

# Analysis of maxillary aesthetic region morphology for immediate implant planning: A CBCT study

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## ABSTRACT

**Aim:** To evaluate morphometric characteristics relevant to immediate implant planning in the maxillary anterior region using cone-beam computed tomography (CBCT).

**Materials and Methods:** In this retrospective study, CBCT images of 597 maxillary anterior teeth, including central incisors, lateral incisors, and canines, from 119 individuals were analyzed. Labial bone thickness, sagittal root position, apical bone height, labial concavity, undercut depth, and alveolar width were assessed. For each tooth, two virtual implant placement strategies were simulated: prosthetically driven and bone-driven.

**Results:** Labial bone thickness was <1 mm in most cases, and sagittal root position predominantly exhibited a Class III distribution (77.8%). Apical bone height was generally adequate for primary stability. More pronounced undercuts and concavities were observed in the lateral incisors. Prosthetically driven implant placement was associated with an increased risk of facial bone compromise, whereas the bone-driven approach resulted in safer implant positioning.

**Conclusion:** Immediate implant planning in the maxillary anterior region frequently requires a bone-driven approach, primarily because of thin labial bone and root-position characteristics. CBCT-based three-dimensional evaluation plays a critical role in achieving safe, predictable, and individualized implant planning.

**Keywords:** Cone-beam computed tomography, dental implants, regional anatomy

## INTRODUCTION

The three-dimensional positioning of a dental implant within the alveolar bone constitutes one of the principal factors determining the success of dental implant therapy (1,2). This requirement is particularly

critical in the maxillary anterior region, where aesthetic expectations are high (3,4). In this region, the thin facial bone structure, limited bone volume, and variable root position within the alveolus make immediate implant placement technically challenging and increase the risk of complications (5,6).

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Immediate implant placement is increasingly preferred because it can shorten treatment time and preserve hard- and soft-tissue contours (1,5,7,8). However, the success of this approach depends not only on surgical technique but also on the extent to which implant positioning is compatible with the existing bone morphology (1,2,5,9). In cases with insufficient facial bone thickness, implant placement along the prosthetic axis may result in facial bone perforation and soft-tissue complications (5,6,10,11).

Post-extraction alveolar bone resorption further complicates implant procedures (12,13). Pronounced early volumetric loss of the facial bone limits the availability of adequate bone support for implant placement and often necessitates a more palatal implant position (12–14). Therefore, immediate implant planning should consider prosthetic requirements and the existing bone morphology.

Cone-beam computed tomography (CBCT) has become an important imaging modality in implant planning because it enables three-dimensional evaluation of alveolar bone structure (15,16). CBCT data allow detailed analysis of preoperative parameters and are critical for safe implant positioning (6,10,11,15,17).

However, only a few studies have comprehensively evaluated critical morphological parameters, such as labial bone thickness, alveolar ridge dimension, sagittal root position, and labial concavity within the same sample (10,18–20). Moreover, studies directly comparing implant placement based on the prosthetic axis with placement optimized according to existing bone morphology remain limited (20). This gap may introduce uncertainty in clinical decision-making about which placement approach is morphologically safer and more predictable for immediate implant planning.

A comprehensive assessment of these interrelated anatomical parameters within the same population may provide a more integrated understanding of the morphological constraints affecting immediate implant placement.

Therefore, this study aimed to analyze alveolar bone morphology in the maxillary anterior region using CBCT and to evaluate the effect of these morphological

characteristics on immediate implant placement strategies.

## MATERIALS AND METHODS

### Ethical approval

This retrospective cross-sectional study was approved by the Non-Interventional Clinical Research Ethics Committee of Canakkale Onsekiz Mart University (decision no. 2025-07/07-19; April 17, 2025) and was conducted in accordance with the principles of the Declaration of Helsinki.

### Sample selection

CBCT images obtained for various clinical indications between 2022 and 2025 at the Faculty of Dentistry of Canakkale Onsekiz Mart University were retrospectively evaluated. The inclusion criteria were as follows:

- Individuals aged  $\geq 20$  years
- Presence of at least one fully erupted maxillary anterior tooth
- Teeth with complete root development
- CBCT records of sufficient image quality
- The exclusion criteria were as follows:
  - Presence of periapical pathology
  - Active orthodontic treatment
  - History of surgical procedures in the relevant region
  - Records showing pronounced alveolar bone loss or imaging artifacts
- Presence of restorations, crowns, posts, orthodontic appliances, or implants in the relevant region

A total of 597 maxillary anterior teeth, including central incisors, lateral incisors, and canines, from 119 individuals who met the study criteria were included in the analysis (Figure 1).

