Original Article

Proximity of upper central incisors to incisive canal among subjects with maxillary dentoalveolar protrusion in various facial growth patterns: *A CBCT analysis*

Remsh Khaled Al-Rokhami[a]; Karim Ahmed Sakran[b]; Maged Sultan Alhammadi[c]; Mubarak Ahmed Mashrah[d]; Baocheng Cao[e]; Majedh Abdo Ali Alsomairi[f]; Naseem Ali Al-Worafi[f]

ABSTRACT

Objective: To investigate the position of the upper central incisor roots (U1) relative to the incisive canal (IC) among subjects with maxillary dentoalveolar protrusion in various facial growth patterns.

Materials and Methods: 240 cone beam computed tomography images of skeletal Class I and II maxillary or bimaxillary protrusive subjects with a mean age of 23.74 ± 3.73 years were enrolled according to their facial growth pattern. The IC volume was measured using Mimics 21 software (Materialise, Leuven, Belgium). The U1 inter-root distance, width of IC, and their proximity were estimated using Invivo6 software (Anatomage, San Jose, CA).

Results: The IC volume was slightly greater among the high angle facial group and female patients than the other groups. Overall, the IC width was greater than the U1 inter-root distance in 55.65%, 57.6%, and 65% among the average, low, and high angle facial groups, respectively, and in 56.5% and 62.9% of males and females, respectively. The overall anteroposterior (sagittal) distances between the U1 roots and IC were 4.36 ± 1.18, 4.78 ± 1.17, and 3.83 ± 0.90 mm among the average, low, and high angle facial groups, respectively.

Conclusions: The high angle facial group and female patients showed slightly greater IC dimensions than the other groups. The overall maximum sagittal distances between the U1 and IC were around 5.5, 6, and 4.7 mm among the average, low, and high angle facial groups, respectively. The low angle facial group and male patients tended to have greater sagittal distances. Therefore, the present findings could serve as a guideline when a considerable amount of upper incisor retraction is planned for Class I or II maxillary or bimaxillary dentoalveolar protrusion patients. (*Angle Orthod.* 2022;92:529–536.)

KEY WORDS: Upper central incisors; Incisive canal; Tooth movement; Retraction; Cone beam computed tomography

[a] Postgraduate Student, Department of Orthodontics, School of Stomatology, Lanzhou University, Lanzhou, Gansu, China.

[b] Doctoral Candidate, State Key Laboratory of Oral Diseases and National Clinical Research Center for Oral Diseases, and Department of Oral and Maxillofacial Surgery, West China Hospital of Stomatology, Sichuan University, Chengdu, Sichuan, China; and Lecturer, Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Ibb University, Ibb, Yemen.

[c] Associate Professor, Division of Orthodontics and Dentofacial Orthopedics, Department of Preventive Dental Sciences, College of Dentistry, Jazan University, Jazan, Saudi Arabia.

[d] Assistant Professor, Key Laboratory of Oral Medicine, Guangzhou Institute of Oral Disease, Stomatology Hospital of Guangzhou Medical University, Guangdong, Guangzhou, China.

[e] Professor, Department of Orthodontics, School of Stomatology, Lanzhou University, Lanzhou, Gansu, China.

[f] Doctoral Candidate, Department of Orthodontics, School of Stomatology, China Medical University, Shenyang, Liaoning, China.

Corresponding author: Dr Baocheng Cao, Professor, Department of Orthodontics, School of Stomatology, Lanzhou University, No. 1 Donggang West Road, Lanzhou City, Gansu 730000, China
(e-mail: caobch@lzu.edu.cn)

Accepted: December 2021. Submitted: August 2021.
Published Online: February 7, 2022

INTRODUCTION

The upper central incisors play an important role in the appearance, phonetics, and function of individuals. Various anatomical structures restrict orthodontic tooth movement, including the periodontal apparatus, tongue, lips, cheeks, muscles, and cortical plates.[1] Consideration of the related limiting structures can reduce the risk of iatrogenic damage to tooth roots and alveolar bone while moving teeth orthodontically.[2]

It was previously thought that the amount of movement possible for the upper incisors during orthodontic treatment were greater for retraction and extrusion than for protraction and intrusion (envelope of discrepancy).[3] The palatal cortical plate was commonly regarded as the main constraint for retracting the upper centrals.[4] However, recent craniofacial anatomical studies found that the incisive canal (IC) was encircled by a thick layer of cortical bone and was closer to the upper central incisors (U1) between the U1 roots than the palatal cortical plate.[5]

External apical root resorption is one of the most common deleterious effects of orthodontic therapy and has been a challenge to orthodontists for a long time. Radiographic estimation revealed incidence of root resorption in a range from 48% to 66%.[6,7] About 20% of cases showed at least one upper incisor with resorption greater than 2 mm after the first year of therapy.[8] Chung et al.[9] found contact of the U1 root with the IC cortical plate and subsequent root resorption was observed after en-masse retraction of the U1. Pan and Chen[10] found that the root length decreased significantly more in the U1-IC contact group (2.63 $\pm$ 0.93 mm) compared to the non-contact group (1.14 $\pm$ 0.83 mm).

