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Original Article

CBCT-Based Evaluation of the Incisive Canal–Root Apex Relationship in Maxillary Central Incisors: Implications for Immediate Implant Placement

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ABSTRACT

The objective of this research was to analyze the spatial correlation between the incisive canal (IC) and the periapical zone of maxillary central incisors in a Korean population, using cone-beam computed tomography (CBCT). The data acquired are meant to refine and support the strategizing and performance of immediate implant insertion in the maxillary aesthetic region. Imaging data were collected from 94 subjects (48 male, 46 female) aged 20–79 years at a dental facility in Seoul, South Korea. Participants were stratified into three age brackets: 20–39 years, 40–59 years, and 60–79 years. Grounds for exclusion encompassed absent maxillary anterior teeth, notable dental crowding, periodontal disease, pathological conditions, and scan distortions. Dimensions from the root tip to the incisive canal (RIC-11-P, RIC-21-P) and from the root tip to the labial bone plate (RBB-11-B, RBB-21-B) were captured from the CBCT scans. Statistical testing employed Welch's t-test, analysis of variance, and Pearson's correlation, adopting a significance threshold of $P < 0.05$. Average separations between the root apex and the incisive canal came to 3.77 mm (RIC-11-P) and 3.62 mm (RIC-21-P), whereas mean labial bone distances were 0.86 mm and 0.94 mm, respectively. Men consistently registered markedly larger spans than women across both NPC-to-apex and labial bone metrics. Age-associated shifts were observed, with younger cohorts showing shorter distances from the IC to the root tip. Still, the ANOVA and Pearson correlation outputs failed to establish a significant statistical relationship among these measurements across the various age tiers. The investigation highlights pronounced sex-based differences in central incisor anatomy, with males exhibiting longer spans from the apex to both the IC and the labial bone, a finding relevant to surgical insertion. Although age-dependent trends emerged, they had little effect on average distances. These observations stress the imperative for individualized therapeutic design in immediate implant procedures, with particular attention directed toward sex and age. Cross-referencing with other ethnic studies suggests that such morphological traits may be stable across diverse populations, though idiosyncratic variability must continue to be weighed.

Keywords: Immediate implant insertion, Incisive canal, Morphology of maxillary central incisors, Palatal osseous width, CBCT scanning, Sex-tailored dental care

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Introduction

Contemporary developments in implantology suggest that replacing upper anterior incisors via immediate insertion in the aesthetic sector yields superior results relative to deferred protocols [1]. This tactic confers multiple clear benefits over delayed approaches, among them the preservation of pre-existing soft and hard tissue contours, fewer operative phases, and superior cosmetic outcomes [2, 3]. Nonetheless, restoring this anterior aesthetic sector introduces unique difficulties stemming from constraints in bone and soft-tissue availability and the proximity of anatomical landmarks, such as the nasopalatine canal, also known as the incisive canal (IC).

Occupying a midline locus directly behind the maxillary central incisors, the IC represents a critical anatomical feature of this region. Coursing through it are the nasopalatine nerve and the terminal ramification of the nasopalatine artery [4]. The literature indicates that implant encroachment into or perforation of the IC might trigger neural tissue contact, culminating in failed osseointegration, neurovascular trauma, or altered sensory function [5, 6].

Operative directives for immediate implants in the maxillary aesthetic zone prescribe a minimum labial bone width of 1–2 mm for optimal outcomes, with the fixture engaging 4-5 mm of bone apico-palatally beyond the root apex and adopting a more palatal orientation to mitigate labial plate stress [7-9]. The architecture of the labial bone governs enduring soft-tissue equilibrium and visual appeal, while the palatal bone mass is fundamental for fixture anchoring and achieving primary stabilization [10]. In real-world practice, achieving a sound prosthodontically guided implant alignment is regularly thwarted by the proximity and shape of the IC, as well as by a labial wall that falls short of the prescribed 2 mm breadth [11-13].

The implant's placement is steered by the accessible palatal bone stock and the IC's nearness to the central incisor apices [13]. This apico-palatal domain is regarded as equally pivotal as labial bone thickness [14]. Hence, evaluating the incisor and investing bone during diagnostic and preparatory work-up must account for the IC's adjacency. Even with the International Team for Implantology's agreement on the necessity of ample palatal osseous bulk, comprehensive inquiry into the exact interplay linking palatal bone metrics, the central incisor, and the IC remains sparse [7, 14].

Cone beam computed tomography (CBCT) enjoys widespread dental applications thanks to its ability to produce suitably precise bi- and tri-dimensional visualizations [15]. Linear values derived from CBCT imagery did not deviate materially from true, direct physical measurements of dento-maxillofacial structures [15-17].

The chief aim of this inquiry is to probe the nearness of the incisive canal to the maxillary central incisor apex, together with the adjacent palatal and labial osseous thickness within a Korean sample. CBCT served as our instrument for furnishing high-resolution, accurate three-dimensional imagery, whose outputs were then interpreted to gauge the ramifications and cautions pertinent to immediate implant placement at this site.