### Image analysis

CBCT images obtained using a NewTom 5G XL device (QR Systems, Verona, Italy) with a field of view (FOV) of  $10 \times 5$  cm, tube voltage of 110 kV, voxel size of 0.200 mm, and exposure time of 3.6 s were evaluated using NNT® Viewer software, and

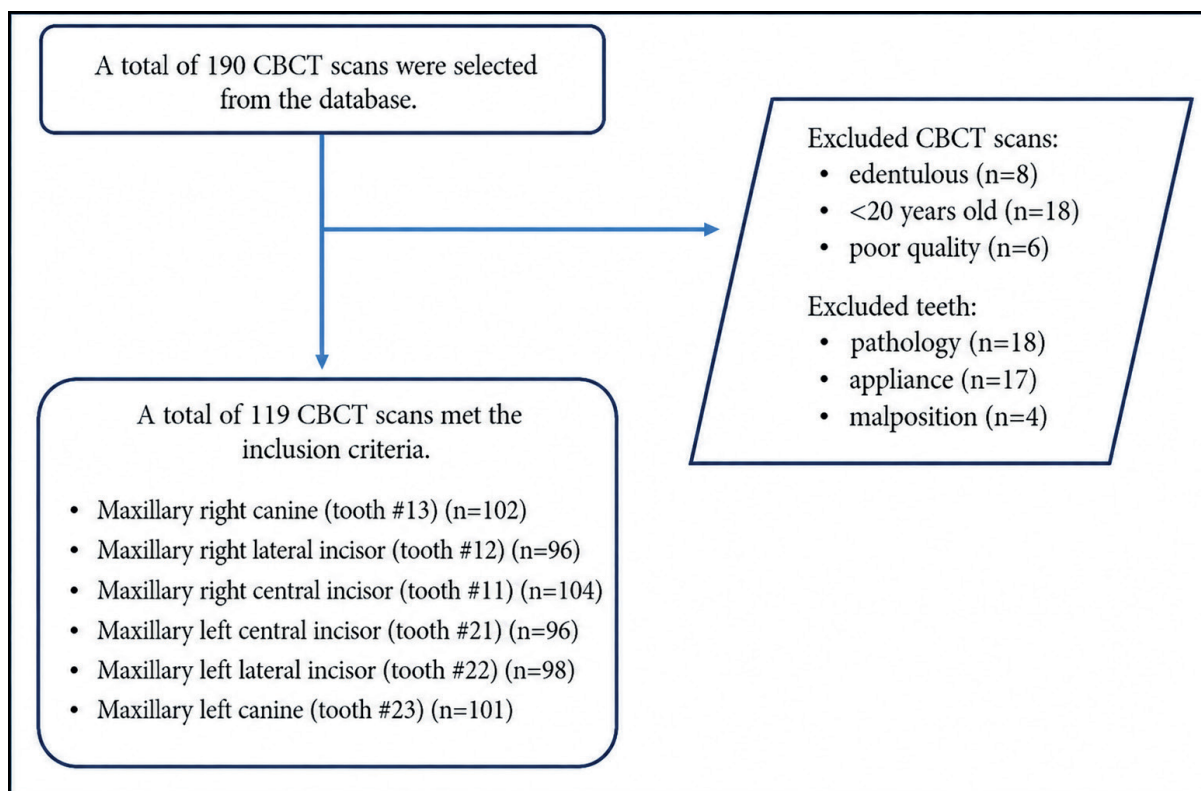


**Figure 1.** Selection of cone-beam computed tomography (CBCT) scans and distribution of the included teeth according to tooth type and exclusion criteria.

all measurements were conducted on sagittal, axial, and coronal reconstructions to ensure accuracy and standardization.

### Morphometric evaluation

All morphometric measurements were performed on sagittal sections using a reference plane that passed through the mesiodistal midpoint of the tooth and was aligned with its long axis. Labial bone thickness (LBT) was measured perpendicular to the long axis at 0, 1, 2, and 4 mm apical to the alveolar crest (LBT0-4) (21). The faciopalatal position of the root within the alveolus was assessed as the sagittal root position (SRP) according to the classification described by Gluckman et al. (11).

Apical bone support was determined by measuring the linear distance between the root apex and the relevant anatomical landmark (RABH-t) and comparing it with the distance between the virtual implant apex and the

same landmark (RABH-b) (22). Alveolar concavity was analyzed using undercut depth (LUD) and concavity angle (LCA), based on a reference line tangent to the labial cortical plate and parallel to the alveolar crest axis (9,23,24). Additionally, alveolar width was evaluated by measuring the mesiodistal distance (MD) between adjacent root surfaces and the faciopalatal dimension (FP) on sagittal sections (25).

