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Original Article

Three-Dimensional CBCT Assessment of the Morphological Relationship Between Maxillary Central Incisors and the Incisive Canal Across Different Skeletal Malocclusions

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Abstract

Background: Accurate assessment of the anatomical relationship between the maxillary central incisors (MCI) and the incisive canal (IC) is essential in orthodontic treatment planning to prevent complications such as root resorption, dehiscence, and fenestration.

Objective: To evaluate the morphology of the incisive canal and its spatial relationship with maxillary central incisor roots using cone beam computed tomography (CBCT) across different skeletal malocclusion patterns, with additional assessment of gender differences.

Methodology: This cross-sectional study included CBCT scans of 84 subjects (43 males, 41 females) aged 15–45 years. Participants were categorized into Class I, II, and III skeletal groups based on ANB angle. Parameters assessed included incisive canal length (ICL), canal width at three levels, angular measurements (θ1, θ2, θ3), and distances (Dr, Dmid, Do) between the MCI root and the IC. Non-parametric tests (Mann–Whitney U and Kruskal–Wallis) were applied for statistical comparisons.

Results: A statistically significant difference in ICL was observed between genders ($p < 0.05$), with males exhibiting greater canal length than females. No significant gender differences were found in other parameters. Across all skeletal malocclusion groups, the shortest distance between the MCI root and IC was consistently observed at the oral level (Do), followed by the middle (Dmid) and nasal (Dr) levels. No statistically significant differences were identified among skeletal groups ($p > 0.05$).

Conclusion: The incisive canal exhibits significant gender-based variation in length, while its spatial relationship with maxillary central incisors remains consistent across skeletal malocclusions. The closest proximity at the oral level highlights a potential risk zone during orthodontic tooth movement. CBCT evaluation is recommended for accurate assessment in treatment planning.

Keywords: Cone beam computed tomography, Incisive canal, Maxillary central incisor, Root resorption.

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Introduction

The position of the maxillary incisors plays a critical role in orthodontic diagnosis and treatment planning, particularly in determining the extent and direction of tooth movement [1]. During the correction of skeletal Class II and Class III malocclusions, orthodontic interventions such as proclination, retraction, lingual movement, and torque adjustments are frequently required.[2] Ackerman et al[3]. introduced the concept of the "envelope of discrepancy," which defines the biological limits within which orthodontic tooth movement can be safely achieved. Exceeding these limits may result in adverse outcomes, including apical root resorption, particularly when tooth roots come into contact with surrounding cortical structures [4].

One such critical anatomical structure is the incisive canal (IC), which lies in close proximity to the roots of the maxillary central incisors. The IC serves as a conduit between the nasal and oral cavities and contains the nasopalatine nerve along with vascular structures, including branches of the greater palatine and sphenopalatine arteries.[5] Direct contact between the MCI roots and the IC has been identified as a significant risk factor for orthodontically induced root resorption.[6] Therefore, understanding the morphology and spatial orientation of the IC is essential for minimizing iatrogenic complications during orthodontic treatment.

Despite its clinical importance, the anatomical relationship between the IC and maxillary incisors has not been extensively explored in conventional orthodontic literature. This limitation is largely due to the inability of traditional two-dimensional imaging modalities to accurately depict the three-dimensional morphology of the canal. With the advent of cone beam computed tomography (CBCT), it is now possible to evaluate these structures with greater precision and reliability. Several studies [7,8] have suggested that factors such as age, sex, and skeletal malocclusion may influence the morphology of the IC; however, findings remain inconsistent, with other studies [9, 10] reporting no significant associations.

Given these inconsistencies, there is a need for further investigation to clarify the relationship between the IC and maxillary central incisors, particularly across different skeletal malocclusion patterns. Identifying patients at higher risk of anatomical proximity can aid in selecting appropriate diagnostic imaging and tailoring orthodontic treatment strategies.

Therefore, the present study aims to evaluate the morphological characteristics of the incisive canal and its spatial relationship with maxillary central incisor roots using CBCT. Additionally, the study investigates variations across skeletal malocclusion types and gender to provide clinically relevant insights for safer and more effective orthodontic treatment planning.

Methodology

Study design

This investigation was designed as a cross-sectional analytical study aimed at evaluating the three-dimensional morphological relationship between the incisive canal (IC) and maxillary central incisors using cone beam computed tomography (CBCT).

