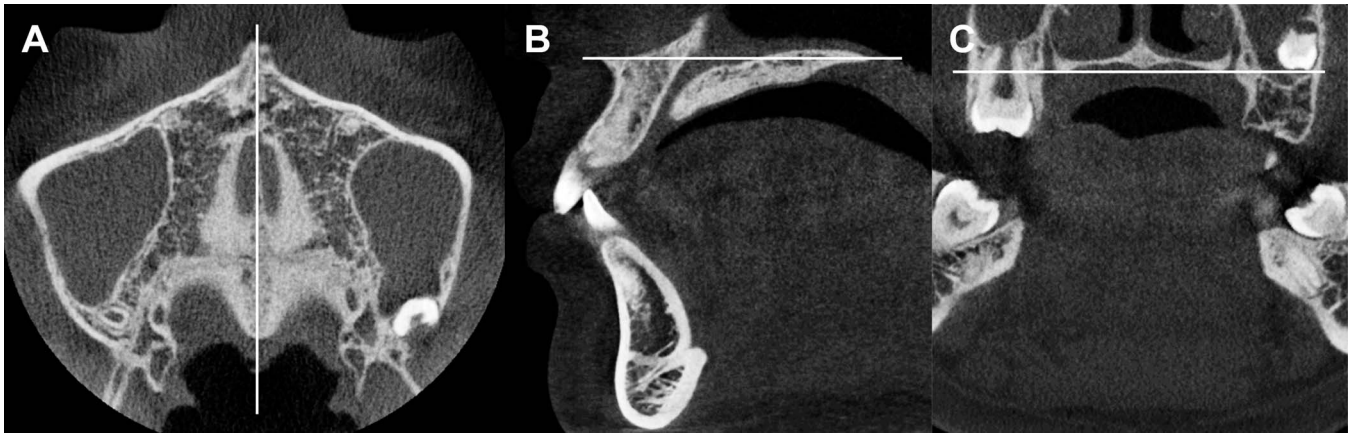

Figure 1. Reference planes. (A) Axial plane: the plane passing through the midpalatal suture, including ANS–PNS. (B) Sagittal plane: the palatal plane, including ANS–PNS, perpendicular to the axial plane. (C) Coronal plane: the most inferior plane of the nasal floor passing through the right and left greater palatine foramina. ANS: anterior nasal spine; PNS: posterior nasal spine.

according to previous studies,[13,14] to confirm the 3D configuration and measure the amount of maxillary central incisor tooth displacement at the incisal edge (TDE) before and after active treatment (Figure 2C).

In the axial plane, four vertical levels were defined parallel to the palatal plane: nasal opening (n); root apex level (r); midlevel (mid); and oral opening (o) of the IC[15] (Figure 3A). Distances from the maxillary central incisors to the IC (D) were measured at three levels: D_r, D_{mid}, and D_o. The left and right maxillary central incisor (U1) values were measured separately. If U1 contacted or entered into the IC, the D value was considered as 0 mm. Teeth with only one of the D values being 0 mm were classified as a contact group, whereas teeth that did not meet the contact group criteria were classified as the noncontact group. Additionally, the cross-sectional area of the IC (CSA) was observed at each level (CSA_n, CSA_r, CSA_{mid}, and CSA_o) (Figure 3B).

3D construction with volume rendering of the IC was performed automatically by the software to separate the IC and surrounding structures, followed by reconstruction and automated computation of the internal volume of the IC (Figure 4).

Statistical Analysis

Sample size was calculated using *t* test by G*Power 3.1.9.7 (Franz Faul, Universität, Kiel, Germany) according to mean ± standard deviation (SD) of the distance between U1 and the IC of contact and noncontact groups (2.30 ± 1.20 mm and 1.07 ± 1.16 mm, respectively) from a previous study.[9] By using a type 1 error of 0.05 and a power of 0.80, it was estimated that at least 10 subjects per group were needed.