In virtual implant placement (VIP), standard implant dimensions were selected according to tooth type: 4.1 × 10 mm for central incisors and canines and 3.3 × 10 mm for lateral incisors (20). The implant platform was positioned approximately 1 mm apical to the alveolar crest, in accordance with previous literature (26). For each tooth, two placement strategies were simulated: prosthetically-driven placement, parallel to the long axis of the tooth (VIP-t), and bone-driven placement, optimized according to the existing bone morphology (VIP-b) (Figure 2).

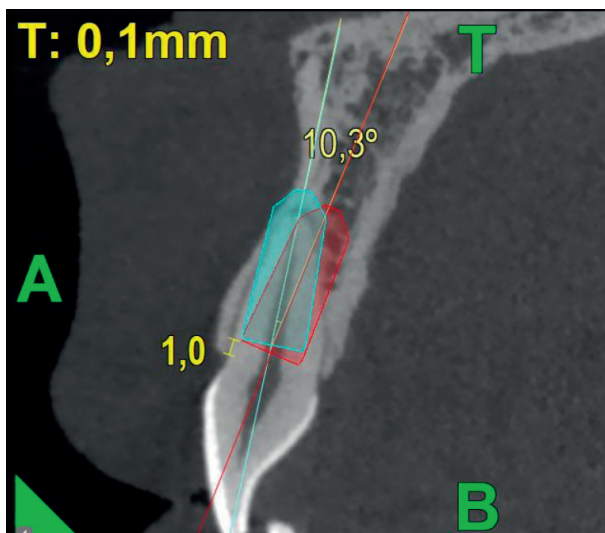


**Figure 2.** Virtual implant placement on cone-beam computed tomography (CBCT) images. Blue: virtual implant positioned parallel to the long axis of the tooth; Red: virtual implant positioned parallel to the long axis of the alveolar crest; Yellow: angle between the two implant positions.

In both approaches, the relationship between the implant and the facial bone was evaluated, and the distance between the implant and the labial bone was classified according to clinical applicability as exposed, <1 mm, or  $\geq 1$  mm. Additionally, the angular difference between the two placement strategies (VIP-angle) was recorded (20).

### Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics 22.0 (IBM Corp., Armonk, NY, USA). The distributional characteristics of continuous variables were assessed using the Kolmogorov-Smirnov test and graphical methods, including histograms and Q-Q plots. Descriptive statistics are presented as mean  $\pm$  standard error for continuous variables and as frequency (n) and percentage for categorical variables.

For comparisons between groups, the *independent-samples t-test* was used for two-group comparisons, and one-way analysis of variance (ANOVA) was used when the data were normally distributed. When ANOVA detected a significant difference, multiple

comparisons were performed using Tukey's post hoc test. Pearson correlation analysis was used to assess the relationships between continuous variables and age.

To assess intra-examiner reproducibility, the intraclass correlation coefficient (ICC) was calculated based on repeated measurements performed at a 2-week interval on selected images, and an ICC  $\geq 0.90$  was considered to indicate "high reliability." For all tests,  $p < 0.05$  was considered statistically significant.

## RESULTS

A total of 597 maxillary anterior teeth from 119 individuals were evaluated. In the sample, 57.6% were female patients ( $n = 344$ ) and 42.4% were male patients ( $n = 253$ ), with a balanced distribution between the right (50.6%) and left (49.4%) sides. The largest age group was 20–29 years (30.7%) (Table 1).

**Table 1.** Demographic and descriptive characteristics of the study sample.

| General Characteristics | n   | %    |
|-------------------------|-----|------|
| Gender                  |     |      |
| Female                  | 344 | 57.6 |
| Male                    | 253 | 42.4 |
| Location                |     |      |
| Right                   | 302 | 50.6 |
| Left                    | 295 | 49.4 |
| Age                     |     |      |
| 20–29                   | 183 | 30.7 |
| 30–39                   | 125 | 20.9 |
| 40–49                   | 160 | 26.8 |
| $\geq 50$               | 129 | 21.6 |
| Tooth                   |     |      |
| 11                      | 104 | 17.4 |
| 12                      | 96  | 16.1 |
| 13                      | 102 | 17.1 |
| 21                      | 96  | 16.1 |
| 22                      | 98  | 16.4 |
| 23                      | 101 | 16.9 |