Ethics

Ethical approval for the study was obtained from the Ethical Review Committee of the Armed Forces Institute of Dentistry (AFID), Rawalpindi (Ref. Letter No. 918/Trg/20/Mar/2023). All procedures adhered to institutional ethical standards, and patient confidentiality was strictly maintained throughout the study.

Setting

The study was conducted at the Department of Orthodontics, AFID, Rawalpindi, utilizing archived CBCT records obtained as part of routine diagnostic assessments.

Participants

A total of 84 subjects (43 males and 41 females), aged between 15 and 45 years, were included using a non-probability consecutive sampling technique. Participants were selected based on the availability of high-quality CBCT scans and absence of prior orthodontic or orthopedic treatment. Subjects were categorized into skeletal Class I, II, and III groups based on ANB angle measurements. Exclusion criteria included CBCT scans showing endodontically treated incisors, evidence of root or bone resorption, presence of mesiodens, implants, cleft lip and palate, or any pathological conditions affecting the anterior maxillary region.

Variables

The primary variables included incisive canal length (ICL), IC width at three levels (upper, middle, and lower), angular measurements ($\theta 1$, $\theta 2$, $\theta 3$), and linear distances (Dr, Dmid, Do) between the maxillary central incisor (MCI) root and the incisive canal. Secondary variables included gender and skeletal malocclusion classification.

Data sources/measurement

CBCT images were acquired using the NewTom VGi machine with standardized parameters (110 kV, 6.11 mA, voxel size, and 3.6-second exposure time). Images were analyzed using NewTom software with optimized brightness and contrast. Standardized orientation was achieved by aligning images parallel to the Frankfort horizontal plane. The IC was evaluated in the mid-sagittal plane perpendicular to the FH plane, extending from anterior nasal spine (ANS) to posterior nasal spine (PNS). Linear and angular measurements were performed on axial cross-sectional images following the methodology described by Ongprakobkul et al.[11] and Gibas-Stanek et al.[12].

Bias

To minimize measurement bias, all analyses were conducted using standardized imaging protocols and consistent software settings. Intra-observer variability was assessed by re-evaluating 15 randomly selected CBCT scans after a two-week interval. Reliability was confirmed using intraclass correlation coefficient (ICC), demonstrating excellent agreement (ICC range: 0.91–0.97).

Study size

The sample size of 84 participants was calculated using G*Power software, based on an effect size of 0.40, alpha error of 0.05, and statistical power of 0.90, ensuring adequate precision and reliability of results.

Quantitative variables

All measurements were recorded as continuous quantitative variables (millimeters for linear dimensions and degrees for angular measurements). These were further stratified based on gender and skeletal classification for comparative analysis.

Statistical methods

Statistical analysis was performed using SPSS version 25.0. Normality of data distribution was assessed using the Shapiro–Wilk test, which indicated non-normal distribution; therefore, non-parametric tests were applied. The Mann–Whitney U test was used for comparison between male and female groups, while the Kruskal–Wallis test was employed for comparisons among skeletal classes. A p-value of ≤ 0.05 was considered statistically significant.

Results

Participants

A total of 84 participants were included in the final analysis, comprising 43 males and 41 females, with a mean age of 25.2 ± 7.2 years. The study population was evenly distributed across skeletal malocclusion groups, including 30 subjects with Class I malocclusion, 30 with Class II malocclusion, and 24 with Class III malocclusion. All selected CBCT scans met the predefined inclusion criteria and were of adequate diagnostic quality for precise morphometric assessment.

Descriptive data

Descriptive analysis of the measured variables demonstrated variation in incisive canal dimensions and spatial relationships across the study population. The mean incisive canal length (ICL) was higher in males compared to females. Similarly, IC width measurements at upper, middle, and lower levels, as well as linear distances (Dr, Dmid, Do) and angular parameters (θ1, θ2, θ3), showed variability within and between gender groups (Figure 1). These descriptive statistics, including means and standard deviations for all variables stratified by gender, are presented in Table 1.

Across skeletal malocclusion groups, the distribution of IC dimensions and positional measurements appeared relatively consistent. Mean values of ICL, IC width at different levels, and angular relationships were comparable among Class I, Class II, and Class III groups, as detailed in Table 2.