By quantifying the spatial interplay between the IC and the periapical region of the maxillary central incisors using axial CBCT in a Korean cohort, this paper aims to contribute to the oral surgical literature. It supplies fundamental intelligence for immediate implant strategizing, underscoring, in particular, sex-driven and structural disparities.

Materials and Methods

Study design

Between June 2024 and September 2024, CBCT records were assembled from individuals who underwent scanning for oral surgical and implantological evaluation associated with implant-prosthetic restorative care at Gangnam Dental Clinic, 415 Gangnam-daero, Seocho-gu, Seoul, South Korea, with informed consent secured beforehand. One of the investigators (Y.S.K.) processed and interpreted the data at Unicamillus International University, taking responsibility for the statistical computations. The retrospective protocol received clearance from the local ethics board under reference number E00332-2024.

A total of 94 patient scans, encompassing 48 males and 46 females, were retained for analysis. The sample set was organized by sex and then allocated into three age-based categories: A) 20–39 years; B) 40–59 years; and C) 60–79 years. Conditions warranting exclusion from the dataset comprised absence of maxillary anterior dentition (from canine to canine), substantial crowding in the targeted zone, advanced periodontal destruction, infectious or pathological lesions at the site of interest, presence of fixed orthodontic hardware, evidence of apical resorption or root-end surgery, and any form of image degradation or artifact obscuring the region under investigation.

Acquisition of CBCT imaging

Capture of all CBCT volumes was performed on a Vatech unit (Green CT 2, Vatech Co, Hwaseong, Republic of Korea) operating at 7.9 mA, 94 kV, with a 9.0-second exposure cycle, 0.2 mm voxel resolution, and a field of view spanning 160 × 900 mm. The resulting datasets were archived in the Digital Imaging and Communications in Medicine (DICOM) standard and subsequently visualized and quantified using the Ez3D Plus professional CBCT platform (Vatech Co., Hwaseong, Republic of Korea). Reconstructed sagittal and axial sections utilized a 0.2 mm interslice interval and a 0.00 mm slice thickness. Each scan was carefully inspected to confirm the presence of fully erupted, structurally intact permanent maxillary central incisors 11 and 21 suitable for evaluation.

Data measurement

A single calibrated examiner (Y.S.K.) performed all measurements. To gauge intra-examiner reliability, repeat measurements of the maxillary incisor variables were obtained from 10 randomly selected subjects after a fortnight, and consistency and precision were verified. The Dahlberg formula was used to estimate methodological error [18], yielding values ranging from 0.21 to 0.68.

Before commencing measurements, key anatomical landmarks—the central incisor root apex, the anterior boundary of the IC, and the buccal alveolar crest margin—were pinpointed and annotated within the software environment. The sagittal plane passing through the midpoint of the mesiodistal dimension of the chosen incisor was displayed **(Figure 1)**. The longitudinal reference axis of the tooth was established by bisecting a line extending from the buccal enamel–dentine junction to its palatal counterpart, concluding at the root tip. Rather than employing the axis of the entire tooth, the root's long axis alone was utilized, given that the angulation between crown and root in maxillary central incisors is documented to average 25.5 degrees [16, 17]. Originating from this reference framework, an orthogonal line was projected from the apex along the root's longitudinal axis, coursing from the anterior contour of the incisive canal toward the buccal osseous surface **(Figure 2).**

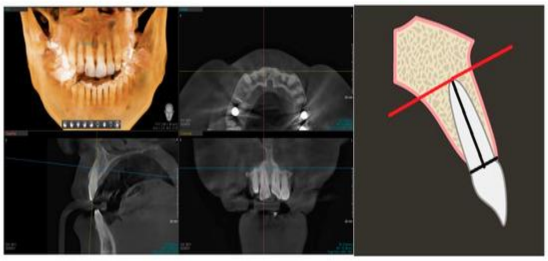

Figure 1. These images portray various CBCT perspectives. Landmarks such as the central incisor root apex and the incisive canal are discernible. On the right, a sagittal slice diagram depicts the central incisor featuring a perpendicular line (RED) traced to the root apex. The axial slices employed for measurement in this study run horizontally relative to this red line.

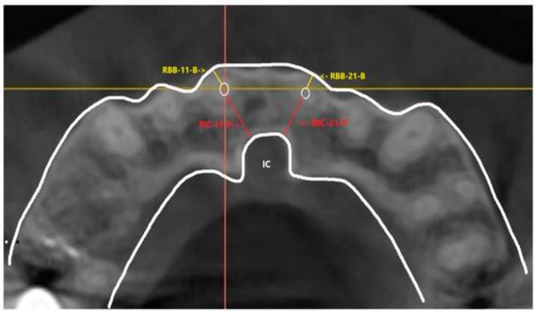

Figure 2. These illustrations show the root apices of central incisors, with linear distances indicated as RIC-11-P and RIC-21-P (red) for root apex to incisive canal, and RBB-11-B and RBB-21-B for root apex to buccal bone.