Despite the anatomy of the IC being well known, its approximate location relative to the U1 is not well-reported in the orthodontic literature. Cho et al.[11] estimated the proximity of the U1 and IC and found greater than 60% of cases had an IC width greater than the U1 inter-root distance. Interestingly, a recent clinical study reported that 53% of cases that underwent more than 4 mm of incisor retraction revealed IC invasion by the incisor roots after maximum incisor retraction. As a result, different degrees of root resorption were observed with an average of 2.39 mm, and the largest degree of invasion demonstrated 6.2 mm of root resorption.[12]

"The safety zone" of orthodontic retraction may be less than traditionally thought. Most previous studies[11,13] identified the IC opening (incisive foramen) as the lowest point of the IC palatal wall rather than the buccal wall, which was presented in the study by Pan and Chen.[10] They revealed that IC length could be a risk factor for U1-IC contact, in which the contact group showed a lower positioned IC (2.86 $\pm$ 1.10 mm) than the non-contact group (4.07 $\pm$ 1.72 mm).[10]

The vertical growth pattern and its effect on the consequences of orthodontic therapy is of vital significance for professionals because the volume and orientation of facial development are involved in orthodontic diagnosis and treatment planning as well as in orthodontic biomechanics and treatment outcomes.[14] Therefore, it is important to reevaluate the distance between the U1 and IC, considering the facial growth pattern in reference to the envelope of discrepancy.

Therefore, the purpose of this study was to evaluate the proximity of the upper central incisor roots (U1) to the incisive canal (IC) among subjects with maxillary dentoalveolar protrusion in various facial growth patterns of both genders.

MATERIALS AND METHODS

Samples

A retrospective study was performed on subjects who visited the hospital of Stomatology, Lanzhou University, China, between 2014 and 2020. The study was approved by the institutional review board of the School of Stomatology, Lanzhou University, China (LZUKQ-2020-20). The sample size was established using G power software (University of Dusseldorf, Dusseldorf, Germany) using a 0.05 significance level and a power around 95%. The estimation was based on a previous study[11] that reported incisive canal width about 4 $\pm$ 0.73, 3.7 $\pm$ 0.73, and 3.5 $\pm$ 0.94 mm at the palatal opening of the IC, midlevel, and the root apex of the U1, respectively. Accordingly, the power analysis revealed the need to enroll 240 cases in the present study.

The inclusion criteria were: (1) adults aged 18 to 30 years, (2) the presence of pretreatment high quality lateral cephalograms and cone beam computed tomography (CBCT) scans, and (3) skeletal Class I (ANB from 0° to 4°) or Class II (ANB $>$4°) malocclusion with maxillary or bimaxillary dentoalveolar protrusion. The exclusion criteria were: (1) facial asymmetry, (2) large diastema, (3) shift of the maxillary midline $\geq$2 mm, (4) history of orthodontic or prosthetic treatment, (5) missing teeth except the third molars, and (6) tooth or bone anomalies in the maxillary midline region.

The samples were divided into average, low, and high angle facial groups based on two angular and one linear measurement after determinants of Fields et al.[15] The sample was identified to have low, average, or high angle facial growth when MP-SN, PP-MP, and ANS-Me measured $<$27°–37°$>$, $<$19°–31°$>$, and $<$64–72 mm$>$, respectively. Subjects who did not