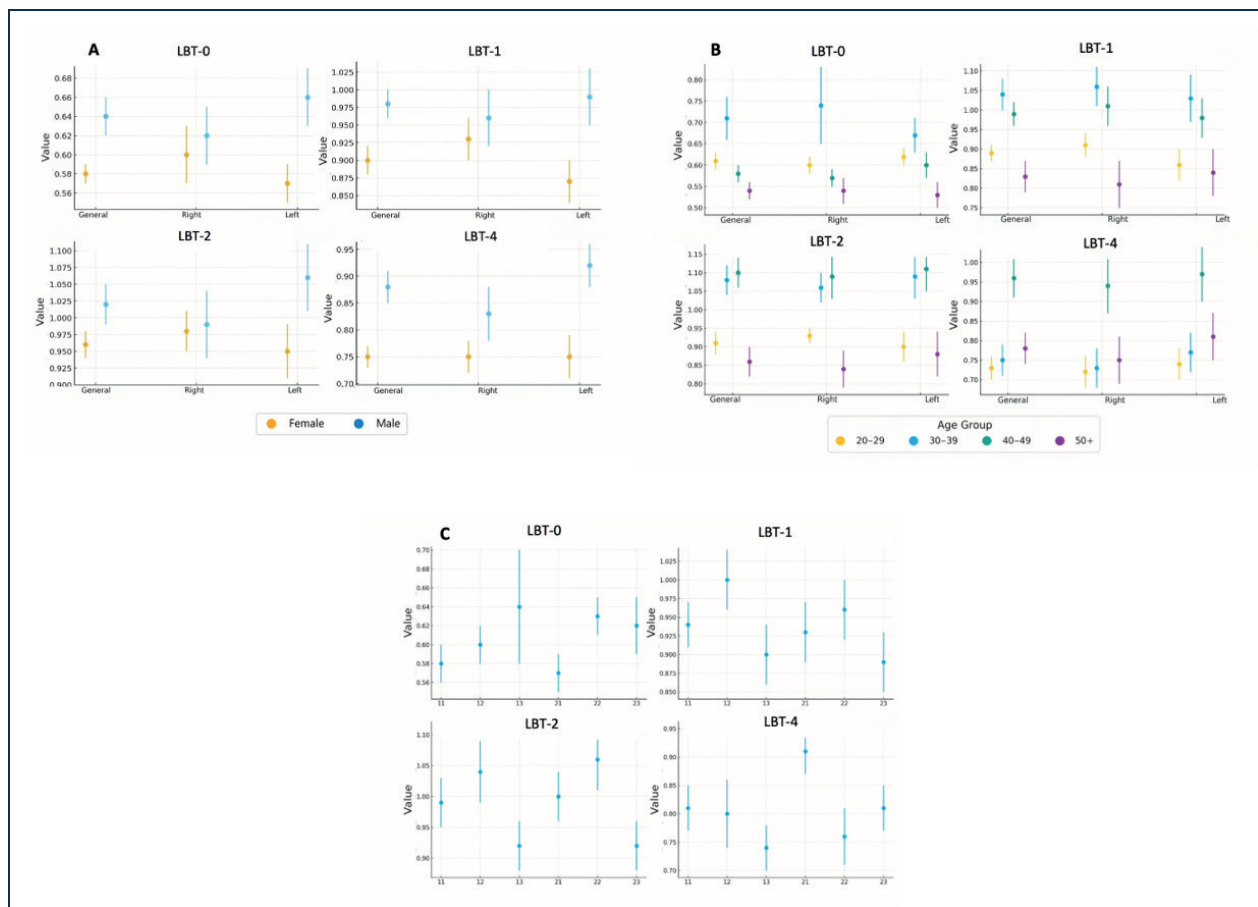


**Figure 3.** A. Distribution of LBT measurements by gender B. Association between LBT measurements and age groups C. Distribution of LBT measurements across teeth in the maxillary anterior region.

LBT: labial bone thickness

LBT values were  $<1$  mm at all levels in most cases. Significantly higher LBT values were observed in male patients at the LBT-1 and LBT-4 levels ( $p = 0.044$  and  $p = 0.002$ , respectively) (Figure 3A). Significant differences were detected among age groups at all LBT levels ( $p < 0.05$ ), with the highest values generally observed in the 30-39- and 40-49-year age groups. Correlation analyses revealed weak negative correlations between age and LBT-0 ( $r = -0.110$ ,  $p = 0.007$ ) and LBT-1 ( $r = -0.082$ ,  $p = 0.046$ ) (Figure 3B). Although no significant differences were observed among tooth types, LBT-0 exhibited the lowest values, whereas LBT-1 and LBT-2 exhibited the highest values (Figure 3C).

