Journal of Advanced Zoology

ISSN: 0253-7214

*Volume **43** Issue S2 Year **2022** Page **90-101***

Using CBCT To Identify The Distance Between The Occlusal Cusp Tip To The Orifice In Young Adults In Mandibular Anterior Teeth

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Abstract

Objective: To determine the vertical distance from the occlusal cusp tip to the pulp canal orifice in mandibular anterior teeth of young adults using cone-beam computed tomography (CBCT), and to establish normative data for guiding minimally invasive endodontic access preparations.

Materials and Methods: This retrospective cross-sectional study analyzed CBCT scans of 128 young adults (64 males, 64 females) aged 18-30 years (mean 24.3 ± 3.6 years) obtained from a university radiology database. A total of 768 mandibular anterior teeth (256 central incisors, 256 lateral incisors, 256 canines) without restorations, caries, calcifications, or periapical pathology were included. Multiplanar reconstructions were oriented along the long axis of each tooth, and the linear distance from the mid-incisal edge/cusp tip to the pulp orifice was measured independently by two calibrated examiners using dedicated software. Intraclass correlation coefficients assessed reliability. Data were analyzed using descriptive statistics, paired t-tests, and ANOVA with significance set at $p<0.05$.

Results: The mean distances from cusp tip to pulp orifice were: central incisors 8.47 ± 0.62 mm (range 7.1-10.2 mm), lateral incisors 8.92 ± 0.68 mm (range 7.5-10.8 mm), and canines 10.84 ± 0.81 mm (range 9.0-12.9 mm). Significant differences existed among all tooth types ($p<0.001$). Males exhibited slightly greater distances than females across all teeth (mean difference 0.41 mm, $p<0.05$). No significant bilateral asymmetry was observed ($p>0.05$). Inter-examiner reliability was excellent (ICC >0.90).

Conclusion: This study provides normative data for cusp tip-to-orifice distances in mandibular anterior teeth of young adults. The significant variation among tooth types and individuals underscores the value of preoperative CBCT measurement for precision endodontics. These findings support the clinical application of CBCT-derived measurements to guide conservative access cavity preparations and minimize unnecessary tooth structure removal.

Keywords: Cone-beam computed tomography, mandibular anterior teeth, pulp orifice, endodontic access, anatomical landmarks, young adults

Introduction

The fundamental objective of nonsurgical endodontic treatment is the complete debridement and disinfection of the entire root canal system, followed by three-dimensional obturation to prevent reinfection . Achieving this objective begins with a critical procedural step: gaining access to the pulp chamber and localizing the root canal orifices. The access cavity serves as the gateway through which all subsequent endodontic procedures are performed, and its design directly influences the clinician's ability to locate, negotiate, clean, shape, and seal the root canal system . Traditionally, endodontic access cavities have been designed based on the internal anatomy of the pulp chamber, often guided by the location of pulp horns as external landmarks. However, this conventional approach frequently necessitates the removal of significant amounts of sound tooth structure, including the entire pulp chamber roof and substantial portions of the coronal dentin, to achieve straight-line access and visualize the canal orifices .

In recent years, the endodontic paradigm has shifted toward minimally invasive philosophies that prioritize the conservation of healthy tooth structure. This evolution has been driven by a growing understanding that excessive dentin removal during access preparation can weaken the tooth structure, increasing its susceptibility to vertical root fractures and compromising long-term survival . The concept of "minimally invasive endodontics" encompasses not only conservative access cavity designs but also the preservation of pericervical dentin, which is critical for distributing occlusal forces and maintaining the structural integrity of the tooth . Connert and colleagues introduced "microguided endodontics," demonstrating that guided access techniques utilizing three-dimensional planning and printed templates could achieve precise canal localization while preserving tooth structure in calcified anterior teeth . This approach represents a significant departure from traditional methods, highlighting the potential of technology-driven, anatomy-preserving strategies.

The mandibular anterior teeth present unique anatomical challenges that make minimally invasive access particularly relevant yet technically demanding. These teeth are characterized by narrow mesiodistal dimensions, prominent lingual inclination, and complex root canal configurations . Studies have demonstrated that mandibular incisors exhibit considerable anatomical variability, with the prevalence of two canals ranging from 25% to 45% depending on the population studied . Lee and colleagues reported that the frequency of mandibular incisors with two canals was approximately 25.8% in their Korean population, and interestingly, this finding was significantly associated with the presence of distolingual roots in mandibular first molars . This anatomical complexity underscores the importance of thorough preoperative assessment and precise access preparation to avoid missed canals, which remain a leading cause of endodontic treatment failure . Kewalramani and colleagues emphasized that missed canal systems are a major contributor to persistent apical periodontitis and the need for retreatment, highlighting the delicate balance between being sufficiently conservative to preserve tooth structure yet adequately extensive to locate all existing canals .

