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ORIGINAL RESEARCH

EVALUATION OF THE RELATIONSHIP BETWEEN MAXILLARY CENTRAL INCISORS AND THE INCISIVE CANAL: A CONE-BEAM COMPUTED TOMOGRAPHY STUDY

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ABSTRACT

Purpose: To analyze the anatomical association between maxillary central incisor (MCI) roots and the incisive canal (IC) by cone-beam computed tomography (CBCT) and to evaluate the influence of age and sex.
Materials and Methods: A retrospective cross-sectional investigation was conducted on 153 Yemeni subjects (80 female, 73 male; age range: 16–45 years). Linear and angular measurements between MCI and IC were recorded through standardized multiplanar reconstructions. Key parameters measured were inter-root distance, IC width, anterioposterior (AP) distance between the root of the maxillary incisor and the incisive canal, and palatal alveolar bone width (PABW).
Results: The IC was located below the incisor apex in 74.5% of the cases. The IC width at the apex (mean 3.97 mm) exceeded the inter-root distance (mean 3.83 mm). Males exhibited significantly larger AP distances and palatal IC widths compared to females. IC width increased with age, particularly at the apex. A strong correlation was observed between AP distance and PABW (r = 0.467), especially in females (r = 0.628).
Conclusion: The IC tended to be located below the root apex. The width of the incisive canal frequently exceeded the distance between the roots of the maxillary central incisors, particularly in females and in older individuals, creating a high-risk anatomical region susceptible to iatrogenic complications with orthodontic retraction of the incisors. CBCT is crucial for personalized treatment planning in these instances.

***Keywords*:** Incisive canal, maxillary central incisors, CBCT, orthodontic planning, anatomical variation

INTRODUCTION

The maxillary central incisors (MCI) are crucial to facial esthetics, phonetics, and masticatory function[1]. Due to their prominent anterior position, they are often the focus of orthodontic concern in patients with maxillary protrusion or dental crowding[2]. However, the inherent anatomical limitations of the anterior maxilla should be well evaluated before initiating tooth movement[3].

Of these constraints, the incisive canal (IC), which

serves as the pathway for the nasopalatine nerve and vasculature, is a significant anatomical one.
Orthodontic retraction in contact with the IC can precipitate potentially catastrophic complications, including apical root resorption, alveolar bone dehiscence, and neurosensory loss, like palatal paresthesia[4].
Traditionally applied 2D imaging modalities, though helpful, are ineffective in assessing the complex spatial relationship of anterior maxilla. Cone-beam computed tomography (CBCT) has revolutionized craniofacial imaging by enabling accurate 3D evaluation of anatomical structures. CBCT is most beneficial in visualizing the lateral relationship of the MCI roots to the IC, an essential factor in planning a safe and effective orthodontic treatment. For cases requiring aggressive retraction (e.g., camouflage treatment with TADs) to avoid root resorption and nerve damage[5].
In orthodontic treatment, the anatomical relationship between the maxillary central incisors and the incisive canal is are important consideration. Inadequate appreciation of this relationship may lead to problems such as nerve damage, sensory disturbance, vascular trauma, or root resorption[6–8]. Importantly, the proximity of maxillary central incisor roots to the cortical walls of the incisive canal has been related to root resorption, particularly in maximum orthodontic retraction[9].
Additionally, the orthodontists assess the shape of the incisive canal and determine the extent to which its posterior movement goes based on the distance between the incisive canal and the maxillary central incisors before treatment. This is to avoid root resorption as an orthodontic outcome[10,11].
Prior research has repeatedly highlighted the clinical significance of this anatomical relationship, noting that the incisive canal (IC) is typically apical to the maxillary central incisors and wider than the inter-root distance[12]. In addition, one study discovered that in more than 60% of cases, the IC width was greater than the inter-root distance. This means that there was less room for safety while retracting the incisors[3].
Anatomical variation among ethnic groups continues to throw a spanner in the works. IC shape, AP distance, and canal width differences have all been found to influence treatment outcomes in studies[9,13,14]. Despite the Increased international literature, there remains a wide lack of information. Since craniofacial anatomy is ethnically variable, locally derived studies are required for optimal risk assessment and treatment planning[15].
This study aims to fill this gap by evaluating the correlation between the maxillary central incisors and the incisive canal, determining age and gender anatomical variations using cone-beam computed tomography (CBCT), and establishing its implications for orthodontic diagnosis and treatment planning.