Transferring this perpendicular line to the axial planes of the CBCT dataset aligned the axial slices horizontally relative to this benchmark. Within the axial sections containing the root apices of the central incisors, the shortest linear span separating the IC from each maxillary central incisor root apex was recorded, representing the dimension of the available palatal bone—denoted as RIC-11-P and RIC-21-P for the right central incisor 11 and the left central incisor 21, respectively. Likewise, the minimal distance between each central incisor root apex and the buccal osseous boundary was documented, defining the apical-level buccal bone thickness—labeled as RBB-11-B and RBB-21-B for the right central incisor 11 and the left central incisor 21, respectively **(Figures 3 and 4).** A parallel linear measurement methodology for axial CBCT sections was described by Ishii *et al*. [19].

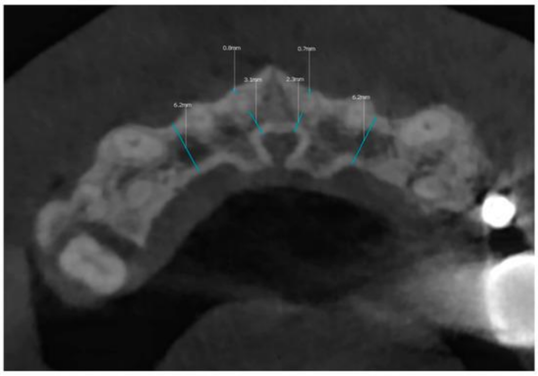

Figure 3. This presents an axial slice showing a linear measurement performed in the viewing software.

In this study, the root apex, together with the orthogonal plane projecting from the apex to the IC, was designated as the datum for the axial or horizontal orientation. This determination stemmed from the fact that the root apex provides an unmistakable, clinically practical reference point, and at this apical level, the palatal bone is readily distinguished from the labial bone by direct visualization of the apex [14]. Clinicians can equally identify this landmark with ease throughout both the diagnostic work-up and surgical phases.

By basing the CBCT measurements on this axial plane, the investigation realistically reproduces the operator's vantage point when placing an implant in the maxillary central incisor territory, relying on the root apex as a well-defined landmark from which measurements radiate. The axial plane took precedence over the sagittal plane owing to the latter's inherent shortcomings in depicting the incisive canal and root apex comprehensively, as morphological variability of the IC and deviations in root tilt and curvature may be encountered [19].

Such an approach yields measurements of greater accuracy and clinical relevance, mirroring the authentic conditions dental clinicians confront during implant surgery.

Although potentially informative, we decided to exclude crestal-level measurements of buccal and palatal bone thickness. The reasoning lay in an unacceptably large margin of error, driven by the bone's extreme thinness in that region. Even with on-screen magnification, resolution degrades to a level unsuitable for reliable quantification. Compounding this, the edge-related beam hardening artifact is persistently present, rendering any attempt to gauge bone thickness at the crestal level essentially meaningless.

The accompanying figures exhibit the measurements undertaken **(Figures 1-3).**

Statistical analysis

A lone calibrated examiner (Y.S.K.) was responsible for capturing every measurement across the entire sample. To evaluate intra-rater reliability, readings of the maxillary incisor from 10 randomly chosen subjects were repeated, confirming both consistency and accuracy of the obtained values. All statistical procedures were run through the Statistical Package for the Social Sciences (SPSS, Chicago, IL, USA). When two independent data series required comparison, the Welch's t-test was selected. Situations demanding simultaneous comparison across three or more independent data sets were handled via analysis of variance (ANOVA). To explore correlational patterns, a Pearson Correlation analysis was conducted, and the resulting correlation coefficient was used to quantify statistical interdependence. The criterion demarcating statistical significance was established at 0.05.

Results and Discussion

Across the entire study sample, the pooled mean distances computed for RIC-11-P (span from root apex of maxillary right central incisor 11 to the incisive canal) and RIC-21-P (corresponding span for maxillary left central incisor 21) equaled 3.77 mm (std 1.07) and 3.62 mm (std 0.99), respectively. In terms of the RBB variable (distance from root apex to buccal bone plate), mean values for maxillary right incisor 11 and maxillary left incisor 21 came to 0.86 mm and 0.94 mm, respectively **(Table 1)**. The t-test showed that male subjects had substantially larger mean spans for both incisors than female subjects, achieving statistical significance ($P < 0.05$), as illustrated in **Table 2 and Figures 4 and 5.**

Table 1. Average distance in mm from each right (11) and left (21) maxillary central incisor root apex to incisive canal (RIC_P) and to buccal bone (RBB_B).

Groups	Count	Sum	Average	Variance
RIC_11_P	94	355	3.7765957	1.1547152
RIC_21_P	94	341.1	3.6287234	0.9981984
RBB_11_B	94	81.2	0.8638298	0.0741615
RBB_21_B	94	89.2	0.9489362	0.0696225

Table 2. Average distance in mm for each variable according to gender and groups, P and B.