Outcome data

The primary outcome measures included differences in IC morphology and the spatial relationship between the maxillary central incisor (MCI) root and the incisive canal. A statistically significant difference was observed in ICL between genders, with males demonstrating significantly greater canal length (13.6 ± 1.57 mm) compared to females (12.05 ± 1.79 mm) ($p < 0.001$), as shown in Table 1. However, no statistically significant gender differences were found for IC width at any level, linear distances (Dr, Dmid, Do), or angular measurements (θ1, θ2, θ3) ($p > 0.05$).

When analyzed across skeletal malocclusion groups, no statistically significant differences were identified for any of the measured variables, including ICL, IC width, linear distances, or angular parameters ($p > 0.05$), as presented in Table 2.

Main results

The analysis of spatial relationships revealed a consistent anatomical pattern across all skeletal malocclusion groups. The shortest distance between the maxillary central incisor root and the incisive canal was observed at the oral level (Do), followed by the middle (Dmid) and nasal levels (Dr),

indicating a progressively increasing distance from oral to nasal regions. Despite this consistent trend, no statistically significant differences were observed among Class I, Class II, and Class III groups at any measurement level ($p > 0.05$), as detailed in Table 2.

The findings highlight that while gender significantly influences incisive canal length, skeletal malocclusion does not appear to have a significant impact on the morphology of the canal or its spatial relationship with maxillary central incisors. The consistent proximity pattern observed at different canal levels provides clinically relevant insight for orthodontic treatment planning, particularly in minimizing the risk of root resorption.