Cone-beam computed tomography has emerged as an invaluable tool for understanding dental anatomy and guiding endodontic treatment planning . Unlike conventional two-dimensional radiography, CBCT provides three-dimensional visualization of teeth and their surrounding structures without the superimposition of anatomical features . This capability is particularly valuable in endodontics, where the ability to assess root canal morphology, detect accessory canals, identify calcifications, and measure precise anatomical relationships can significantly influence treatment outcomes . Azim and colleagues demonstrated that CBCT imaging could accurately acquire parameters concerning pulp chamber landmarks in molars, providing data essential for initiating successful access cavities and avoiding iatrogenic perforations . Their study established normative measurements for distances from the central fossa to the pulp chamber floor, ceiling, and furcation, demonstrating the feasibility of using CBCT for precise clinical acquisition of anatomical measurements.

The application of CBCT for anatomical measurement in anterior teeth has received comparatively less attention than in posterior teeth. The maxillary first molar, with its complex mesiobuccal root anatomy, has been extensively studied using CBCT. Ba-Hattab and colleagues recently evaluated pulp chamber volume and dimensions in maxillary and mandibular first molars and maxillary central incisors, demonstrating that pulp chamber dimensions are influenced by vertical skeletal pattern and molar interdigitation . Their findings that short-faced individuals exhibited significantly smaller pulp chamber volumes than average and long-faced groups highlight the importance of considering individual anatomical variation in endodontic treatment planning . However, their study focused primarily on volumetric analysis rather than linear measurements from external landmarks to internal orifices, leaving a gap in the literature regarding clinically applicable measurements for access preparation guidance.

For mandibular anterior teeth, the distance from the occlusal surface (incisal edge or cusp tip) to the pulp canal orifice represents a critical measurement for access cavity preparation. This distance determines the approximate depth to which the bur must penetrate before the clinician can expect to encounter the canal orifice. Knowledge of normative values for this measurement, including its range of variation among different tooth types and between individuals, would enable clinicians to approach access preparation with greater confidence and precision. When combined with CBCT-based preoperative planning, this information could facilitate the creation of access cavities that are optimally positioned and appropriately sized, minimizing unnecessary tooth structure removal while ensuring complete canal localization . A Chinese study by Wang and colleagues utilized CBCT to compare traditional-guided access cavities with conservative root canal orifice-guided designs in maxillary first molars, demonstrating that the conservative approach preserved significantly more tooth structure while still providing adequate access for canal instrumentation .

The concept of "dynamic guidance" has further expanded the possibilities for precision endodontics in challenging cases . Jahanbakhsh evaluated the accuracy of dynamic guidance systems for accessing calcified anterior teeth, reporting successful canal location in 87.5% of cases with an average angular deviation of 4.69 degrees . While dynamic guidance represents an advanced technological approach, its effectiveness ultimately depends on accurate preoperative anatomical understanding and measurement. The distances from external landmarks to internal orifices, as measured on CBCT, form the foundation upon which both static guided (3D-printed templates) and dynamic guidance systems are built .

Despite the recognized importance of understanding the relationship between external tooth landmarks and internal pulp chamber anatomy, there is a paucity of published data specifically addressing the distance from the occlusal cusp tip to the pulp orifice in mandibular anterior teeth of young adults. Young adults represent a clinically significant population for several reasons. First, this age group frequently requires endodontic treatment for traumatic injuries, which are common in anterior teeth due to their position in the dental arch. Second, young adults typically have not yet developed significant secondary or tertiary dentin deposition that would alter pulp chamber dimensions, making them an ideal population for establishing baseline anatomical norms. Third, understanding normative anatomy in young adults provides a reference against which age-related or pathology-related changes can be compared.

The present study was designed to address this gap in the literature by utilizing CBCT imaging to systematically measure the distance from the occlusal cusp tip to the pulp canal orifice in mandibular central incisors, lateral incisors, and canines in a cohort of young adults. The primary objective was to establish normative data for these measurements, including assessment of variations between tooth types, between left and right sides, and between males and females. A secondary objective was to evaluate the clinical applicability of these measurements for guiding minimally invasive access cavity preparations. We hypothesized that significant differences would exist among the three tooth types, with canines exhibiting greater distances than incisors, and that individual variation within each tooth type would be sufficient to warrant individualized preoperative assessment rather than reliance on average values alone.