Gender	**Average of RIC_11_P**	**Average of RIC_21_P**
Female	3.556521739	3.404347826
Male	3.9875	3.84375
Grand Total	3.776595745	3.628723404
Gender	Average of RBB_11_B	Average of RBB_21_B
Female	0.793478261	0.880434783
Male	0.93125	1.014583333
Grand Total	0.863829787	0.94893617

The age range of participants was 20-79 years, with a mean age of 46.47 ± 17.5.

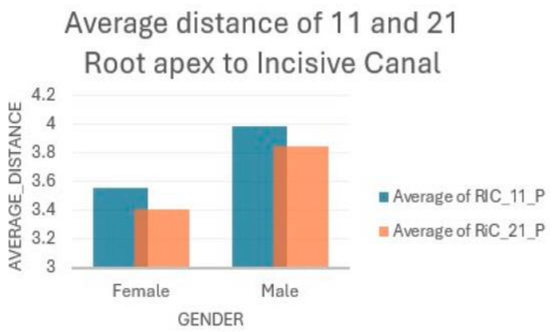

Figure 4. Average distance (mm) from root apex of 11 (RIC-11-P) and 21 (RIC-21-P) to incisive canal in female and male patients.

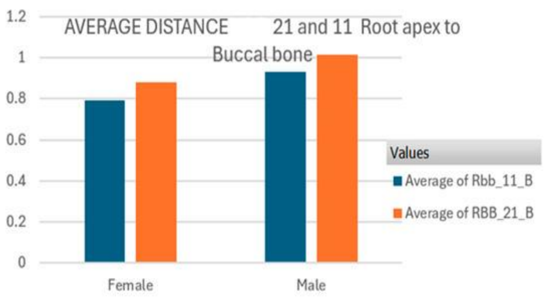

Figure 5. Average distance (mm) from root apex of 11 (RBB-11-B) and 21 (RBB-21-B) to buccal bone in female and male patients.

To formally test gender-based divergence, Welch's t-test was applied to the mean values of the root apex–to–incisive canal gap for teeth 11 and 21 (RIC-11-P and RIC-21-P) between male and female members of the sample. An analogous analysis was subsequently performed on the average root apex–to–buccal bone spans for both teeth (RBB-11-B and RBB-21-B) across the two sexes. The output revealed that, at a confidence threshold of 0.05, the null hypothesis of equal means between males and females could be rejected, as the resulting P-value is less than 0.05. Male participants unambiguously outstrip female participants in both the root–to–incisive canal dimension and the root–to–buccal bone dimension.

A Pearson correlation test was further used to examine whether a measurable association existed between the sex variable and the four distance parameters (RIC-11-P, RIC-21-P, RBB-11-B, RBB-21-B). The outcomes confirmed positive correlational trends, with correlation coefficients of a relatively modest magnitude: 0.02156358 for RIC-11-P and 0.221028314 for RIC-21-P. Concerning the two root–to–buccal bone spans (RBB_11_B and RBB_21_B), the correlation coefficients reached 0.254252344 and 0.255508454, lending further weight to the observed association, i.e., the direction of the relationship indicates that male sex is linked with larger distances from the root terminus to both the incisive canal and buccal osseous boundary relative to female sex.

A breakdown by age within the female subset produced the following average RIC-11-P values: among the youngest tier (20–39 years), 3.61 mm; the middle tier (40–59 years), 3.39 mm; and the oldest tier (60–79 years), 3.65 mm. For male subjects, the equivalent figures were 4.02 mm, 3.78 mm, and 4.15 mm across the respective age brackets (20–39, 40–59, and 60–79 years). Shifting to tooth 21, average RIC_21_P readings for females stood at 3.30 mm (20–39 years), 3.27 mm (40–59 years), and 3.66 mm (60–79 years); their male counterparts yielded 4.17 mm, 3.70 mm, and 3.53 mm in the corresponding age categories **(Figure 6)**. A minor upward trend in mean values is discernible within the male stratum across most age groups.

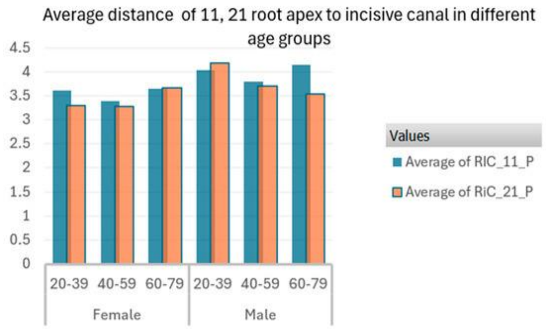

Figure 6. Average distance of 11 and 21 to the incisive canal in group_P.