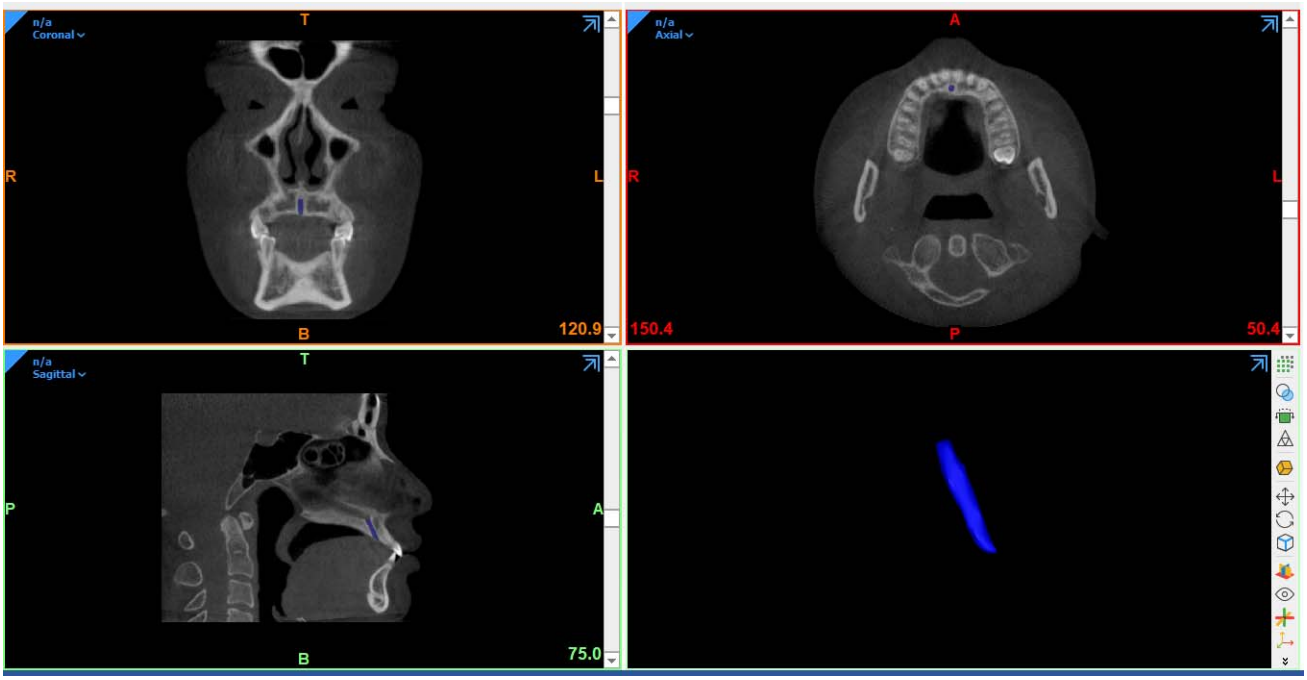

Figure 1. Incisive canal volume measurement shows segmentation of the internal portion of the incisive canal with the resulting 3D model.

meet all mentioned categories, MP-SN, PP-MP, and ANS-Me, were excluded.

CBCT Analysis

Analysis was done on CBCT images derived from the I-CAT Imaging System (Imaging Sciences International Inc. Hatfield, PA, USA). All subjects were scanned with standard protocol: field of view of 17 cm, normalized head position, maximum intercuspation, horizontal plane parallel to the floor, exposure parameter settings (120kVp, 20.27 MAs, and 14.9 s), and image acquisition at 0.4 mm voxel size. Prior to proceeding with any estimation, all the scans were realigned parallel to the Frankfort-horizontal (FH) plane in the sagittal plane.

The internal volume of the IC was segmented using 3D segmentation and image analysis software (Mimics 21, Materialise, Leuven, Belgium), and 3D volumetric models of the IC were generated from these segmentations (Figure 1). The registered 3D IC models were cropped superiorly at the floor of the nasal cavity and inferiorly at the roof of the palate. These 3D models were used to calculate the IC volume automatically.

Invivo dental imaging software (version 6, Anatomage, San Jose, CA) was used to measure the other 3D parameters and linear measurements. All the linear measurements were established on the axial cross-sectional images based on the method of Cho et al.[11] with some modifications at three vertical levels situated on the sagittal plane (Figure 2A). At each of the three marked levels, landmarks were identified and measurements were established as presented in Figures 2B and 2C. Regarding the sagittal measurements, the smaller value from the bilateral measures was considered for analysis.

Statistical Analysis

The statistics were performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY). Descriptive statistics were reported for all parameters. One-way analysis of variance (ANOVA) followed by Tukey test and independent *t*-test were conducted to estimate the variances among the facial groups and genders, respectively. The values were considered significant at $P < .05$. All the measurements were performed by two trained examiners. The intraclass correlation coefficient (ICC) through Cronbach's Alpha test confirmed intra- and interobserver validity, which ranged from 0.9 to 1.0.

RESULTS

Demographic Data

Two hundred forty adults were selected in the present study, with a mean age of 23.74 ± 3.73 years. Exactly 49.17% (118) of cases were male and 50.83% (122) were female. The cases were identified according to the facial growth pattern, with 80 (33.3%) cases in each facial group. The gender and age distribution among the facial groups is shown in Table 1.