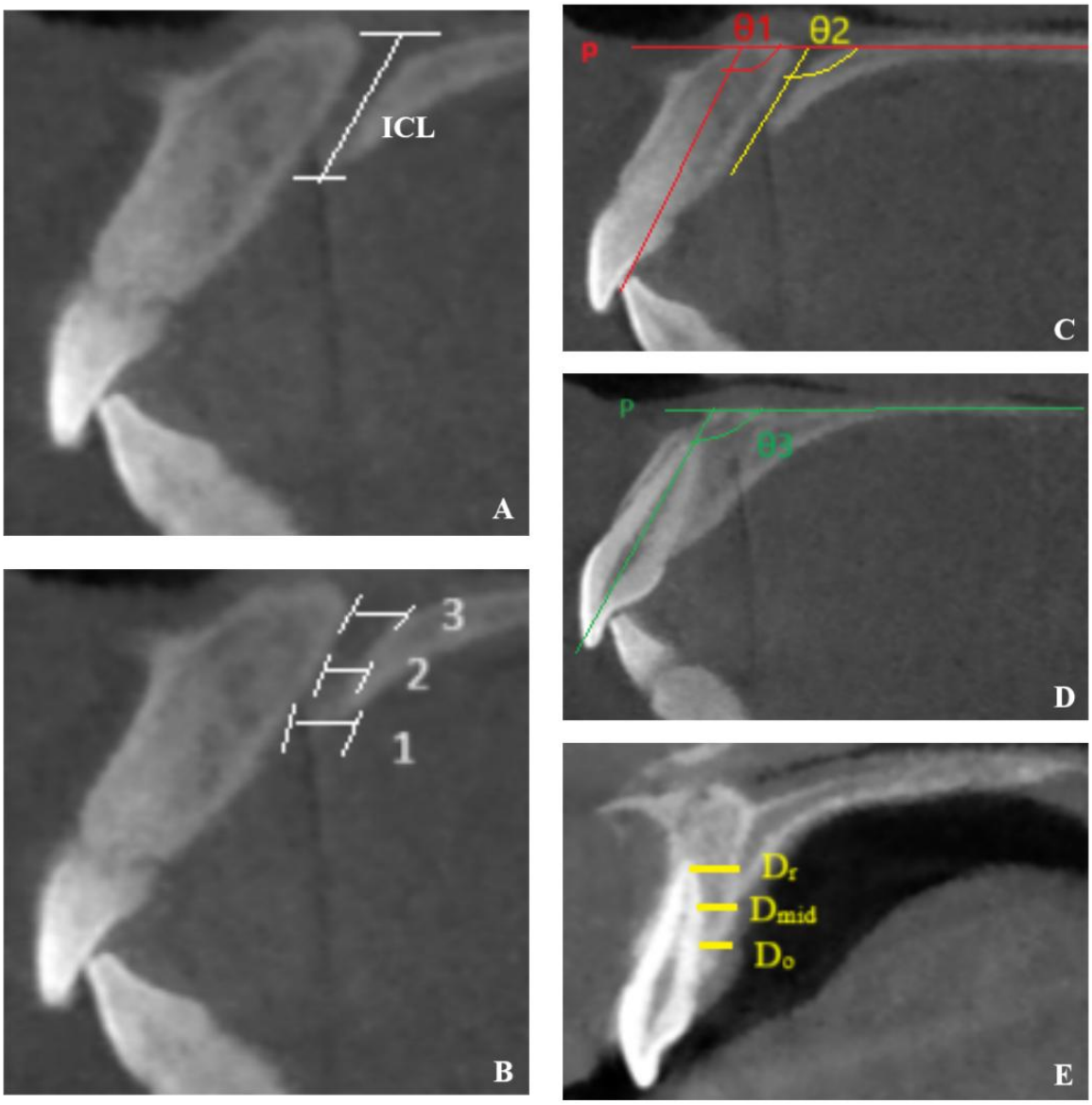


Figure 1. Landmarks, linear and angular measurements on CBCT images (A) ICL: the distance from centre of nasal to oral opening of IC (B) The IC width in anteroposterior diameter were measured 1: upper level (at the nasal opening), 2: middle level (midpoint of the nasopalatine canal), and 3: lower level (at the oral opening); (C) Angular measurements — θ1 and θ2 represent the angles formed between palatal plane and the axes of maxillary alveolar border and the IC, respectively; (D) θ3 denotes angle between palatal plane and the axis of the MCI; (E) Distances (D) from the MCI to the IC— measured at three points: Dr (upper), Dmid (middle), and Do (lower). *(Photographs reproduced with the permission of the patient).*

Table 1: The difference in IC variables between male and female subjects

Variables	Gender	N	Mean	Std. Deviation	p-value
ICL (mm)	Male	43	13.6	1.57	<0.001*
	Female	41	12.05	1.79	
IC Width at Lower level (mm)	Male	43	2.27	1.13	0.330
	Female	41	2.37	0.72	
IC Width at Middle level (mm)	Male	43	1.73	1.05	0.776
	Female	41	1.51	0.62	
IC Width at Upper level (mm)	Male	43	1.80	1.28	0.461
	Female	41	1.70	1.20	
Dr (mm)	Male	43	3.44	1.55	0.370
	Female	41	3.11	1.19	
Dmid (mm)	Male	43	3.04	1.18	0.673
	Female	41	2.90	1.08	
Do (mm)	Male	43	2.79	1.05	0.683
	Female	41	2.64	0.84	
θ1 (Degrees)	Male	43	112.23	8.83	0.819
	Female	41	111.19	8.84	
θ3 (Degrees)	Male	43	109.36	18.98	0.939
	Female	41	111.34	9.86	
θ2 (Degrees)	Male	43	105.05	10.77	0.378
	Female	41	107.27	10.60	

Table 2: Comparison of incisive canal variables among various sagittal skeletal patterns.

Variable	Class I (n=30)	Class II (n=30)	Class III (n=24)	Min	Max	p-value
ICL (mm)	12.56 ± 1.99	12.81 ± 1.68	13.29 ± 1.87	8.00	15.80	0.511
IC Width at Lower level (mm)	2.37 ± 0.83	2.40 ± 1.16	2.18 ± 0.81	0.70	5.90	0.830
IC Width at Middle level (mm)	1.66 ± 0.69	1.63 ± 0.94	1.59 ± 1.02	0.60	5.80	0.337
IC Width at Upper level (mm)	1.66 ± 1.05	1.30 ± 0.63	2.45 ± 1.70	0.50	4.80	0.098
Dr (mm)	3.41 ± 1.08	3.28 ± 1.89	3.13 ± 1.00	0.60	8.60	0.646
Dmid (mm)	3.15 ± 1.05	2.95 ± 1.40	2.79 ± 0.85	0.60	6.40	0.339
Do (mm)	2.84 ± 0.85	2.77 ± 1.25	2.52 ± 0.59	0.90	5.90	0.581
θ1 (Degrees)	111.90 ± 8.96	112.53 ± 8.62	110.50 ± 9.07	94.00	137.00	0.816
θ2 (Degrees)	104.21 ± 9.29	107.50 ± 11.91	106.83 ± 10.79	82.00	131.00	0.538
θ3 (Degrees)	109.52 ± 8.39	110.97 ± 22.45	110.54 ± 10.27	3.00	138.00	0.196

Kruskal-Wallis test. *p-value ≤0.05.