As conveyed in **Figure 7**, the mean spans from the root tip of upper central incisor 11 to the buccal bone surface (RBB_11_B) among females registered as 0.8333 mm in the 20–39 bracket, 0.7357 mm in the 40–59 bracket, and 0.8 mm in the 60–79 bracket. Male data returned corresponding means of 0.926 mm, 1.0267 mm, and 0.8357 mm for those same sequential age windows. Turning attention to the left central incisor 21 and its root apex–to–buccal bone distance (RBB_21_B), the female cohort exhibited averages of 0.9611 mm (20–39), 0.764 mm (40–59), and 0.8929 mm (60–79), whereas the male cohort averaged 1.0578 mm, 1.0333 mm, and 0.9357 mm across the same three age divisions.

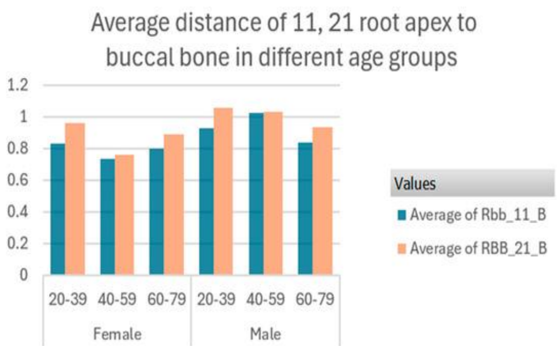

Figure 7. Average distance of 11 and 21 to the incisive canal in group B.

Analysis of variance was applied to evaluate whether the mean spans from the root apex to the IC and to the buccal bone surface differed across the three designated age strata—namely, (20–39), (40–59), and (60–79)—with the significance benchmark set at 0.05. The outputs for RIC-11-P and RIC-21-P yielded a P-value of 0.654, well above the 0.05 threshold, indicating that the null hypothesis could not be rejected. This finding indicates that, based on the present dataset, there is no statistically significant divergence in the mean distances across the six age-defined subgroups. Supporting this, the computed F-statistic (0.661) fell below the critical F value (2.264), further reinforcing the absence of any significant intergroup variation at the 0.05 significance level.

A comparable pattern emerged from the ANOVA conducted on the average root apex–to–buccal bone spans (RBB-11-B and RBB-21-B) across the same age categories. Here, the p-value reached 0.107, again exceeding the 0.05 significance cutoff, while the F-statistic (1.842) remained beneath the critical F value (2.264). These results jointly confirm that there is no pronounced difference between the age groups in the mean distance separating the root apex from the buccal cortical plate.

Expressed differently, the mean distances obtained for these age brackets do not deviate from one another in any statistically appreciable manner.

A correlation matrix was constructed to quantify the relationship between age category and the root apex–to–IC dimension. The coefficient linking RIC_11_P to the transformed age-group variable was 0.020355652, indicating a very weak positive correlation. With a coefficient hovering near zero, this implies that age exerts virtually no measurable influence over the RIC_11_P distance. Conversely, the correlation between RIC_21_P and the transformed age-group variable was −0.070519491, indicating a weak inverse association. The negative direction suggests that advancing age is associated with a subtle reduction in the RIC_21_P span; however, the modest magnitude of the coefficient indicates that age is a poor predictor of this measurement.

Regarding the buccal bone distances, the age group variable exhibited negative correlations with both RBB-11-B and RBB-21-B, producing coefficients of −0.091550606 and −0.1599506, respectively. This indicates that age is inversely related to RBB_11_B and RBB_21_B, such that as age increases, the apices of both upper central incisors 11 and 21 tend to move closer to the buccal osseous surface. Still, the weakness of these negative coefficients precludes a robust claim of a correlational link.

Finally, a Pearson correlation test was performed on the pooled mean distances from the incisor root tip to the IC and to the buccal bone across the entire study population.

A negative correlation of −0.03893335 was detected between the root–to–buccal bone span (RBB_11_B) and the root–to–incisive canal span (RIC_11_P), implying that an enlargement in the RBB_11_B distance tends to be accompanied by a decrease in the RIC_11_P distance. Likewise, a negative correlation of −0.0494404 emerged between the root–to–buccal bone distance for tooth 21 (RBB_21_B) and the root–to–incisive canal distance for tooth 11 (RIC_11_P); this similarly denotes that a lengthening of the buccal gap corresponds inversely with the palatal gap. Put another way, a wider palatal bone dimension—represented by the expanse between the incisor root tip and the IC—generally coincides with a narrower buccal bone dimension, manifested as a reduced span from the root tip to the buccal plate.

The present investigation explored the three-dimensional positional interplay between the incisive canal and the periapical zone of the maxillary central incisors to characterize buccal and palatal osseous thickness in a Korean cohort using CBCT. Subsequent analysis of the collected data focused on discerning the clinical ramifications of immediate implant insertion in the aesthetic zone. To contextualize potential anatomical variability relevant to treatment planning and surgical execution, the findings were juxtaposed with analogous research conducted in other populations.