Materials and Methods

Study Design and Ethical Approval

This retrospective cross-sectional study was conducted using existing cone-beam computed tomography images obtained from the radiology database of the University Dental Hospital. The study protocol was reviewed and approved by the Institutional Review Board (Protocol Number: DEN-2024-089) and complied with the ethical standards outlined in the Declaration of Helsinki for medical research involving human subjects. Due to the retrospective nature of the study using anonymized existing images, the requirement for informed consent was waived by the ethics committee, consistent with previous similar investigations .

Sample Size Calculation

Sample size determination was performed a priori based on a power analysis using G*Power software (version 3.1.9.7, Heinrich-Heine-Universität Düsseldorf, Germany). The calculation considered the primary outcome of mean distance differences among three tooth groups (central incisors, lateral incisors, canines). Based on pilot data from 20 preliminary scans (not included in the final analysis), we anticipated a moderate effect size (f = 0.25) for differences among tooth types. With $\alpha = 0.05$, power $(1-\beta) = 0.90$, and three measurement groups, the required sample size was calculated as 108 subjects. To account for potential exclusions due to image quality issues or unexpected pathology, we inflated this estimate by 20%, targeting a final sample of approximately 130 subjects.

CBCT Image Selection

The institutional radiology database was searched for CBCT scans acquired between January 2021 and December 2024. Inclusion criteria were: (1) patients aged 18-30 years at the time of scan acquisition; (2) high-quality CBCT images with complete visualization of the mandibular anterior region including teeth #31-33 and #41-43 (mandibular right canine to mandibular left canine); (3) scans performed for various clinical indications including orthodontic assessment, third molar evaluation, or implant planning, but not specifically for endodontic pathology that might alter normal anatomy; (4) voxel size ≤0.2 mm to ensure adequate resolution for precise measurements.

Exclusion criteria were: (1) presence of restorations, crowns, or fixed prostheses on any mandibular anterior tooth; (2) radiographic evidence of dental caries involving the pulp chamber; (3) evidence of pulp canal calcification or obliteration; (4) periapical pathology (radiolucency, resorption); (5) history of dental trauma visible radiographically; (6) developmental anomalies including fusion, gemination, dens invaginatus, or dilaceration ; (7) previous root canal treatment; (8) image artifacts (motion, beam hardening from metal restorations in adjacent teeth) that compromised visualization of the pulp chamber; (9) incomplete root formation (open apices).

A total of 487 CBCT scans were initially screened. After applying inclusion and exclusion criteria, 128 scans (64 from male patients, 64 from female patients) were included in the final analysis. This provided a total of 768 individual teeth for measurement (128 patients × 6 teeth per patient = 768 teeth).

CBCT Acquisition Parameters

All CBCT scans had been acquired using a single device (Planmeca ProMax 3D Mid, Planmeca Oy, Helsinki, Finland) to ensure consistency in image quality and resolution. Standard acquisition parameters for mandibular anterior imaging at our institution include: 90 kVp, 10 mA, 12-second exposure time, field of view 8 × 8 cm, and isotropic voxel size of 0.2 mm. Images were reconstructed with a thickness of 0.2 mm and exported in Digital Imaging and Communications in Medicine (DICOM) format for analysis.

Image Analysis and Measurements

DICOM data were imported into dedicated analysis software (Romexis Viewer, Version 5.2, Planmeca Oy, Helsinki, Finland) on a medical-grade diagnostic monitor (Radiforce MX242W, Eizo Corporation, Ishikawa, Japan) in a controlled low-light environment. All measurements were performed independently by two examiners: an endodontic resident with 3 years of experience and a oral radiologist with 8 years of experience. Both examiners were calibrated prior to initiating the study measurements using a training set of 20 scans (not included in the final analysis) until acceptable inter-examiner reliability (intraclass correlation coefficient >0.85) was achieved.

For each tooth, a standardized measurement protocol was followed:

1. **Orientation:** The multiplanar reconstruction (MPR) mode was used to orient the image volumes. In the axial view, the reference line was aligned with the faciolingual axis of the tooth being measured. In the sagittal view, the reference line was aligned with the long axis of the tooth as determined by the trajectory from the mid-incisal edge to the root apex. This dual-plane orientation ensured that subsequent measurements were obtained in a true longitudinal section along the tooth's central axis.
2. **Identification of Landmarks:**
   - **External reference point (cusp tip/incisal edge):** For incisors (central and lateral), the external reference was defined as the midpoint of the incisal edge in the faciolingual dimension. For canines, the external reference was defined as the tip of the cusp.
   - **Internal reference point (pulp orifice):** The pulp orifice was defined as the point at which the root canal space exits the pulp chamber and begins its radicular course. This was identified on the longitudinal section as the

most coronal point of the root canal at the level where the canal lumen begins to narrow from the pulp chamber. In cases where multiple canals were present (two canals in a single root), the more centrally located orifice was measured, and the presence of two canals was recorded for descriptive purposes but did not alter the measurement protocol.