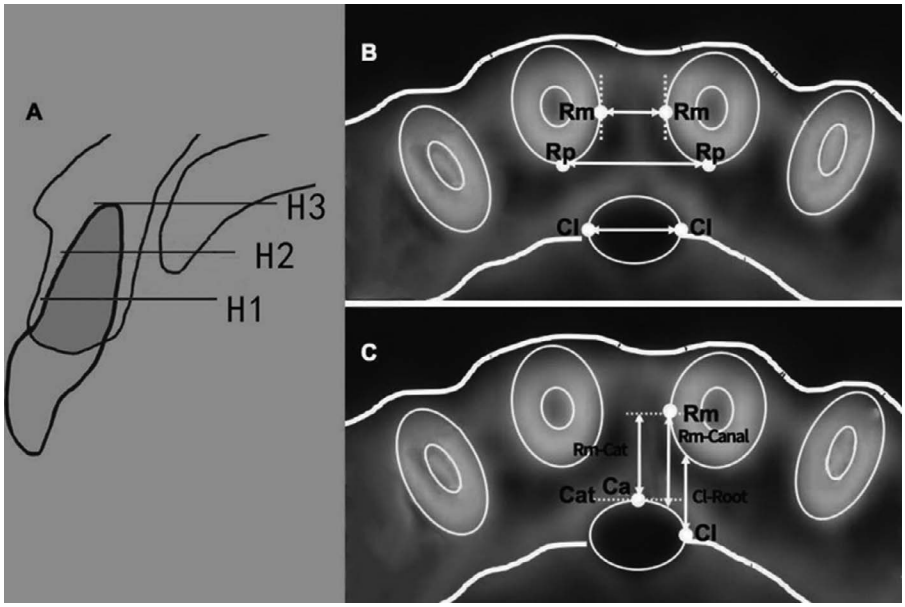

Figure 2. Landmarks and linear measurements. (A) Levels of measurements: H1, the lowest point of the incisive canal buccal wall; H2, midlevel; H3, root apex level. (B) Landmarks for transverse measurements: Rm, the most medial point of the upper central incisor (U1) root; Rp, the most posterior point of the U1 root; Cl, the most lateral point of the incisive canal (IC); Rm-Rm, interroot distance; Rp-Rp, posterior interroot distance; Cl-Cl, canal width. (C) Landmarks for sagittal measurements: Ca, the most anterior point of the IC; Cat, the tangent line through Ca; Rm-Cat, the anteroposterior distance from Rm to Cat; Rm-Canal, the anteroposterior distance from Rm to the anterior border of the IC; Cl-Root, the anteroposterior distance from Cl to the posterior border of the U1 root.

Additionally, skeletal and dental sagittal and vertical relationships are shown in Table 2.

Incisive Canal Dimensions and Interroot Distances

The incisive canal showed volumetric values about 114 ± 34.82, 110 ± 41.11, and 118 ± 32.29 mm^3 among the average, low, and high angle facial groups, respectively. At H2, the incisive canal width (CI-CI) was significantly greater in the high angle facial group (3.40 ± 0.74 mm) than the low angle facial group (3.06 ± 0.79 mm) (Table 3). The IC volume was slightly greater in females than males, and CI-CI was significantly greater in females compared to males of the average angle facial group (Table 4). In all the facial groups and in both genders, CI-CI was significantly decreased from H1 to H3 ($P < .001$) (Table 5). On the other hand, the interroot distances (Rm-Rm and Rp-Rp) were slightly greater in the average and low angle facial groups and in males than in the high angle facial group and females (Tables 3, 4). In addition, Rm-Rm was significantly increased from H1 to H3 ($P < .001$), while Rp-Rp was significantly decreased from H1 to H3 ($P < .001$) (Table 5).

At the H1 level, 82.5%, 91.3%, and 85% of average, low, and high angle facial group cases revealed CI-CI greater than Rm-Rm. At the H2 level, the average, low, and high angle facial groups showed CI-CI greater than Rm-Rm in 28.8%, 23.8%, and 45% of cases, respectively (Table 6). Additionally, in all facial groups, male subjects tended to have slightly lower rates of IC width greater than Rm-Rm at the H1 and H2 levels (Table 6).

Proximity of U1 and IC

At the three vertical levels, almost all the CI-Root, Rm-Canal, and Rm-Cat sagittal (anteroposterior) distances (see Figure 2 for definitions) were significantly greater among the low angle facial group cases compared with the average and high angle facial groups (Table 3). The average angle facial group also had some sagittal distances significantly greater than

Table 1. Descriptive Data of the Enrolled Cases

	Gender n (%)			
Facial Group	Male	Female	Total n (%)	Age (y) Mean ± SD
Average	36 (15)	44 (18.33)	80 (33.33)	23.36 ± 3.80
Low	48 (20)	32 (13.33)	80 (33.33)	23.74 ± 3.52
High	34 (14.17)	46 (19.17)	80 (33.34)	24.11 ± 3.86
Total	118 (49.17)	122 (50.83)	240 (100)	23.74 ± 3.73