All statistical analyses were performed using statistical software (IBM SPSS Statistics Version 22.0, IBM, Armonk, NY, USA). The results are presented as the mean ± SD. Descriptive statistics were obtained for all parameters. Paired *t*-test was used to compare the data obtained before and after maxillary anterior tooth retraction. Independent *t*-test was used to evaluate factors affecting U1 contacting the IC between the contact and noncontact groups. Logistic regression was used to calculate the noncontact probability of U1 with the IC after anterior retraction. The final model fit was assessed using the Hosmer–Lemeshow goodness-of-fit test. Intraclass correlation coefficient (ICC) was used to analyze intraexaminer reliability by 10 randomly selected patients that were remeasured at a one-month interval. The interexaminer reliability was evaluated by comparing the measurements between an experienced radiologist and the investigator. The ICC values for all measurements ranged between 0.91 and 0.94 (values greater than 0.90 indicate excellent reliability). All measurements were performed by a single examiner. A *P* value less than .05 was considered statistically significant.

RESULTS

The descriptive values and mean differences in linear, angular, area, and volume CBCT measurements before and after maxillary anterior tooth retraction are shown in Table 1. All parameters significantly decreased after anterior retraction, except for the ICL.

According to the IC analysis (Table 2), 12 of 36 patients had U1 contact with the IC. Regarding the proximity between U1 and the IC, the following measures were significantly different between the two groups: θ1, θ2, CSA_{mid}, CSA_o, and volume. θ1 of the contact group was significantly lower than the noncon-