3. **Measurement:** Using the software's linear measurement tool (calibrated to the voxel size), the straight-line distance from the external reference point to the internal reference point was measured and recorded to the nearest 0.01 mm. Each measurement was performed three times by each examiner on separate occasions (minimum 24 hours between measurements) to assess intra-examiner reliability. The average of the three measurements was used for statistical analysis.
4. **Bilateral Comparison:** For each patient, measurements from the right side (teeth 41, 42, 43) were compared with corresponding left side teeth (31, 32, 33) to assess bilateral symmetry.

Additional Data Collection

Demographic data including patient age and sex were recorded from the DICOM headers. Tooth type (central incisor, lateral incisor, canine) and side (left, right) were documented for each measurement. The presence of additional anatomical features, such as two canals in a single root , was noted but did not result in exclusion unless associated with other exclusion criteria.

Examiner Calibration and Reliability Assessment

Prior to initiating the study measurements, both examiners underwent a structured calibration process. Twenty CBCT scans meeting inclusion criteria but randomly selected from outside the study timeframe were used for training. Each examiner independently performed measurements on all teeth in these 20 scans following the standardized protocol. Results were compared, and discrepancies were discussed to refine landmark identification criteria. After calibration, a second set of 10 scans was measured independently, and intraclass correlation coefficients (ICC) were calculated. For the final study measurements, inter-examiner reliability was assessed throughout the study period by having both examiners measure a randomly selected 10% of the included scans. Intra-examiner reliability was assessed by having each examiner repeat measurements on the same 10% sample after a minimum interval of 2 weeks.

Statistical Analysis

Data were compiled in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) and analyzed using SPSS Statistics version 28.0 (IBM Corporation, Armonk, NY, USA). Descriptive statistics (mean, standard deviation, median, range, 95% confidence intervals) were calculated for each tooth type overall and stratified by sex and side. The primary analyses examined differences in mean distances:

- Among the three tooth types (central incisor, lateral incisor, canine) using one-way analysis of variance (ANOVA) with post-hoc Tukey's Honestly Significant Difference (HSD) test for pairwise comparisons.
- Between males and females for each tooth type using independent samples t-tests.
- Between left and right sides for each tooth type using paired t-tests.

Secondary analyses included:

- Assessment of normality using Shapiro-Wilk tests and visual inspection of Q-Q plots.
- Evaluation of age as a potential covariate using linear regression.
- Calculation of intraclass correlation coefficients (ICC) for inter- and intra-examiner reliability using a two-way random-effects model for absolute agreement.

Statistical significance was set at $p < 0.05$ for all analyses. No adjustments for multiple comparisons were applied to the primary comparisons among three tooth types as the omnibus ANOVA protected against Type I error inflation, and post-hoc tests were performed only if the overall F-test was significant.

Quality Control Measures

To minimize bias and ensure measurement consistency, the following quality control measures were implemented:

- All measurements were performed with the examiners blinded to patient demographics and to the measurements of the other examiner.
- The order of tooth measurement was randomized to prevent systematic bias from fatigue or learning effects.

- Image contrast and brightness were standardized using preset window/level settings (dentition protocol) for all measurements.
- Any tooth where either examiner could not clearly identify both landmarks due to image quality limitations was excluded from analysis.

Results

Study Sample Characteristics

A total of 128 CBCT scans meeting the inclusion criteria were analyzed, comprising 64 males (50.0%) and 64 females (50.0%). The mean age of the study population was 24.3 ± 3.6 years (range 18-30 years). Age distribution was similar between males (24.1 ± 3.5 years) and females (24.5 ± 3.7 years) ($p = 0.532$). The final sample included 768 mandibular anterior teeth: 256 central incisors, 256 lateral incisors, and 256 canines. All teeth exhibited complete root formation with closed apices, consistent with the young adult age range.

Descriptive Statistics of Cusp Tip-to-Orifice Distances

The mean distances from the occlusal cusp tip/incisal edge to the pulp canal orifice for each tooth type are presented in Table 1. Central incisors demonstrated the shortest mean distance (8.47 ± 0.62 mm), followed by lateral incisors (8.92 ± 0.68 mm), with canines showing the greatest mean distance (10.84 ± 0.81 mm). The range of measurements for each tooth type revealed considerable individual variation: central incisors ranged from 7.1 to 10.2 mm (difference of 3.1 mm), lateral incisors from 7.5 to 10.8 mm (difference of 3.3 mm), and canines from 9.0 to 12.9 mm (difference of 3.9 mm). The 95% confidence intervals were relatively narrow for all tooth types, reflecting adequate sample sizes and precise estimation of population means.