Within our Korean sample, the overall mean distances registered between the maxillary central incisor root apex and the IC were 3.77 mm for the right central incisor 11 and 3.62 mm for the left central incisor 21. Moreover, the spans from the apex to the buccal bone measured 0.86 mm and 0.94 mm for the upper right central incisor 11 and left central incisor 21, respectively. The IC tended to lie in closer apposition to the left central incisor 21, yielding a shorter recorded distance. Sex-stratified analysis revealed that males consistently outpaced females in both palatal and buccal bone width dimensions. A review of prior investigations across diverse ethnic and demographic cohorts reveals a range of values that differ from those in the current study. Research by Cho *et al.* [20], also targeting a Korean population, documented a higher mean palatal bone width of 4.9 mm between the root apex and IC, as well as a buccal bone width averaging 1.18 mm.

Meanwhile, a recent report from Japan, encompassing 157 subjects, estimated the apex-to-IC gap at roughly 3.3 mm, a figure that aligns more closely with our own measurements [19]. That Japanese study further resonated with our observation of the left incisor root apex being situated nearer to the incisive canal than its right-sided counterpart. Yet conflicting evidence exists in the literature, with some studies reporting that the incisive canal is in closer proximity to the right central incisor [21, 22]. An investigation featuring a more ethnically diverse sample, conducted by Alkanderi *et al*. [23], yielded a comparable mean palatal bone value (3.25 mm) between the root apex and the IC and likewise uncovered a robust association between male sex and enlarged distances. An additional study originating from Saudi Arabia reported a higher average (4.28 mm) for the palatal bone width measured between identical landmarks (maxillary central incisor root apex to IC) and similarly found that males tended to possess larger spans and greater osseous dimensions in this anatomical territory [24].

The bulk of the existing literature on palatal bone width at the apical level of upper central incisors reports substantially larger mean values, ranging from 5.06 mm to 7.43 mm, in contrast to our own results [14, 16, 25]. This discrepancy likely stems from the methodological reliance on sagittal, rather than axial, CBCT slices for gauging palatal bone width—an approach where the IC may not even be visible, and where the measurement parameter did not incorporate the IC. Consistent with our data, a sex-based disparity was also documented in these studies, with male patients exhibiting greater palatal bone width than their female counterparts.

Drawing from our analysis of the Korean sample, the measured spans separating the root tip from the buccal bone margin came to 0.86 mm for the upper right central incisor 11 and 0.94 mm for its left counterpart 21. Both figures fall below the 1 mm cutoff routinely proposed as the lowest acceptable threshold when devising a treatment blueprint for immediate implant surgery. Mean values recorded among males surpassed those seen in females. An earlier Korean data set published by Jung *et al*. [26] placed the average buccal plate thickness at the central incisor apex at 1.18 mm—an estimate that slightly exceeds our own; even so, 58.3% of central incisors evaluated in that cohort exhibited a buccal dimension of less than 1 mm. That research additionally examined incisor root siting in connection to buccal plate width, concluding that in the preponderance of specimens the root lay in tight adjacency to the buccal lamella while the overlying bone remained slim. Work by Lau *et al*. [16], based on a Hong Kong population, reported a marginally higher mean of 2.04 mm; however, a more granular breakdown of the distribution revealed that a majority (51.8%) had a thickness below 2 mm. One must bear in mind, however, that those comparable investigations employed sagittal reconstructions to gauge the apex-to-buccal-bone interval. This circumstance plausibly yields modestly inflated averages relative to our axial-plane methodology. Yet the overarching message that emerges consistently across populations is that buccal bone is inherently lean, commonly falling short of 1 mm in a large fraction of cases. The sex-based gradient we detected—males possessing more robust buccal bone versus females—harmonized with findings reported elsewhere [27, 28].

Compared with a sizeable body of prior research, the mean palatal and buccal osseous widths derived from the current study tended toward the lower end of the spectrum, and differences by population and ethnic origin appear to exist. However, they do not conform to any clear, systematic pattern. That males demonstrated broader palatal and buccal bone dimensions in this apical region of the central incisors aligns with a recurring theme in the antecedent literature. A potential explanation for this disparity may lie in compensatory or adaptive osseous remodeling stimulated by elevated biomechanical loading in male individuals, resulting in greater distances from the root tip to the incisive canal [27]. The recurrence of this observation across ethnically distinct cohorts hints that sexual dimorphism in the maxillary bone surrounding the IC constitutes a broadly shared anatomical characteristic.

The extent to which aging influenced palatal and buccal bone dimensions remained relatively muted within our dataset, echoing the non-significant relationships reported in comparable investigations [25, 27]. The ANOVA performed here confirmed the absence of any statistically significant difference in average spans from the root apex to either the IC or the buccal cortex across the separate age brackets. This suggests that, despite subtle shifts in average values, chronological age fails to substantially recalibrate the spatial configuration linking the maxillary central incisor root to these anatomical structures. Moreover, the correlation between age and these parameters was not uniform, suggesting that factors beyond age alone contribute to shaping these distances.