Table 2. Baseline Comparison of 3D Measurements Among the Facial Groups

Measurement	Average, Mean ± SD	Low, Mean ± SD	High, Mean ± SD	*P* Value
ANB (°)	5.13 ± 1.78	5.02 ± 1.85	5.07 ± 2.05	.937
MP-SN (°)	32.85 ± 2.61	24.22 ± 2.91	39.77 ± 2.30	<.001
ANS-Me (mm)	67.58 ± 3.07	60.48 ± 2.64	74.84 ± 1.99	<.001
PP-MP (°)	23.77 ± 3.30	16.04 ± 2.83	34.18 ± 2.41	<.001
SNA (°)	87.13 ± 1.87	88.64 ± 2.84	86.12 ± 2.13	<.001
SNB (°)	81.97 ± 2.14	83.55 ± 3.02	81.62 ± 2.28	<.001
A-NV (mm)	5.59 ± 3.11	6.49 ± 3.23	5.54 ± 2.15	.064
B-NV (mm)	0.38 ± 4.84	1.06 ± 4.89	-0.49 ± 3.63	.094
U1-SN (°)	106.64 ± 9.29	108.73 ± 9.67	109.75 ± 6.67	.071
U1-NA (°)	20.48 ± 10.07	21.30 ± 9.55	23.76 ± 7.49	.063
U1-NA (mm)	4.78 ± 2.05	4.36 ± 1.94	5.18 ± 2.02	.038
L1-MP (°)	98.35 ± 5.99	103.65 ± 7.70	97.07 ± 5.34	<.001
L1-NB (°)	32.87 ± 5.67	32.16 ± 7.59	33.35 ± 5.80	.496
L1-NB (mm)	6.01 ± 1.83	4.96 ± 1.85	6.32 ± 2.15	<.001

the high angle facial group. Additionally, these sagittal distances were slightly greater among males than females, which was significant in the average angle facial group (Table 4). At the H3 level, the CI-Root and Rm-Canal were not analyzed as the root apex was farther away from the middle plane than was the most lateral border of the IC. The Rm-Canal and Rm-Cat distances were significantly decreased from the H1 to H3 levels while the CI-Root was slightly increased and this was similar among the facial groups and genders (Table 5).

DISCUSSION

The proximity of the upper incisor (U1) roots to the incisive canal (IC) or the potential for approximation or intrusion of the tooth roots into the IC after movement has not been comprehensively investigated in the orthodontic literature. Interestingly, the incidence of orthodontic induced root resorption is by far more frequent in the upper centrals, even with their larger tooth dimensions.[16] Hence, an evaluation of the relationship between the upper central incisors and the incisive canal is a valuable measure to estimate the risk of expected root resorption. This consideration is particularly important in maximum retraction cases that involve Class I or II maxillary or bimaxillary dentoalveolar protrusion. Therefore, the current study was conducted to estimate the position of the upper central incisors relative to the incisive canal among the different facial groups of skeletal Class I and II maxillary and bimaxillary dentoalveolar protrusive subjects.

Similar to previous findings,[11] the current study revealed that the incisive canal width was significantly decreased, while the interroot distance was significantly increased from the H1 to H3 levels similarly among

Table 3. Comparison of Measurements (mm) Among the Different Facial Groups[a]

	Average	Low	High		Tukey Test		
Measurement	Mean ± SD	Mean ± SD	Mean ± SD	ANOVA *P*	A/L	A/H	L/H
IC volume	114 ± 34.82	110 ± 41.11	118 ± 32.29	.317	NS	NS	NS
CI-CI-H1	4.30 ± 0.80	4.13 ± 0.81	4.22 ± 0.78	.412	NS	NS	NS
CI-CI-H2	3.25 ± 0.76	3.06 ± 0.79	3.40 ± 0.74	.019	NS	NS	*
CI-CI-H3	2.75 ± 0.79	2.62 ± 0.76	2.89 ± 0.74	.083	NS	NS	NS
Rm-Rm-H1	3.05 ± 0.94	2.86 ± 0.97	2.90 ± 0.96	.417	NS	NS	NS
Rm-Rm-H2	4.26 ± 1.35	4.04 ± 1.18	3.90 ± 1.13	.174	NS	NS	NS
Rm-Rm-H3	7.03 ± 1.80	6.92 ± 1.81	6.42 ± 1.80	.075	NS	NS	NS
Rp-Rp-H1	7.86 ± 0.97	7.90 ± 0.93	7.53 ± 1.04	.033	NS	NS	*
Rp-Rp-H2	7.57 ± 1.21	7.70 ± 1.20	7.35 ± 1.15	.159	NS	NS	NS
Rp-Rp-H3	7.03 ± 1.80	6.92 ± 1.81	6.42 ± 1.80	.103	NS	NS	NS
CI-Root-H1	3.47 ± 1.14	3.94 ± 1.21	2.92 ± 0.81	0	*	*	**
CI-Root-H2	3.84 ± 1.35	4.09 ± 1.21	3.05 ± 0.96	0	NS	**	**
Rm-Canal-H1	5.24 ± 1.02	5.70 ± 1.12	4.84 ± 0.92	0	*	*	**
Rm-Canal-H2	4.87 ± 1.20	5.36 ± 1.12	4.50 ± 0.88	0	*	NS	**
Rm-Cat-H1	4.80 ± 1.03	5.34 ± 1.13	4.34 ± 1.05	0	*	*	**
Rm-Cat-H2	4.44 ± 1.15	4.96 ± 1.15	4.06 ± 0.96	0	*	NS	**
Rm-Cat-H3	3.83 ± 1.31	4.51 ± 1.26	3.38 ± 1.02	0	*	*	**

* $P < .05$, ** $P < .001$.