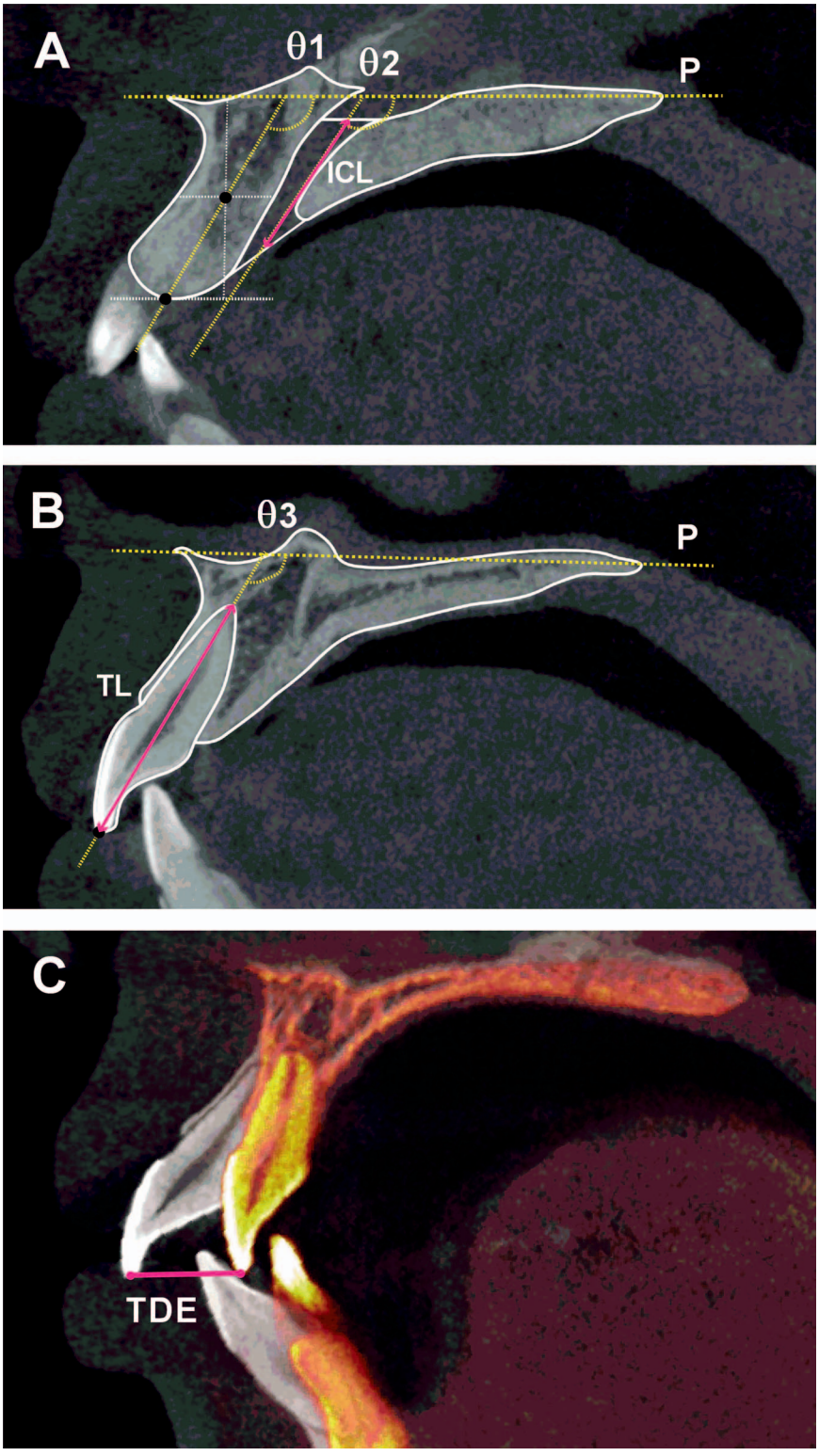

Figure 2. Definitions of linear, angular, and superimposition of pre- and postretraction CBCT measurements in the sagittal plane. (A) P: palatal plane; ICL: incisive canal length; θ1 and θ2: angles between the palatal plane and axes of the maxillary alveolar border and incisive canal, respectively. (B) TL: maxillary central incisor length; θ3: angle between the palatal plane and the axis of the maxillary central incisor. (C) TDE: maxillary central incisor tooth displacement from before to after retraction at the incisal edges.

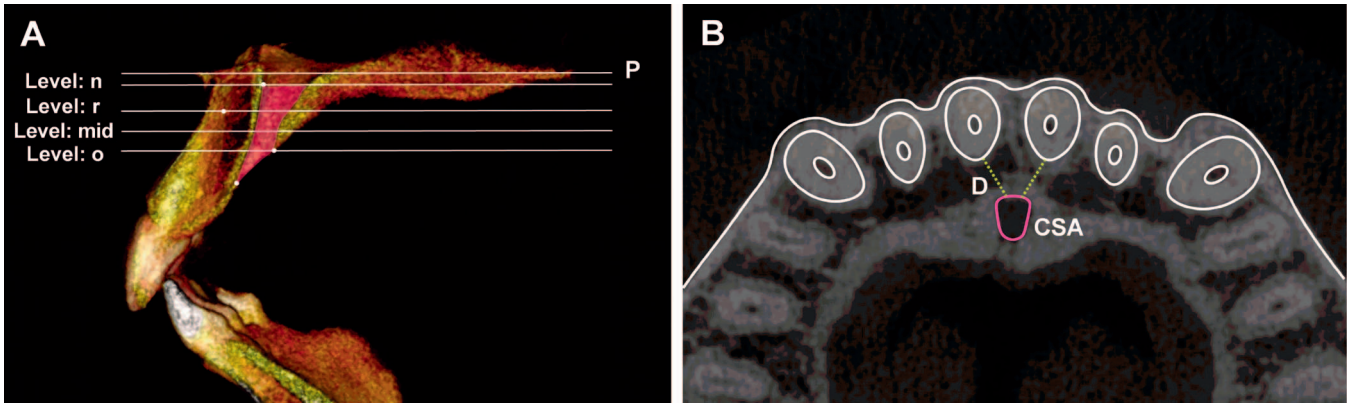

Figure 3. CBCT demonstrating the landmarks of vertical levels for linear, area, and volumetric measurements and definitions of measurement in the axial plane. (A) Four vertical levels related to the IC: nasal opening (n), root apex level (r), midlevel (mid), and oral opening (o). The red area indicates upper and lower borders of volumetric measurement. (B) D: the shortest distance (displacement) from U1 to the IC; CSA: area of the IC.