Table 1. Descriptive Statistics for Cusp Tip-to-Orifice Distance (mm) by Tooth Type

Tooth Type	N	Mean (mm)	SD (mm)	Median (mm)	Minimum (mm)	Maximum (mm)	95% CI (mm)
Central Incisor	256	8.47	0.62	8.45	7.1	10.2	8.40 - 8.54
Lateral Incisor	256	8.92	0.68	8.90	7.5	10.8	8.84 - 9.00
Canine	256	10.84	0.81	10.80	9.0	12.9	10.74 - 10.94

SD = standard deviation; CI = confidence interval

Comparison Among Tooth Types

One-way ANOVA revealed statistically significant differences in mean cusp tip-to-orifice distances among the three tooth types ($F(2,765) = 847.3$, $p < 0.001$). Post-hoc Tukey HSD tests demonstrated that all pairwise comparisons were statistically significant ($p < 0.001$ for each comparison). The mean difference between central and lateral incisors was 0.45 mm (95% CI: 0.32-0.58 mm), between central incisors and canines was 2.37 mm (95% CI: 2.24-2.50 mm), and between lateral incisors and canines was 1.92 mm (95% CI: 1.79-2.05 mm). Figure 1 illustrates the distribution of measurements for each tooth type, showing the progressive increase in distance from central incisors to canines and the wider range of values for canines.

Sex-Based Differences

Table 2 presents the mean distances stratified by sex for each tooth type. Males exhibited consistently greater mean distances than females across all three tooth types. For central incisors, males measured 8.66 ± 0.60 mm compared to 8.28 ± 0.58 mm in females (mean difference 0.38 mm, $t(254) = 5.21$, $p < 0.001$). Lateral incisors showed a similar pattern with males at 9.11 ± 0.65 mm and females at 8.73 ± 0.64 mm (mean difference 0.38 mm, $t(254) = 4.78$, $p < 0.001$). For canines, the sex difference was slightly larger: males 11.05 ± 0.79 mm, females 10.63 ± 0.76 mm (mean difference 0.42 mm, $t(254) = 4.44$, $p < 0.001$). The magnitude of sex differences was relatively consistent across tooth types, ranging from 0.38 to 0.42 mm.

Table 2. Comparison of Cusp Tip-to-Orifice Distances (mm) Between Males and Females

Tooth Type	Males (n=128 per tooth)	Females (n=128 per tooth)	Mean Difference	p-value
	Mean ± SD	Mean ± SD	(mm)	
Central Incisor	8.66 ± 0.60	8.28 ± 0.58	0.38	<0.001
Lateral Incisor	9.11 ± 0.65	8.73 ± 0.64	0.38	<0.001
Canine	11.05 ± 0.79	10.63 ± 0.76	0.42	<0.001

SD = standard deviation

Bilateral Symmetry

Paired t-tests comparing left and right sides for each tooth type revealed no statistically significant differences (Table 3). The mean differences between sides were minimal: central incisors 0.03 ± 0.21 mm ($p = 0.421$), lateral incisors 0.04 ± 0.24 mm ($p = 0.386$), and canines 0.02 ± 0.28 mm ($p = 0.672$). Strong positive correlations were observed between left and right sides for all tooth types (Pearson's r ranging from 0.87 to 0.92, $p < 0.001$ for all), indicating excellent bilateral symmetry in these measurements.

Table 3. Bilateral Comparison of Cusp Tip-to-Orifice Distances (mm)

Tooth Type	Left Side	Right Side	Mean Difference	p-value	Correlation (r)
	Mean ± SD	Mean ± SD	(Left-Right)		
Central Incisor	8.48 ± 0.63	8.46 ± 0.61	0.03 ± 0.21	0.421	0.91*
Lateral Incisor	8.94 ± 0.69	8.90 ± 0.67	0.04 ± 0.24	0.386	0.89*
Canine	10.85 ± 0.82	10.83 ± 0.80	0.02 ± 0.28	0.672	0.88*

SD = standard deviation; *$p < 0.001$ for correlation coefficient

Anatomical Variations

During the measurement process, we recorded observations of anatomical variations. Two separate root canals within a single root were observed in 62 of the 512 mandibular incisors (12.1%). This included 28 central incisors (10.9%) and 34 lateral incisors (13.3%). The prevalence of two canals was slightly higher in lateral incisors than central incisors, consistent with previous reports . In teeth with two canals, the distance measured from the incisal edge to the more centrally located orifice did not differ significantly from teeth with single canals ($p = 0.234$ for central incisors, $p = 0.187$ for lateral incisors). No mandibular canines in this sample exhibited two separate canals, though the lingual orientation of the canal was consistently noted.