At the same time, some published works contend that maxillary labial osseous thickness progressively reduces with age; Zhang *et al*. [29] specifically documented thinner labial bone in older women [28, 30]. Inconsistencies across studies and the wider literature may be rooted in ethnic divergences in craniofacial form, alongside lifestyle factors and physiological determinants that shape bone density and cortical dimensions. The Pearson correlation performed in the present investigation revealed a negative association between age and the apex-to-buccal-plate span (RBB-11-B and RBB-21-B). While the corresponding coefficient was of low magnitude, it might be viewed as a subtle indicator that the root tip edges progressively approach the buccal cortical plate as the years advance. This trend could be particularly relevant for implant-based rehabilitation in older individuals. These observations collectively serve as a reminder that clinicians should maintain a heightened awareness of potentially thin labial bone, a concern that is especially pertinent among elderly female patients.

Turning to the aesthetic zone, achieving a favorable outcome with immediate implant therapy depends on an adequate buccal bone reservoir to buttress the soft tissue envelope, combined with sufficient palatal bone apical to the extraction socket to secure primary stabilization of the fixture. In scenarios involving the maxillary central incisors, accounting for their proximity to the IC is an absolute necessity during both treatment planning and the clinical sequence. The metric data gathered here afford quantification of the maxillary bone stock situated anterior to the IC—information that constitutes a foundational prerequisite for dental implant positioning [31].

Published recommendations indicate that the pilot osteotomy should be oriented into the palatal bone, extending beyond the mid-to-apical extent of the socket, and a bone plate whose thickness exceeds 2 mm should be used in the zone anterior to the IC [32].

Engagement between the implant body and the socket confines typically commences near the mid-root segment on the palatal side of the extraction site, advancing toward the apico-palatal osseous bridge positioned between the root terminus and the IC, with an additional 4 mm of extension beyond the apex [25, 27]. The mean palatal bone span of 3–3.5 mm derived from our data quantifies the osseous reserve and, consequently, helps chart the intended trajectory of implant anchorage. Just how near the IC sits relative to the maxillary incisor apices fundamentally dictates the manner in which a fixture should be inserted [33]. The current evidence implies that adequate bone volume is present within this region to enable secure implant engagement without imperiling the IC or deviating from the prescribed anchorage pathway. This conclusion aligns with the palatal engagement paradigm in the literature, as the apico-palatal domain offers substantially greater bone volume than the buccal aspect.

Even though our dataset, in concert with earlier reports, suggests that average IC-to-root-apex intervals at the apical tier are broadly sufficient for implant engagement while avoiding encroachment on the IC, it is crucial to underscore that markedly smaller spans (on the order of 1–2 mm) were regularly encountered across individual specimens. A parallel observation emerged in the investigation by Chatriyanuyoke *et al.* [27], in which the lower bound of the IC-to-root-apex data ranged from 1.01 to 2.00 mm. Caution is therefore warranted when evaluating bone mass anterior to the IC, recognizing that, in select instances, the canal may be considerably closer and that anatomical variability is an ever-present reality. Bearing these factors in mind, tapered implants are advocated for maxillary central incisor sites, as they require less osseous volume for apical fixation and have demonstrated greater primary stability than cylindrical counterparts [26, 27, 31-33]. Jia *et al*. [34] documented a perforation rate of 16.7% within a Chinese cohort following virtual implant positioning in both fully dentate and partially edentulous subjects. Remarkably, this perforation rate was more than halved to 8.3% when tapered rather than parallel-walled fixtures were selected.

The buccal bone dimension stands as yet another decisive parameter governing the success of immediate implant protocols [35-37]. Our study found that buccal bone thickness remains below 1 mm, the recommended minimum prerequisite for implant insertion.

The correlational findings indicated that in instances where a more generous palatal bone volume occupied the space between the root apex and the IC, the buccal bone layer on the opposite aspect of the root tended to have reduced thickness. A systematic review by Chen and Buser [1] documented a notable prevalence of gingival recession accompanied by osseous resorption at immediately placed implants within this zone, a pattern linked to the widespread occurrence of a thin labial cortical plate throughout the maxillary aesthetic region. Although prevailing guidelines advocate directing the implant trajectory toward the palatal bone to avert excessive compression of the buccal plate, practitioners must equally guard against an overly pronounced buccal inclination and exercise diligence to prevent inadvertent slippage or perforation into the fragile, attenuated buccal lamella [25, 32, 38].

Chronological age exerted no measurable influence on buccal bone width in the present investigation. Yet, a clear sex-based dichotomy emerged, with male subjects exhibiting a thicker buccal plate than female subjects. These outcomes bring to the fore the necessity of integrating gender into the treatment planning calculus, as the diminished buccal bone dimensions encountered in women could introduce added complexity for immediate implant protocols. Buccal bone width proved to be characteristically slender, registering below 1 mm in this cohort and across a substantial body of prior research [25, 27, 36, 37]. The implication is that supplementary interventions, such as bone grafting, may warrant consideration as a routine component of the treatment blueprint when immediate implant placement is envisioned in this aesthetic sector.