tact group before and after anterior retraction. Similarly, $\theta 2$ of the contact group was significantly lower than the noncontact group after anterior retraction. In addition, CSA_{mid} and CSA_o were significantly larger before anterior retraction and reduced after anterior retraction in the contact group more than in the noncontact group. The IC volume in the contact group was significantly greater than the noncontact group before and after anterior retraction.

In the analysis of each incisor (Table 3), 18 of 72 U1 roots contacted the IC. The findings revealed that the following factors significantly affected the proximity between U1 and the IC: TDE, $\theta 3$, D_r, D_{mid}, and D_o. The amount of TDE in the contact group was significantly greater than the noncontact group (5.58 $\pm$ 1.94 mm vs 4.09 $\pm$ 1.98 mm; $P < .01$). $\theta 3$ of the contact group was significantly smaller than the noncontact group before and after anterior retraction. Additionally, the D_r, D_{mid}, and D_o were significantly narrower in the contact group than in the noncontact group before and after anterior retraction.

Binary logistic regression analysis was performed to predict the noncontact probability of U1 to the IC after anterior tooth retraction using the pretreatment parameters (Table 4). The odds of U1 not contacting IC increased 13.5% and 8.7% for every degree increase in $\theta 1$ and $\theta 3$, respectively (Table 5). The Hosmer–Lemeshow test ($P = .831$) confirmed the goodness of fit