2. MATERIAL AND METHODS

Study Design and Ethical Approval

This retrospective, cross-sectional study was conducted on CBCT images taken for diagnostic purposes. Ethical permission was granted by the Medical Ethics Committee of the Faculty of Dentistry, Sana'a University (Ref. No.: 703; Date: 2/8/2024). All patient identifiers were anonymized for confidentiality *with the ethical principles outlined in the Declaration of Helsinki.*

Study Population and Sampling:

The present retrospective cross-sectional study was conducted in the Orthodontic Department, Faculty of Dentistry, Sana'a University, among a group of Yemeni adult population. The relationship between IC position and MCI. CBCT images of 153 Yemeni patients (80 female, 73 male), 16-45 years old, were retrospectively assessed. Data was collected from November 2024 to February 2025 from Al-Weed X-ray center in Sana'a. The initial sample size was calculated using the formula for quantitative variables with a 10% margin of error and a 95% level of confidence. Taking an anticipated population proportion of 50% (historical research), a sample size of at least 96 was calculated. The expansion of the sample to 153 was to provide greater statistical power, greater generalizability, and allowance for possible exclusions.

Study Procedure

CBCT scans were used to assess IC position. The CBCT was taken from a PaX-i3D Green CBCT system (Model: PHT-60CFO; Vatech Co., Hwaseong, Korea). The acquired images were exported and saved in multi-file Digital Imaging and Communications in Medicine (DICOM) format to be analyzed later using Carestream's CS 3D Imaging software. From Al-Weed X-ray center.
The CBCT images were processed and analyzed using Carestream's CS 3D Imaging software on an HP laptop equipped with a 64-bit Windows 10 operating system. The image interpretation was performed on a 15.6-inch full HD display screen with a resolution of 1920 × 1080 pixels. All the image measurements were performed in ambient-free, low-lighting conditions to prevent glare and visual distraction.
In the software, image adjustment tools were used to alter parameters such as contrast, sharpness, and brightness. The alterations enhanced image clarity and allowed for proper visualization of anatomical structures, and therefore proper and reliable

interpretation of the maxillary central incisors and the incisive canal.

All cone-beam computed tomography (CBCT) scans were oriented at the level of the palatal plane (from the posterior nasal spine to the anterior nasal spine) as the primary reference in the sagittal view. Standardized, reproducible multiplanar reconstructions were used to obtain sagittal and axial images using the suture line at the midpalate as the reference, and coronal images were obtained using the line between the right and left greater palatine foramina to ensure repeatability and consistency of linear and angular measurements **(Table 1 and Figure**

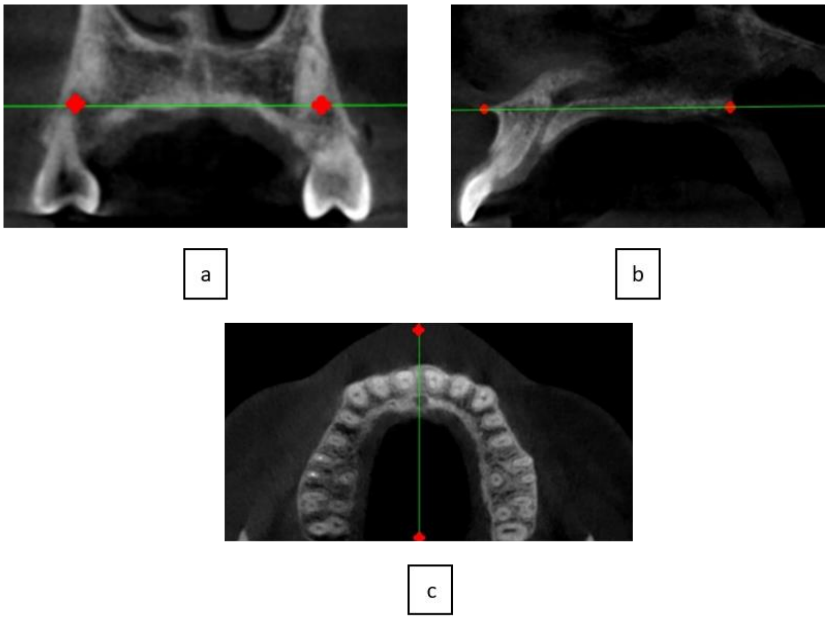

Figure 1. The images show (a) sagittal construction, horizontal plane passing palatal plane from ANS to PNS (b) axial construction, plane passing through midpalatal suture, (C) coronal construction, plane passing through greater palatine foramina on two sides