The reproducible gender-based divergence seen in both RIC and RBB distances—evident in our dataset and echoed across disparate studies—underscores the imperative of treating biological sex as a pivotal variable in implant treatment strategizing. Conversely, heterogeneity in age-associated shifts and buccal bone dimensions across populations counsels against wholesale extrapolation of findings and reinforces the need for individualized therapeutic design. Notably, the comparatively thinner buccal bone and the palatal bone in closer apposition to the IC observed among female patients may warrant the use of ancillary surgical modalities, including bone augmentation, IC grafting procedures, and modifications in implant macrogeometry, to achieve optimal clinical outcomes [39].

A further distinguishing feature of the present research is its reliance on axial-plane imagery for mensuration, rather than the more conventional sagittal views. This axial perspective offers a different vantage point on the anatomical hurdles inherent to implant surgery. By facilitating the identification of the shortest linear spans, the axial view can be instrumental in determining whether fixture placement can be achieved without encroaching on the IC [27].

It merits noting that the quantitative data generated here may also be informative for orthodontic treatment planning, particularly in situations requiring substantial retraction of the upper central incisors to enhance soft-tissue contours and occlusal relationships. A considerable orthodontic literature has centered on establishing the dimension separating the upper central incisor root apex from the IC. Appreciation of this gap is essential for mitigating the risk of root resorption, which may occur if the root comes into contact with the IC during therapy; parallel attention must also be directed toward soft-tissue management, osseous resorption, and provisional prosthetic management [19, 21, 40, 41].

The single-center origin of this study constitutes a potential constraint. The CBCT scans used in our analysis were obtained from an existing practice archive. Accordingly, the generalizability of the results is limited to the patient population attending the Gangnam dental practice in Seoul, Korea—a private clinical setting—and may not fully reflect the broader Korean population.

It is vital to underscore that all measurements reported here were derived from axial, not sagittal, image reconstructions—the latter being the more customary format in implant planning workflows. The axial orientation was deliberately selected to replicate the operator's intraoperative viewpoint and permits the capture of the briefest distances from the root apex to both the IC and the buccal cortical boundary at precisely defined measurement planes. Consequently, interpreting these outcomes calls for a mindful appreciation of this methodological choice.

This research furnishes meaningful insights into the anatomical imperatives associated with the adjacent incisive canal that must be weighed during immediate implant insertion in the maxillary aesthetic zone among a Korean demographic:

- The mean palatal bone dimension spanning from the central incisor root apex to the IC approximated 3 mm for both the right and left central incisors.
- Buccal bone thickness at the level of the incisor root apex is predominantly meager, its average failing to surpass 1 mm—a figure that falls short of the guideline-endorsed minimum osseous requirement for immediate implant placement.
- An inverse relationship was detected between the buccal bone width and the palatal bone width at the apical level relative to the IC; stated otherwise, the more substantial the osseous reserve between the root apex and the IC, the narrower the buccal bone dimension tends to be.
- A sex-linked disparity emerged, wherein males registered higher mean distances than females. Age, by contrast, showed no discernible effect, spotlighting the inherent variability of the anterior maxillary territory and, hence, the criticality of bespoke treatment planning that meticulously appraises the IC's nearness to the incisor alongside the enveloping buccal and palatal bone to ensure procedural success. The data signal that heightened caution is warranted when managing female patients, given their proclivity for thinner buccal bone and closer IC-to-incisor proximity.
- Tapered implant designs are advisable for this anatomical locale, and adjunctive measures such as bone grafting ought to be entertained as integral elements of the treatment schema.

Looking ahead, subsequent research endeavors should seek to corroborate these observations in expanded, multi-institutional cohorts encompassing patients from diverse ethnic backgrounds, thereby enabling the evaluation of population-specific anatomical idiosyncrasies. Longitudinal study designs could examine how the three-dimensional interrelationships among the IC, palatal bone, and buccal bone evolve over time and in response to tooth loss or other dental pathologies. Furthermore, the application of virtual surgical simulation and finite element modeling to replicate varying implant configurations and positional scenarios relative to the IC could furnish a more rigorous foundation for clinical decision-making. Finally, prospective clinical investigations might test whether embedding these anatomical insights into immediate implant protocols translates into superior surgical outcomes, diminished complication rates, and augmented long-term aesthetic durability.

Conclusion

Within this Korean cohort, the palatal bone adjacent to the incisive canal averaged 3 mm, whereas the buccal bone thickness was typically less than 1 mm. Sex-based differences reached statistical significance, with males exhibiting greater osseous dimensions; age did not affect osseous dimensions. These results buttress the call for customized implant planning, particularly for female patients, and endorse the use of tapered implant designs, with the possible adjunct of bone grafting in this region.

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