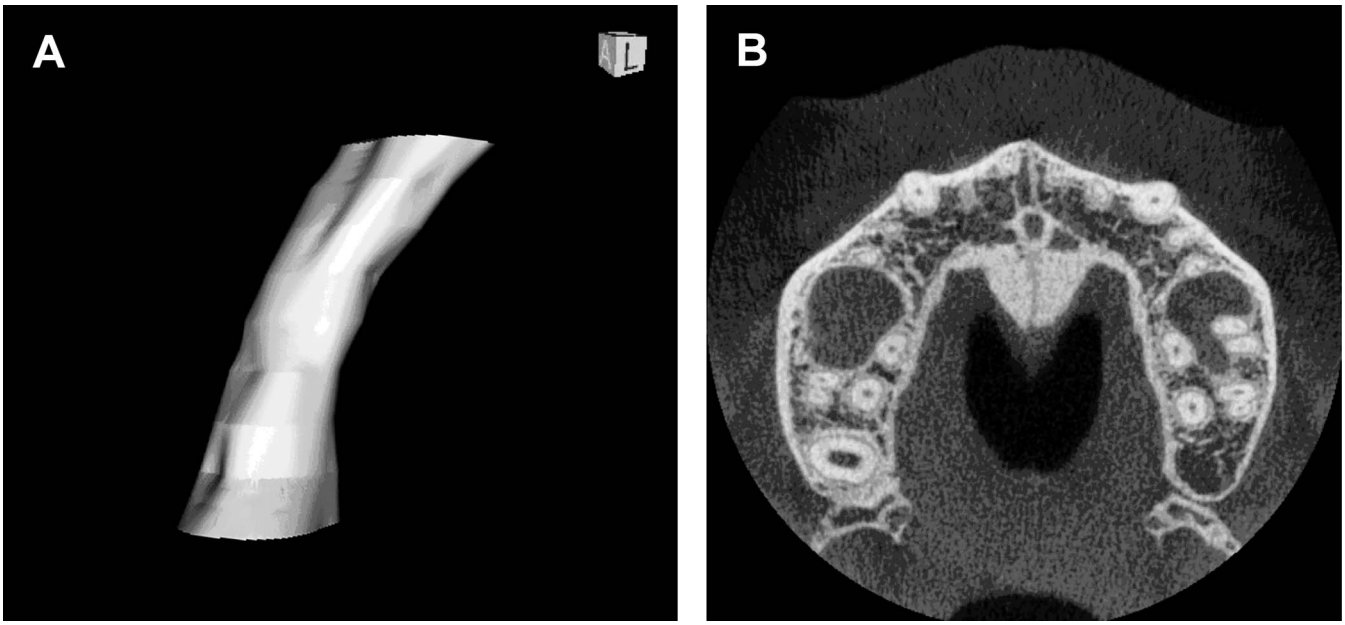

Figure 4. CBCT demonstrating volumetric measurements and incisive canal shape in the axial plane. (A) 3D volume rendering of the cylindrical IC with an oval shape in the axial plane. (B) Cross-sectional image of the oval-shaped IC

Table 1. Descriptive Statistics and Mean Differences in the Linear, Angular, Area, and Volume CBCT Measurements Before and After Maxillary Anterior Tooth Retraction[a]

	T1		T2		T1–T2			
Variables	Mean	SD	Mean	SD	Mean Difference	SD	95% CI	*P* Value
ICL (mm)	15.76	1.80	15.74	2.01	0.02	0.58	−0.17 to 0.22	.819
TL (mm)	23.87	1.52	23.08	1.92	0.79	1.08	0.54 to 1.04	<.001***
θ1 (°)	111.39	6.72	104.64	6.70	6.75	5.43	4.91 to 8.59	<.001***
θ2 (°)	110.76	6.21	108.71	6.03	2.05	2.93	1.06 to 3.04	<.001***
θ3 (°)	115.63	8.91	107.12	8.64	8.51	7.65	6.71 to 10.31	<.001***
D_r (mm)	3.50	1.68	3.12	1.65	0.38	1.45	0.04 to 0.72	.030*
D_{mid} (mm)	3.38	1.51	2.59	1.76	0.79	1.19	0.51 to 1.07	<.001***
D_o (mm)	3.11	1.57	1.95	1.82	1.15	1.13	0.89 to 1.42	<.001***
CSA_n (mm^2)	10.51	7.20	9.62	7.39	0.88	1.48	0.38 to 1.38	.001**
CSA_r (mm^2)	8.67	5.61	7.20	5.33	1.47	1.40	0.99 to 1.94	<.001***
CSA_{mid} (mm^2)	8.91	4.30	7.13	3.66	1.77	1.53	1.26 to 2.29	<.001***
CSA_o (mm^2)	10.40	3.21	8.18	2.48	2.21	1.73	1.63 to 2.80	<.001***
Volume (mm^3)	79.62	33.86	68.16	34.28	11.47	7.63	8.89 to 14.05	<.001***

* $P < .05$; ** $P < .01$; *** $P < .001$.

[a] CBCT indicates cone beam computed tomography; CI, confidence interval; CSA, cross-sectional area of the incisive canal; ICL, incisive canal length; SD, standard deviation; TL, maxillary central incisor length.

Table 2. Comparisons of Factors Affecting Contact of U1 to the IC Between Contact and Noncontact Groups According to Incisive Canal Analysis[a]