[a] A indicates average face; ANOVA, analysis of variance; L, low face; H, high face; NS, not significant; SD, standard deviation.

Table 4. Comparison of Measurements (mm) Between Gender of Each Facial Group[a]

	Average			Low			High		
Measurement	Male	Female	*P*	Male	Female	*P*	Male	Female	*P*
IC volume	113 ± 29.50	114 ± 38.97	NS	108 ± 37.76	111 ± 46.28	NS	116 ± 37.74	119 ± 27.94	NS
CI-CI-H1	4.26 ± 0.82	4.33 ± 0.79	NS	4.18 ± 0.92	4.06 ± 0.60	NS	4.39 ± 0.83	4.09 ± 0.72	NS
CI-CI-H2	3.02 ± 0.78	3.44 ± 0.69	*	3.06 ± 0.85	3.04 ± 0.69	NS	3.49 ± 0.87	3.33 ± 0.63	NS
CI-CI-H3	2.51 ± 0.76	2.95 ± 0.76	*	2.52 ± 0.82	2.76 ± 0.64	NS	2.99 ± 0.92	2.80 ± 0.58	NS
Rm-Rm-H1	3.13 ± 1.00	2.98 ± 0.89	NS	3.06 ± 1.03	2.56 ± 0.80	*	2.99 ± 0.96	2.83 ± 0.97	NS
Rm-Rm-H2	4.38 ± 1.57	4.16 ± 1.15	NS	4.29 ± 1.06	3.66 ± 1.27	*	4.16 ± 1.35	3.71 ± 0.89	NS
Rm-Rm-H3	7.04 ± 1.85	7.02 ± 1.76	NS	7.58 ± 1.76	5.91 ± 1.37	**	6.41 ± 1.75	6.43 ± 1.84	NS
Rp-Rp-H1	7.99 ± 0.98	7.76 ± 0.96	NS	8.30 ± 0.86	7.29 ± 0.68	**	7.86 ± 1.07	7.28 ± 0.96	*
Rp-Rp-H2	7.63 ± 1.41	7.53 ± 1.02	NS	8.22 ± 1.11	6.93 ± 0.88	**	7.62 ± 1.21	7.15 ± 1.08	NS
Rp-Rp-H3	7.04 ± 1.85	7.02 ± 1.76	NS	7.58 ± 1.76	5.91 ± 1.37	**	6.41 ± 1.75	6.43 ± 1.84	NS
CI-Root-H1	3.95 ± 1.23	3.08 ± 0.89	**	4.06 ± 1.30	3.77 ± 1.06	NS	3.13 ± 0.74	2.76 ± 0.83	*
CI-Root-H2	4.24 ± 1.53	3.52 ± 1.09	*	4.40 ± 1.26	3.63 ± 0.97	*	3.12 ± 1.01	3.00 ± 0.93	NS
Rm-Canal-H1	5.80 ± 1.06	4.79 ± 0.72	**	5.96 ± 1.11	5.30 ± 1.04	*	4.80 ± 0.97	4.87 ± 0.88	NS
Rm-Canal-H2	5.50 ± 1.20	4.35 ± 0.94	**	5.52 ± 1.05	5.13 ± 1.18	NS	4.53 ± 0.88	4.47 ± 0.88	NS
Rm-Cat-H1	5.27 ± 1.04	4.41 ± 0.85	**	5.53 ± 1.12	5.04 ± 1.11	NS	4.23 ± 1.10	4.42 ± 1.02	NS
Rm-Cat-H2	4.95 ± 1.24	4.02 ± 0.88	**	5.12 ± 1.12	4.74 ± 1.18	NS	4.03 ± 0.87	4.08 ± 1.03	NS
Rm-Cat-H3	4.26 ± 1.37	3.49 ± 1.17	*	4.61 ± 1.34	4.38 ± 1.12	NS	3.45 ± 1.00	3.41 ± 1.05	NS

* $P < .05$, ** $P < .001$.
[a] NS indicates not significant.

the facial groups and genders. The high angle facial group and females showed higher overall rates (65% and 62.9%, respectively) of IC width greater than the UI interroot distance compared to the average and low facial angle groups and males (55.65%, 57.6%, and 56.5%, respectively), especially at the H2 level, and this could predispose the high angle facial group and female cases to be at higher risk of possible root invasion and/or resorption than the other groups. Additionally, alterations in root parallelism in cases of poor bracket positioning or addition of root torque during retraction may also induce root convergence of the incisors and further reduce the interroot distance.[17] Therefore, careful monitoring of the roots throughout treatment could help avoid iatrogenic complications, particularly in maximum retraction cases.