Table 1. Linear and angular measurements

Linear and angular measurements	
Sagittal Measurements	➢ Incisor/Palatal Plane Angle (CI/PP) ➢ Incisive Canal/Palatal Plane Angle (IC/PP) ➢ Palatal Alveolar Bone Width (PABW) at the apical level ➢ IC Width at palatal opening
Axial Measurements	➢ Inter-root Distance (IRD) ➢ IC Width at root apex ➢ Anteroposterior Distance 1 (AP): From medial root surface to anterior IC wall ➢ Anteroposterior Distance 2 (AP2): From posterior root surface to lateral IC wall
Vertical Positional Classification	The vertical association between the IC and root apex was classified as: ➢Above the apex ➢At the apex ➢Below the apex

Reliability Testing:

For ascertaining the accuracy of measurement, intra- and inter-examiner reliability were evaluated:

- Intra-examiner reliability: 20% of the images were re-measured two weeks post-first measurement.
- Inter-examiner reliability: A radiographic technician independently examined 10 randomly chosen images.
- Statistical validation: Intraclass correlation coefficients (ICCs) were computed and revealed excellent agreement, from 0.765 to 1.000.
- **Statistical Analysis**

- Data was analyzed using IBM SPSS Statistics (Version 28.0). The Shapiro–Wilk test was used to assess the normality of the data. Descriptive statistics included mean, standard deviation, and frequencies. Independent t-tests and Mann–

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Whitney U tests were used for gender comparisons. ANOVA and Kruskal–Wallis tests were used for age group comparisons. Pearson's correlation coefficient (r) assessed associations between continuous variables. A p-value of < 0.05 was considered statistically significant.

3. RESULTS

A total of 153 CBCT scans were analyzed, comprising 80 females (52.3%) and 73 males (47.7%). Most participants (58.8%) were aged between 20-30 years. The vertical position of the incisive canal (IC) relative to the maxillary central incisor (MCI) root apex was classified as follows:

Gender Comparison of Anatomical Parameters (Mann–Whitney U Test)

Comparative analysis was conducted using the Mann–Whitney U test. Analysis of gender differences in the MCI–IC relationship showed that most parameters were comparable between males and females. However, males had a significantly greater palatal IC width (3.59 mm vs. 3.33 mm, $p = 0.029$) and anteroposterior (AP) distance (3.88 mm vs. 3.54 mm, $p = 0.023$). These differences suggest that males tend to have slightly more lateral and sagittal clearance between the incisive canal and the maxillary central incisor roots, potentially reducing the risk of root–canal contact during orthodontic tooth movement **(Table 2)**.

Table 2. Gender Comparison of Anatomical Parameters (Mann–Whitney U Test)

Measurement	Female (Mean)	Male (Mean)	p-value
CI/PP angle (°)	110.44	112.48	0.079
IC/PP angle (°)	108.89	109.73	0.524
PABW (mm)	3.27	3.26	0.693
IC Width Palatal (mm)	3.33	3.59	**0.029***
IC Width at Apex (mm)	4.04	3.89	0.355
Inter-root Distance (mm)	3.83	3.84	0.926
AP Distance (mm)	3.54	3.88	**0.023***
AP2 Distance (mm)	2.83	2.98	0.176

*statistically significant at p<0.05

Anatomical Measurements by Age Group (Kruskal–Wallis Test)

Participants were divided into three age groups. The Kruskal–Wallis test was used to analyze differences among them. When comparing IC and MCI anatomical parameters across age groups (<20, 20–30, and >30 years), the only statistically significant change was in IC width at the apex ($p = 0.010$). This width increased progressively with age from 3.53 mm in the youngest group to 4.26 mm in the oldest. This widening is likely due to physiological bone remodeling or canal expansion over time, which reduces the available vertical bone between the IC and incisor roots in older individuals. Although other measurements did not reach statistical significance, slight trends (such as reduced AP distance with increasing age) may still hold clinical relevance **(Table 3)**.