	Contact		Noncontact		
Variables	Mean	SD	Mean	SD	
No. of Patients	n = 12		n = 24		*P* Value
ICL (mm)					
T1	15.63	2.38	15.83	1.49	.793
T2	15.49	2.49	15.75	1.74	.611
Δ T1–T2	0.13	0.65	0.08	0.55	.439
θ1 (°)					
T1	108.05	6.20	113.07	6.45	.033*
T2	100.65	6.40	106.64	6.03	.009**
Δ T1–T2	7.39	5.67	6.43	5.40	.622
θ2 (°)					
T1	108.21	6.22	112.03	5.92	.081
T2	105.64	6.58	110.24	5.23	.029*
Δ T1–T2	2.56	2.32	1.79	3.21	.465
CSA_n (mm^2)					
T1	13.14	7.77	9.19	6.68	.122
T2	12.56	9.21	8.15	5.99	.092
Δ T1–T2	0.58	2.06	1.04	1.10	.386
CSA_r (mm^2)					
T1	10.17	5.90	7.92	5.43	.264
T2	8.06	5.31	6.77	5.40	.503
Δ T1–T2	2.11	2.06	1.15	0.80	.145
CSA_{mid} (mm^2)					
T1	11.32	4.71	7.70	3.60	.015*
T2	8.58	3.39	6.41	3.65	.095
Δ T1–T2	2.74	2.19	1.29	0.72	.045*
CSA_o (mm^2)					
T1	12.95	3.65	9.12	2.04	.004**
T2	9.72	2.67	7.42	2.02	.007**
Δ T1–T2	3.23	2.14	1.70	1.23	.037*
Volume (mm^3)					
T1	100.39	38.94	69.24	26.11	.007**
T2	86.29	40.01	59.09	27.66	.022*
Δ T1–T2	14.10	7.97	10.15	7.27	.146

* $P < .05$; ** $P < .01$.

[a] CSA indicates cross-sectional area of the incisive canal; IC, incisive canal; ICL, incisive canal length; SD, standard deviation.

of the logistic regression model. The probability plot showed the positive prediction of U1 not contacting IC was associated with larger degrees of the pretreatment maxillary alveolar bone angle (i.e., $\theta 1 \geq 117°$, Figure 5A) and maxillary central incisor angle (i.e., $\theta 3 \geq 125°$, Figure 5B).

Table 3. Comparisons of Factors Affecting Contact of U1 to IC Between Contact and Noncontact Groups According to Incisor Analysis[a]

	Contact		Noncontact		
Variables	Mean	SD	Mean	SD	
No. of U1 Roots	n = 18		n = 54		*P* Value
TDE (mm)	5.58	1.94	4.09	1.98	.007**
TL (mm)					
T1	24.20	1.68	23.76	1.46	.294
T2	23.22	2.32	23.04	1.79	.726
Δ T1–T2	0.97	1.01	0.73	1.10	.404
θ3 (°)					
T1	110.58	10.55	117.32	7.68	.020*
T2	102.48	7.46	108.67	8.51	.008**
Δ T1–T2	8.11	6.44	8.65	8.07	.797
D_r (mm)					
T1	2.31	1.21	3.89	1.64	<.001***
T2	1.67	1.15	3.60	1.51	<.001***
Δ T1–T2	0.64	1.56	0.29	1.42	.386
D_{mid} (mm)					
T1	2.22	1.05	3.77	1.44	<.001***
T2	0.83	1.19	3.18	1.51	<.001***
Δ T1–T2	1.45	1.64	0.85	1.75	.204
D_o (mm)					
T1	1.95	1.18	3.49	1.50	<.001***
T2	0.00	0.00	2.61	1.65	<.001***
Δ T1–T2	1.95	1.18	0.87	1.78	.019*

* $P < .05$; ** $P < .01$; *** $P < .001$.

[a] IC indicates incisive canal; SD, standard deviation; TDE, tooth displacement at the incisal edge; TL, maxillary central incisor length.

Table 4. Comparisons of Linear, Angular, Area, and Volume CBCT Measurements Between Males and Females[a]

	Male (n = 15)		Female (n = 21)		
Variables	Mean	SD	Mean	SD	*P* Value
ICL (mm)	16.44	1.62	15.27	1.80	.053
TL (mm)	24.40	1.53	23.49	1.41	.011*
θ1 (°)	112.12	6.66	110.87	6.88	.592
θ2 (°)	112.20	6.39	109.73	6.01	.244
θ3 (°)	118.19	9.09	113.81	8.41	.039*
D_r (mm)	3.71	1.75	3.35	1.64	.370
D_{mid} (mm)	3.47	1.42	3.32	1.58	.687
D_o (mm)	2.95	1.31	3.22	1.73	.465
CSA_n (mm^2)	11.80	8.07	9.59	6.56	.372
CSA_r (mm^2)	7.90	4.52	9.22	6.33	.494
CSA_{mid} (mm^2)	8.60	3.27	9.13	4.97	.721
CSA_o (mm^2)	10.98	3.24	9.98	3.19	.366
Volume (mm^3)	83.92	30.45	76.55	36.51	.528

* $P < .05$.