Discussion

Orthodontic tooth movement, particularly involving the maxillary central incisors (MCI), carries an inherent risk of root contact with adjacent anatomical structures such as the incisive canal (IC), potentially leading to root resorption. A comprehensive understanding of the morphology and spatial relationship of the IC is therefore essential to optimize treatment planning and minimize iatrogenic complications.

The present study evaluated key morphometric parameters of the IC and its proximity to the MCI across different skeletal malocclusion patterns and gender.[11,12] A significant finding was the presence of gender-based differences in incisive canal length (ICL), with males demonstrating greater canal length than females. This observation is consistent with previous studies conducted in different populations, including those by Acar et al. [13] and Rai et al. [14], both of which reported significantly longer IC in males. However, contrasting findings have been reported by Panda et al. [15], who found no statistically significant gender differences, suggesting that population-specific anatomical variations may influence IC morphology.

In addition to canal length, the study assessed IC width at three different levels. The findings indicated that the canal tends to be widest at the lower (oral) level and gradually narrows toward the middle and upper (nasal) levels, particularly in Class I and Class II malocclusions. Similar patterns have been reported by Bornstein et al. [16] and Milanovic et al. [17], although these studies did not evaluate variations across skeletal malocclusion groups. This highlights the importance of incorporating malocclusion classification into anatomical assessments for more clinically relevant interpretations.

A key finding of this study was the consistent pattern of proximity between the MCI root and the IC across all skeletal malocclusion groups. The shortest distance was observed at the oral level (Do), followed by the middle (Dmid) and nasal (Dr) levels. This finding aligns with previous research by Arnaut et al. [10] and Matsumura et al. [18], which also demonstrated closer proximity at the oral opening of the canal. Clinically, this suggests that the apical region near the oral opening represents a critical zone where orthodontic tooth movement may pose a higher risk of root contact and subsequent resorption.

Interestingly, no statistically significant differences were observed in IC morphology or MCI proximity among different skeletal malocclusion groups. These findings are in agreement with studies by Ishii et al. [2] and Costa et al. [7], which reported minimal influence of sagittal skeletal patterns on this anatomical relationship. However, Jang et al. [19] reported reduced distances in Class II malocclusion, particularly at the nasal level (Dr), indicating potential variability depending on population characteristics or methodological differences.

Importantly, previous literature suggests that incisor inclination may have a more substantial impact on IC proximity than skeletal classification. Ishii et al. [2] demonstrated a negative correlation between labial inclination of incisors and the distance to the IC, emphasizing the role of tooth positioning in determining risk.[18,19] This underscores the need for individualized treatment planning, especially in cases requiring significant incisor movement, such as camouflage treatment in Class II malocclusion. In such cases, increased retraction may bring the roots closer to the palatal cortex and IC, thereby elevating the risk of root resorption [20].

The clinical relevance of these findings lies in the identification of anatomical risk zones and patient-specific variations. CBCT imaging has proven to be an invaluable tool in accurately assessing the morphology of the IC and its relationship with MCI roots, allowing clinicians to plan orthodontic interventions more safely and effectively [21].

Conclusion

This study provides valuable insights into the morphological characteristics of the incisive canal and its spatial relationship with maxillary central incisors. The findings demonstrate that incisive canal length is significantly greater in males, while other morphometric parameters show no significant gender differences.

Importantly, the spatial relationship between the incisive canal and maxillary central incisors remains consistent across different skeletal malocclusion patterns. The closest proximity at the oral level highlights a critical anatomical zone that may be particularly susceptible to root contact during orthodontic tooth movement.

Authors' Contributions:

All authors meet the ICMJE criteria for authorship.

Author 1: Substantial contribution to conception and design, drafting the manuscript, final approval, agreed to be accountable for all the work.

Author 2: Substantial contribution to conception and design, data acquisition, drafting the manuscript, final approval, agreed to be accountable for all the work.

Author 3: Analysis and interpretation of data, drafting the manuscript, final approval, agreed to be accountable for all the work.

Author 4: Analysis and interpretation of data, critical revision, final approval, agreed to be accountable for all the work.

Author 5: Substantial contribution to conception and design, drafting the manuscript, final approval, agreed to be accountable for all the work.

Author 6: Substantial contribution to conception and design, data acquisition, drafting the manuscript, final approval, agreed to be accountable for all the work.

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