Table 3. Anatomical Measurements by Age Group (Kruskal–Wallis Test)

Measurement	<20 years	20–30 years	>30 years	p-value
CI/PP angle (°)	111.82	111.43	111.22	0.869
IC/PP angle (°)	108.65	109.12	109.85	0.728
PABW (mm)	3.59	3.13	3.43	0.145
IC Width Palatal (mm)	3.43	3.36	3.64	0.200
IC Width at Apex (mm)	3.53	3.90	4.26	**0.010***
Inter-root Distance (mm)	3.37	3.90	3.88	0.070
AP Distance (mm)	4.07	3.70	3.57	0.604
AP2 Distance (mm)	2.98	2.86	2.96	0.148

*statistically significant at p<0.05

Pearson Correlation Between AP Distance and Selected Variables:

Pearson correlation was used to evaluate relationships among continuous variables. The analysis identified palatal alveolar bone width (PABW) as significantly and positively correlated with AP distance ($r = 0.467$, $p < 0.001$). This means individuals with thicker palatal bone generally have greater sagittal clearance between the MCI apex and the

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IC, creating a protective buffer during tooth movement. No meaningful correlations were observed between AP distance and other variables such as age, IC widths, or angular measures. Clinically, this underscores PABW as an important anatomical predictor for safe incisor retraction, particularly for patients with inherently limited sagittal space **(Table 4)**.

Table 4. Pearson Correlation Between AP Distance and Selected Variables

Variable	Correlation (r)	p-value
CI/PP Angle	0.070	0.387
IC/PP Angle	0.064	0.434
Age	–0.027	0.744
PABW	**0.467**	**<0.001**
IC Width Palatal	0.101	0.216
IC Width at Apex	–0.082	0.313
Inter-root Distance	0.003	0.973

*statistically significant at $p<0.05$

4. DISCUSSION

This study is the initial comprehensive CBCT-based investigation of the anatomical relationship between the maxillary central incisors (MCI) and the incisive canal (IC) among Yemeni individuals. The findings indicate several clinically relevant anatomical relationships with direct treatment planning implications in cases of orthodontic incisor retraction or intrusion. The most noteworthy result was that within 74.5% of the population, the IC was located below the apex of the root[12].

This configuration increases the prospect of direct root contact with the IC during orthodontic movement, leading to root resorption, perforation of the alveolar bone, or neurosensory impairment, as indicated by previous studies[16].

Dimensionally, the mean IC width at the apex (3.97 mm) was larger than the mean inter-root distance (3.83 mm). This means that, in the majority of cases, the IC will be wider than the available bone width between roots, excluding the "safe zone" traditionally used for retraction[17].

The same has been noticed in other cohorts, supporting the application of individualized evaluation rather than standardized limits (e.g., 5.5–7 mm retraction guidelines)[7]. Notably, the gender differences also manifested: males demonstrated significantly greater AP distances and larger palatal IC widths compared to females[18].

These values suggest that incisor movement may be more anatomically favorable in male patients with larger sagittal clearance and less chance of IC involvement[19]. Conversely, female patients, especially those with smaller inter-root spacing and less bone width of the palate, may be at increased risk for iatrogenic events and more conservative treatment planning. These observations are consistent with prior study evidence and demonstrate the value of gender-specific risk analysis[13]

Age-related changes also became apparent, and the most significant was the extensive widening of IC at the apex with increasing age[20]. This may be due to physiological bone remodeling or canal expansion over a period. Clinicians need to understand that adult patients, most significantly those older than 30 years of age, may have anatomical constraints not present in adolescents and require adequate pre-treatment imaging[21].

One major clinical observation was the favorable correlation between palatal alveolar bone width (PABW) and AP distance ($r = 0.467$), but even more so in women ($r = 0.628$). This would indicate there is greater sagittal space available for patients with thicker palatal bones and, as such, a potential protective cushion[22].

These results collectively illustrate the anatomical variability and complexity of the MCI–IC relationship with the awareness that orthodontic tooth movement must remain within individualized biological limits. Classical reliance on lateral cephalograms or population averages is perhaps insufficient and, in some cases, risky.

5. CONCLUSION

The results of this study show that the connection between the maxillary central incisors and the incisive canal in Yemeni individuals varies greatly and is affected by both gender and age. These changes in anatomy have a direct effect on how orthodontic treatment is planned. Furthermore, this means that female patients are more likely to have complications related to IC and should have more careful treatment plans. Additionally, a significant increase in IC width at the apex was observed with age, validating a requirement for greater sensitivity in adult orthodontic treatment.

DECLARATIONS

Ethical approval and consent to participate

Ethical permission was granted by the Medical Ethics Committee of the Faculty of Dentistry, Sana'a University (Ref. No.: 703; Date: 2/8/2024). All patient identifiers were anonymized for confidentiality *with the ethical principles outlined in the Declaration of Helsinki.*

Availability of data and material

All data generated or analyzed during this study are included in the published article.

Competing interests

The authors declare that there are no competing interests.

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