[a] CBCT indicates cone beam computed tomography; CSA, cross-sectional area of the incisive canal; ICL, incisive canal length; SD, standard deviation; TL, maxillary central incisor length.

Table 5. Logistic Regression Demonstrating Effects of Pretreatment Maxillary Alveolar Bone Angle and Maxillary Central Incisor Angle on Occurrence of U1 Not Contacting IC After Anterior Tooth Retraction[a]

Variables	B	SE	OR	95% CI	*P* Value
Alveolar bone angle (θ1)	0.127	0.064	1.135	1.002 to 1.287	.047*
Tooth angle (θ3)	0.084	0.032	1.087	1.022 to 1.157	.009**

* $P < .05$; ** $P < .01$.

[a] CI indicates confidence interval; IC, incisive canal; OR, odds ratio; SE, standard error of the mean.

DISCUSSION

Orthodontic retraction in the premaxillary region could have a limited boundary due to the cortical bone thickness, surrounding periosteum, and IC. The effects of anatomical structures and IC invasion related to maxillary anterior tooth rehabilitation,[6,16] cystic lesions, and implant placement have been studied.[17] However, the consequences of incisor roots contacting or invading the IC during orthodontic retraction are incompletely described. According to previous studies, maxillary incisor root resorption was noted after contacting or invading the IC, but neurologic problems were not reported.[8,18] Implant placement adjacent to the IC could abut or compress the nasopalatine nerve, predispose to the risk of vascular injury, and impair sensation of the anterior palate.[17] Although orthodontic retraction is a gradual process of closing the extraction spaces, IC configuration and dimensions should be properly determined before and during anterior tooth retraction to prevent unexpected nerve injury.

This study visualized IC remodeling resulting from anterior tooth retraction using 3D volume rendering. IC remodeling was found, demonstrating a significant reduction in IC volume after retraction and relative position changes due to the reduction of IC angulation. IC position may change because of alveolar bone loss after tooth extraction in edentulous patients.[6,17] Additionally, the cross-sectional areas of the IC at midroot and oral opening levels were significantly decreased in the contact group compared to the noncontact group, consistent with the incisor retraction position. The results showed that IC remodeling occurred as an adaptation of the surrounding structure, causing minimum root resorption.

Changes in location and inclination of the maxillary incisors during anterior retraction led to morphological changes in the maxillary alveolar border due to bone