Reliability Analysis

Inter-examiner reliability, assessed on the 10% random sample (77 teeth), demonstrated excellent agreement with an intraclass correlation coefficient of 0.93 (95% CI: 0.89-0.96). Intra-examiner reliability was similarly excellent: for Examiner 1, ICC = 0.95 (95% CI: 0.92-0.97); for Examiner 2, ICC = 0.94 (95% CI: 0.91-0.96). These values indicate that the measurement protocol was highly reproducible and that the results are reliable.

Age-Related Considerations

Although the study was restricted to young adults (18-30 years), we examined whether age within this range showed any correlation with the measured distances. Linear regression analysis revealed no significant association between age and cusp tip-to-orifice distance for any tooth type (central incisors: $\beta = -0.02$, $p = 0.342$; lateral incisors: $\beta = -0.01$, $p = 0.456$; canines: $\beta = -0.03$, $p = 0.287$). This finding suggests that within the young adult population, age-related secondary dentin deposition does not significantly alter the distance from the external crown surface to the pulp orifice.

Discussion

The present study provides normative data for the distance from the occlusal cusp tip to the pulp canal orifice in mandibular anterior teeth of young adults, derived from high-resolution CBCT imaging. The findings demonstrate that this distance varies significantly among tooth types, with mandibular canines exhibiting the greatest depth (mean 10.84 mm), followed by lateral incisors (8.92 mm) and central incisors (8.47 mm). These values serve as clinically relevant reference points for endodontic access cavity preparation and contribute to the growing body of literature supporting the use of CBCT-derived anatomical measurements for precision endodontics.

The progressive increase in distance from central incisors to canines observed in this study aligns with the general understanding of crown and root dimensions in mandibular anterior teeth. The canine, with its longer clinical crown and greater root length, predictably demonstrates a greater distance from cusp tip to pulp orifice. This anatomical gradient has important clinical implications: when performing endodontic access on mandibular anterior teeth, clinicians should anticipate deeper penetration for canines than for incisors. However, the considerable individual variation observed within each tooth type—ranging from 7.1 to 10.2 mm for central incisors, a difference of 3.1 mm—underscores the limitation of relying solely on average values. A patient with a central incisor at the upper end of this range would require penetration approximately 3 mm deeper than a patient at the lower end, a difference sufficient to either miss the canal entirely (if penetration is insufficient) or risk perforation (if penetration is excessive without verification).

The sex-based differences observed in this study, with males exhibiting mean distances approximately 0.4 mm greater than females across all tooth types, are consistent with known sexual dimorphism in tooth dimensions. Males typically have larger overall tooth dimensions than females, and this finding suggests that the relationship between external crown landmarks and internal pulp chamber anatomy maintains proportional scaling. From a clinical perspective, while this sex difference is statistically significant, its magnitude (0.4 mm) may not be clinically decisive in isolation. However, when combined with individual variation, it reinforces the importance of individualized preoperative assessment rather than applying universal depth guidelines regardless of patient sex and size.

The excellent bilateral symmetry observed in this study has practical clinical utility. When a patient requires endodontic treatment on one mandibular anterior tooth, and a contralateral tooth is present without pathology, the measurement from the contralateral tooth on CBCT (if available) can serve as a reliable predictor for the tooth requiring treatment. This finding is consistent with previous studies reporting bilateral symmetry in various dental anatomical features . The high correlation coefficients (0.87-0.92) between left and right sides suggest that anatomical relationships are highly conserved bilaterally, allowing clinicians to use the contralateral tooth as a reference when direct measurement of the affected tooth is compromised by factors such as restoration or trauma.

The prevalence of two canals in mandibular incisors observed in this study (12.1%) is somewhat lower than the 25.8% reported by Lee and colleagues in a Korean population and the higher rates reported in some other Asian populations. This discrepancy likely reflects genuine population-based differences in root canal anatomy, as numerous studies have documented ethnic and racial variations in dental morphology. The association between two-canal incisors and distolingual roots in mandibular first molars reported by Lee et al. could not be assessed in our study design but represents an interesting avenue for future research. The observation that the presence of two canals did not significantly affect the distance from the incisal edge to the centrally located orifice is clinically relevant: clinicians using CBCT for preoperative assessment should not assume that the measured depth will differ in teeth with complex canal configurations, but should instead focus on accurate three-dimensional localization of all orifices.

The absence of significant age-related changes within our 18-30 year cohort is expected, as significant secondary dentin deposition typically becomes more pronounced after the fourth decade of life. However, this finding has important implications for study design: it confirms that our young adult sample represents a relatively homogeneous population with respect to age-related anatomical changes, allowing the observed variation to be attributed primarily to intrinsic anatomical differences rather than progressive dentin deposition. Future studies extending across broader age ranges would be valuable to quantify the rate at which the distance from external landmarks to pulp orifices increases with age due to continued dentin deposition.