A recent clinical study[12] had significant and shocking results, in which 53% of the cases that underwent maximum retraction showed IC invasion with grade 3 root resorption. The amount of root resorption was significantly higher with IC invasion than without invasion (2.39 mm vs 0.82 mm, $P < .0001$). Based on the current findings, the overall maximum U1 to IC sagittal distances were roughly 5.5, 6, and 4.7 mm in the average, low, and high facial groups, respectively, somewhat less than that traditionally thought (7 mm) to be within the "envelope of discrepancy."[18] In addition, the average, low, and high angle facial groups revealed different overall U1 to IC sagittal measurements of 4.36 ± 1.18, 4.78 ± 1.17, and 3.83 ± 0.9 mm, respectively. Overall, the low angle facial group showed relatively greater U1 to IC sagittal distance, which was in agreement with previous investigations, indicating that the alveolar bone of the low angle facial group subjects was thicker than that in the other facial groups.[19]

The current study also revealed that males tended to have relatively wider (safe) sagittal distances between the U1 and IC than females, which was significant in the average angle facial group. Accordingly, females might be at greater risk for UI and IC approximation and subsequent complications than males. Generally,

Table 5. Comparison of Measurements (mm) at the Different Vertical Heights (H1, H2, and H3)

						Tukey Test		
Measurement	N	H1, Mean ± SD	H2, Mean ± SD	H3, Mean ± SD	*P*	H1/H2	H1/H3	H2/H3
CI-CI	240	4.21 ± 0.80	3.23 ± 0.77	2.75 ± 0.77	0	**	**	**
Rm-Rm	240	2.93 ± 0.96	4.07 ± 1.23	6.79 ± 1.81	0	**	**	**
Rp-Rp	240	7.76 ± 0.99	7.54 ± 1.19	6.79 ± 1.81	0	NS	**	**
CI-Root	240	3.44 ± 1.14	3.66 ± 1.26	NA	.048	NA	NA	NA
Rm-Canal	240	5.26 ± 1.08	4.91 ± 1.13	NA	.001	NA	NA	NA
Rm-Cat	240	4.82 ± 1.14	4.49 ± 1.15	3.91 ± 1.28	0	*	**	**

* $P < .05$, ** $P < .001$.
[a] H1 indicates at the lowest point of incisive canal buccal wall; H2, at midlevel; H3, at root apex; NA not applicable; NS, not significant; SD, standard deviation.

Table 6. Percentage of Subjects With Incisive Canal Width Greater Than U1 Inter-Root Distance

	Average			Low			High		
Cl-Cl > Rm-Rm	Male	Female	Overall	Male	Female	Overall	Male	Female	Overall
H1	77.8	86.4	82.5	89.6	93.8	91.3	88.2	82.6	85
H2	27.8	29.5	28.8	14.6	37.5	23.8	41.2	47.8	45
H3	0	0	0	0	0	0	0	0	0

these findings were in agreement with those reported by Klinge et al.[20] who found that the alveolar bone cross sections in males were wider than females.

Even though remodeling of the IC was reported in some previous studies, contact with or invasion of the U1 roots to the IC was fairly high after maximum anterior retraction.[21] Chung et al.[12] reported only 24% of subjects showed IC remodeling after maximum retraction and, a more recent study by Yu et al.[21] reported only 11.4% of subjects showed some signs of IC remodeling. In addition, the remodeling group still demonstrated apical root resorption, though it was less than in the non-remodeling group.

Class I or II maxillary or bimaxillary protrusive cases planned to have maximum maxillary incisor retraction should be evaluated carefully, considering the U1-IC relationship, especially for those in the high angle facial group and for females, who showed a bit shorter distance between the U1 and IC, and a wider IC width. The IC could be considered as one of the anatomic/biologic limiting parameters for orthodontic tooth movement that was not comprehensively investigated in the orthodontic literature and could be among the risk factors that induce root resorption.

Future clinical studies are recommended to estimate, three dimensionally, the possible side effects of maximum incisor retraction to determine the limits within the envelope of discrepancy in the 3D era.

CONCLUSIONS

- The high angle facial group and females showed a relatively higher frequency of IC width greater than the U1 interroot distance, especially at the H2 level.
- The facial groups showed differences in U1 to IC sagittal distances, which were significantly greater in the average and low angle facial groups (4.36 $\pm$ 1.18 and 4.78 $\pm$ 1.17 mm, respectively) than in the high angle facial group (3.83 $\pm$ 0.90 mm).
- Males had relatively greater sagittal distances than females, with differences that were significant in the average angle facial group.