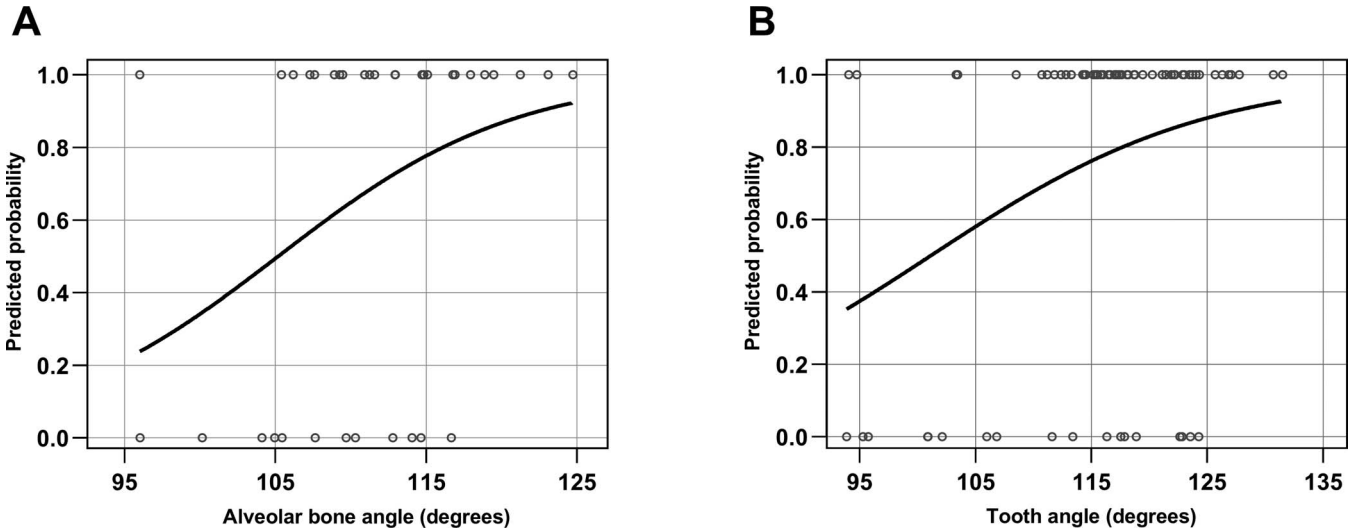

Figure 5. Logistic regression analysis curves predicting the probability of U1 not contacting the IC after anterior tooth retraction based on the pretreatment maxillary alveolar bone angle (A) and maxillary central incisor angle (B).

remodeling on the labial and palatal cortical plates of the alveolar ridge.[11,19] Interestingly, the logistic regression models demonstrated that the angle between the palatal plane and axes of the maxillary alveolar border and maxillary central incisors significantly correlated with the probability of the incisors contacting the IC after anterior tooth retraction. Consequently, these findings could provide a novel pretreatment analysis index leading to the prediction of possible orthodontic treatment outcomes.

The limit of upper anterior retraction orthodontically was previously identified as 7 mm according to the "envelope of discrepancy" concept.[2,3] However, current results suggested that a mean for incisal edge retraction of 5.5 mm, slightly less than the conventional guideline, could be considered as a limit regarding the increased probability of incisors contacting the IC. This 5.5 mm distance was estimated as the starting point for a maximum anchorage situation.[20] However, 5.5 mm is not always implied as a safety limit because the risk of canal contact or invasion decreases even during maximum retraction when a relatively larger interroot distance exists compared with the IC width.[21] Therefore, additional CBCT assessment may be useful to provide more precise three-dimensional information for an individualized orthodontic treatment plan.

According to the anatomy of the central incisors and IC, the incisor roots have a conical shape and the interradicular distance gets narrower at the cervical aspect, corresponding to a higher risk of contact site, which occurs at the oral opening and midlevel of the IC. Also, the IC shape is known to vary among patients. Cylindrical and funnel shapes are observed in 70% of patients,[6] while the spindle shape has been reported as the largest canal volume.[16] The present study suggests that large canal volume significantly affects the chance of U1 contacting the IC after orthodontic retraction. Consequently, the IC shape, maxillary central incisor configuration, and proximity between the IC and maxillary central incisors should be observed from the midsagittal and frontal views.

In this study, during unmonitored retraction, the safety rate observed was approximately 66.7% of patients (24 of 36), and 75% of U1s (54 of 72). With conventional radiography, it would be difficult to evaluate the relationship between U1 and the IC precisely. Therefore, in complicated cases, routine two-dimensional radiographs combined with CBCT should be encouraged to achieve precise treatment outcomes after extreme anterior tooth retraction.

CONCLUSIONS

- The volume and cross-sectional area of the IC, the inclinations of maxillary central incisors and alveolar bone, and the proximity between the IC and maxillary incisors were associated with the central incisor contacting the IC after maxillary anterior retraction with premolar extractions.
- Root contacts of maxillary incisors to IC were significantly associated with pretreatment maxillary alveolar bone angle and central incisor angle.
- The results could contribute to the prediction of the possible outcome after anterior tooth retraction and could be incorporated into the development of a classification system based on CBCT imaging.

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