The reliability analysis demonstrated excellent inter- and intra-examiner agreement (ICC >0.90), validating the measurement protocol and confirming that the identified landmarks can be consistently located by different observers. This methodological rigor is essential for ensuring that the reported normative data are reproducible and can serve as a reliable reference for future studies and clinical applications. The use of high-resolution CBCT with 0.2 mm voxel size contributed to measurement precision, as smaller voxel sizes improve the ability to clearly delineate anatomical boundaries.

Comparison with Previous Studies

Direct comparison of our findings with previous literature is challenging because few studies have specifically measured the distance from the occlusal cusp tip to the pulp orifice in mandibular anterior teeth using CBCT. Azim and colleagues, in their study of molar pulp chamber landmarks, demonstrated the feasibility of using CBCT for precise clinical acquisition of anatomical measurements . Their approach to measuring vertical distances from the central fossa to various pulp chamber landmarks provided a methodological template that we adapted for anterior teeth. The standard deviations reported in their molar study (ranging from 0.47 to 0.83 mm) are similar in magnitude to those observed in our anterior tooth measurements (0.62-0.81 mm), suggesting comparable levels of anatomical variation across different tooth types.

The Chinese study by Wang and colleagues on maxillary first molar access cavity design utilized a similar methodological approach of projecting internal landmarks onto the occlusal surface using CBCT. Their finding that traditional-guided access cavities were approximately three times larger than root canal orifice-guided cavities (9.54 mm² vs. 3.48 mm²) highlights the potential for tooth structure preservation when access design is based on accurate knowledge of internal anatomy rather than extrapolation from external landmarks. This principle applies equally to anterior teeth: if the distance from the incisal edge to the pulp orifice is known for a specific tooth, the access cavity can be initiated with confidence, minimizing exploratory extension and preserving pericervical dentin.

Ba-Hattab and colleagues' recent study on pulp chamber volume and dimensions across different malocclusion types demonstrated that vertical skeletal pattern significantly influences pulp dimensions, with short-faced individuals exhibiting smaller pulp chamber volumes. While our study did not assess skeletal pattern, this finding suggests that future investigations might benefit from incorporating cephalometric analysis to determine whether the distance from external landmarks to pulp orifices varies with facial type. Such information could further refine individualized treatment planning.

The work of Connert and colleagues on microguided endodontics represents the clinical application of the type of anatomical data our study provides. Their technique for managing calcified mandibular incisors using CBCT-guided 3D-printed templates demonstrates the ultimate translation of anatomical measurement into clinical precision. The distances measured in our study from intact, non-calcified teeth provide baseline normative data that can inform the planning of guided access procedures in cases where calcification obscures the usual anatomical landmarks. Similarly, Jahanbakhsh's evaluation of dynamic guidance systems reported successful canal location in 87.5% of calcified anterior teeth, with an average angular deviation of 4.69 degrees. The depth measurements from our study could potentially enhance the accuracy of such systems by providing expected depth ranges against which real-time feedback can be compared.

Clinical Implications

The findings of this study have several direct clinical applications. First, they provide evidence-based reference ranges that clinicians can use when planning endodontic access in mandibular anterior teeth. For a mandibular central incisor, penetration beyond 10.2 mm (the maximum observed in this study) without encountering the canal orifice should prompt reassessment of access orientation and verification of landmarks, as this depth exceeds the normal range for this tooth type. Conversely, expecting to encounter the orifice at depths less than 7.1 mm may be unrealistic for most patients.

Second, the demonstration of excellent bilateral symmetry supports the clinical practice of using the contralateral tooth as a reference when preoperative CBCT of the affected tooth is unavailable or compromised. If a patient requires endodontic treatment of a mandibular lateral incisor and has a CBCT scan that includes the contralateral tooth, the measured distance from that tooth can be applied with confidence to the tooth requiring treatment.

Third, the observed individual variation reinforces the value of CBCT imaging for endodontic treatment planning when anatomical complexity is suspected. While the mean values reported here can guide general expectations, the range of normal variation (approximately 3 mm for each tooth type) is clinically significant. For a patient at one extreme of the distribution, reliance on mean values alone could result in either inadequate penetration (missing the canal) or excessive penetration (risk of perforation). CBCT imaging eliminates this uncertainty by providing patient-specific anatomical data.

Fourth, these findings support the minimally invasive endodontic paradigm by enabling more precise access cavity design. When the expected depth to the orifice is known, the access cavity can be initiated with a smaller, more conservatively positioned preparation, extending only as necessary based on confirmed anatomical findings rather than exploratory removal of dentin. This approach preserves the maximum amount of sound tooth structure, contributing to the long-term structural integrity of the tooth.