ACKNOWLEDGMENTS

This research was supported by The Natural Foundation (1208RJZA236), The Key Technology Plan Program (20YF8FA071), and The Key Technology Support Program (1604FKCA089) of Gansu Province-China. The authors declare no conflicts of interest related to this study.

REFERENCES

1. Ackerman JL, Proffit WR. Soft tissue limitations in orthodontics: treatment planning guidelines. *Angle Orthod*. 1997; 67(5):327–336.
2. Mulie RM, Hoeve AT. The limitations of tooth movement within the symphysis, studied with laminagraphy and standardized occlusal films. *J Clin Orthod*. 1976;10:882–893.
3. Proffit W, Fields H, Sarver D. *Contemporary Orthodontics*. 5th ed. St Louis: Elsevier; 2013.
4. Horiuchi A, Hotokezaka H, Kobayashi K. Correlation between cortical plate proximity and apical root resorption. *Am J Orthod Dentofac Orthop*. 1998;114(3):311–318.
5. Al-Amery SM, Nambiar P, Jamaludin M, John J, Ngeow WC. Cone beam computed tomography assessment of the maxillary incisive canal and foramen: Considerations of anatomical variations when placing immediate implants. *PLoS One* 2015;10(2):1–16.
6. Apajalahti S, Peltola JS. Apical root resorption after orthodontic treatment – a retrospective study. *Eur J Orthod*. 2007;29(4):408–412.
7. Levander E, Bajka R, Malmgren O. Early radiographic diagnosis of apical root resorption during orthodontic treatment: a study of maxillary incisors. *Eur J Orthod*. 1998;20(1):57–63.
8. Artun J, Smale I, Behbehani F, Doppel D, Van't Hof M, Kuijpers-Jagtman AM. Apical root resorption six and 12 months after initiation of fixed orthodontic appliance therapy. *Angle Orthod*. 2005;75(6):919–926.
9. Chung CJ, Choi YJ, Kim KH. Approximation and contact of the maxillary central incisor roots with the incisive canal after maximum retraction with temporary anchorage devices: report of 2 patients. *Am J Orthod Dentofac Orthop*. 2015; 148(3):493–502.
10. Pan Y, Chen S. Contact of the incisive canal and upper central incisors causing root resorption after retraction with orthodontic mini-implants: a CBCT study. *Angle Orthod*. 2019;89(2):200–205.
11. Cho EA, Kim SJ, Choi YJ, Kim KH, Chung CJ. Morphologic evaluation of the incisive canal and its proximity to the maxillary central incisors using computed tomography images. *Angle Orthod*. 2016;86(4):571–576.
12. Chung CJ, Nguyen T, Lee J-H, Kim K-H. Incisive canal remodelling following maximum anterior retraction reduces apical root resorption. *Orthod Craniofac Res*. 2021;24 Suppl 1:59–65.
13. Nakada T, Motoyoshi M, Horinuki E, Shimizu N. Cone-beam computed tomography evaluation of the association of cortical plate proximity and apical root resorption after orthodontic treatment. *J Oral Sci*. 2016;58(2):231–236.

14. Schudy FF. Vertical growth versus anteroposterior growth as related to function and treatment. *Angle Orthod*. 1964;34(2): 75–93.
15. Fields HW, Proffit WR, Nixon WL, Phillips C, Stanek E. Facial pattern differences in long faced children and adults. *Am J Orthod*. 1984;85(3):217–223.
16. Segal GR, Schiffman PH, Tuncay OC. Meta analysis of the treatment-related factors of external apical root resorption. *Orthod Craniofac Res*. 2004;7(2):71–78.
17. Kraut RA, Boyden DK. Location of incisive canal in relation to central incisor implants. *Implant Dent*. 1998;7(3):221–225.
18. Proffit WR, Ackerman JL. Diagnosis and treatment planning. In: Graber T, and Swain B, eds. *Current Orthodontic Concepts and Techniques*. St Louis: Mosby; 1982:3–100.
19. Ozdemir F, Tozlu M, Germec-Cakan D. Cortical bone thickness of the alveolar process measured with cone-beam computed tomography in patients with different facial types. *Am J Orthod Dentofac Orthop*. 2013;143(2):190–196.
20. Klinge A, Becktor K, Lindh C, Becktor JP. Craniofacial height in relation to cross-sectional maxillary and mandibular morphology. *Prog Orthod*. 2017;18(1):32.
21. Yu JH, Nguyen T, Kim Y, Hwang S, Kim K, Chung CJ. Morphologic changes of the incisive canal and its proximity to maxillary incisor roots after anterior tooth movement. *Am J Orthod Dentofac Orthop.* In Press. (https://doi.org/10.1016/j.ajodo.2020.08.022).