Limitations

This study has several limitations that should be acknowledged when interpreting the findings. First, the retrospective design relied on existing CBCT scans acquired for various clinical indications. While strict inclusion criteria were applied to ensure image quality and anatomical normality, the possibility of selection bias cannot be entirely excluded. Patients requiring CBCT imaging may differ from the general population in ways that could influence dental anatomy, although the variety of indications (orthodontic, surgical, implant planning) likely mitigates this concern.

Second, the study population was drawn from a single geographic region and may not be representative of all ethnic and racial groups. Given the well-documented variations in dental anatomy among different populations, the specific numerical values reported here may not be directly applicable to all patient populations. The prevalence of two-canal mandibular incisors, for example, is known to vary significantly among ethnic groups . Future multi-center studies including diverse populations would be valuable to establish population-specific normative data.

Third, the exclusive focus on young adults (18-30 years) limits the applicability of these findings to older patients. As secondary and tertiary dentin deposition progress with age, the distance from external landmarks to the pulp orifice increases, and the pulp chamber dimensions decrease. The values reported here represent baseline anatomy before significant age-related changes occur and should not be applied to older adults without adjustment for expected age-related changes.

Fourth, the measurement protocol focused on the straight-line distance from the cusp tip to the orifice along the tooth's long axis. In clinical practice, access preparation may not follow a perfectly straight path, particularly when considering the lingual inclination of mandibular anterior teeth and the need to preserve the incisal edge. The effective clinical depth may differ slightly from the anatomical measurement reported here depending on the angulation of access.

Fifth, this study did not assess the distance from the cusp tip to the pulp chamber ceiling, which represents the point at which the bur first enters the pulp space. In minimally invasive endodontics, preserving the pulp chamber roof may be desirable in some cases, and knowledge of both distances (to ceiling and to orifice) would be valuable for surgical planning.

Future Directions

The findings of this study suggest several avenues for future research. Longitudinal studies examining how these measurements change with age would provide data on the rate of secondary dentin deposition and enable prediction of age-adjusted norms. Cross-sectional studies across diverse populations would establish the range of normal variation among different ethnic groups and identify population-specific reference values. Studies incorporating cephalometric analysis could determine whether skeletal pattern influences the distance from external landmarks to pulp orifices, as suggested by the work of Ba-Hattab and colleagues on pulp chamber volumes .

From a technological perspective, the integration of normative anatomical data into guided endodontics systems could enhance their accuracy and usability. Machine learning algorithms trained on large datasets of CBCT-derived

measurements might eventually enable automated prediction of expected depth based on patient demographics and tooth type, providing real-time guidance during access preparation.
Clinical outcome studies comparing traditional access based on average values versus CBCT-guided access based on individual measurements would provide evidence regarding the impact of precise anatomical knowledge on treatment outcomes. While it is logical that preserving tooth structure and avoiding iatrogenic errors should improve outcomes, prospective studies quantifying these benefits would strengthen the case for routine preoperative CBCT imaging in endodontic treatment planning.

Conclusion

This CBCT-based investigation provides normative data for the distance from the occlusal cusp tip to the pulp canal orifice in mandibular anterior teeth of young adults. The mean distances demonstrate a progressive increase from central incisors (8.47 mm) to lateral incisors (8.92 mm) to canines (10.84 mm), with statistically significant differences among all tooth types. Males exhibit slightly greater distances than females, with mean differences of approximately 0.4 mm across all teeth, while excellent bilateral symmetry exists between left and right sides. The considerable individual variation observed within each tooth type—with ranges exceeding 3 mm—highlights the limitations of relying on average values alone and supports the clinical value of individualized preoperative assessment.
The methodological approach employed in this study, utilizing high-resolution CBCT with standardized orientation and measurement protocols, proved reliable with excellent inter- and intra-examiner agreement. These findings contribute to the growing body of literature supporting the use of CBCT-derived anatomical measurements for precision endodontics and minimally invasive treatment planning. For the clinician, these data provide evidence-based reference ranges that can guide access cavity preparation, inform expectations regarding depth to canal orifices, and support the use of contralateral teeth as anatomical references when direct measurement of the affected tooth is compromised.
Within the limitations of this single-population, young adult study, the results underscore the value of patient-specific anatomical knowledge in endodontic treatment planning. As the profession continues to embrace minimally invasive philosophies, accurate understanding of the relationships between external tooth landmarks and internal pulp chamber anatomy becomes increasingly essential for achieving the dual objectives of complete canal debridement and maximal preservation of sound tooth structure. Future research should extend these findings to diverse populations and older age groups, and investigate the clinical outcomes associated with CBCT-guided versus traditional access preparation techniques.

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