In the SRP distribution, Class III was markedly predominant (77.8%), whereas the remaining classes were observed at substantially lower frequencies. SRP distribution was independent of sex, age, and location (Table 2).

No significant sex-related difference was observed in RABH-t values ( $p > 0.05$ ), whereas RABH-b values, calculated based on bone-driven placement, were significantly higher in male patients ( $p < 0.001$ ) (Figure 4A). While RABH-t values remained comparable across age groups, RABH-b values differed significantly ( $p < 0.001$ ), with the highest values observed in the 40-49-

**Table 2.** Associations of SRP categories with gender, age group and location.

|       |       |                       | Gender |        | Total  |                        | Age Group |        |        |        | Total               |            | Location |        |        |
|-------|-------|-----------------------|--------|--------|--------|------------------------|-----------|--------|--------|--------|---------------------|------------|----------|--------|--------|
|       |       |                       | Female | Male   |        |                        | 20-29     | 30-39  | 40-49  | ≥50    |                     |            | Right    | Left   | Total  |
| SRP   | CI-2A | Count                 | 5      | 9      | 14     | Count                  | 4         | 2      | 5      | 3      | 14                  | Count      | 7        | 7      | 14     |
|       |       | % Gender              | 1.5%   | 3.6%   | 2.4%   | % Age Group            | 2.2%      | 1.6%   | 3.2%   | 2.3%   | 2.4%                | % Location | 2.3%     | 2.4%   | 2.4%   |
|       | CI-2B | Count                 | 34     | 39     | 73     | Count                  | 24        | 21     | 12     | 16     | 73                  | Count      | 43       | 30     | 73     |
|       |       | % Gender              | 10.0%  | 15.4%  | 12.3%  | % Age Group            | 13.1%     | 16.8%  | 7.6%   | 12.4%  | 12.3%               | % Location | 14.3%    | 10.2%  | 12.3%  |
|       | CI-3  | Count                 | 276    | 186    | 462    | Count                  | 149       | 94     | 125    | 94     | 462                 | Count      | 230      | 232    | 462    |
|       |       | % Gender              | 80.9%  | 73.5%  | 77.8%  | % Age Group            | 81.4%     | 75.2%  | 79.6%  | 72.9%  | 77.8%               | % Location | 76.7%    | 78.9%  | 77.8%  |
|       | CI-4  | Count                 | 6      | 4      | 10     | Count                  | 1         | 0      | 4      | 5      | 10                  | Count      | 4        | 6      | 10     |
|       |       | % Gender              | 1.8%   | 1.6%   | 1.7%   | % Age Group            | 0.5%      | 0.0%   | 2.5%   | 3.9%   | 1.7%                | % Location | 1.3%     | 2.0%   | 1.7%   |
|       | CI-5  | Count                 | 20     | 15     | 35     | Count                  | 5         | 8      | 11     | 11     | 35                  | Count      | 16       | 19     | 35     |
|       |       | % Gender              | 5.9%   | 5.9%   | 5.9%   | % Age Group            | 2.7%      | 6.4%   | 7.0%   | 8.5%   | 5.9%                | % Location | 5.3%     | 6.5%   | 5.9%   |
| Total |       | Count                 | 341    | 253    | 594    | Count                  | 183       | 125    | 157    | 129    | 594                 | Count      | 300      | 294    | 594    |
|       |       | % Gender              | 100.0% | 100.0% | 100.0% | % Age Group            | 100.0%    | 100.0% | 100.0% | 100.0% | 100.0%              | % Location | 100.0%   | 100.0% | 100.0% |
|       |       | χ² = 7.254; p = 0.123 |        |        |        | χ² = 19.497; p = 0.077 |           |        |        |        | χ² = 2.921; p=0.571 |            |          |        |        |

SRP: Sagittal root position, CI: Class; CI 2-5: SRP classes according to Gluckman et al.

year age group. A weak positive correlation between RABH-b and age was identified ( $r = 0.095$ ,  $p = 0.021$ ; Figure 4B). Among tooth types, RABH-t differed significantly ( $p < 0.001$ ), whereas RABH-b did not differ significantly ( $p = 0.364$ ) (Figure 4C).

LUD values did not differ by sex ( $p > 0.05$ ; Figure 5A). However, LUD increased significantly across age groups ( $p < 0.001$ ), with the highest values observed in the 40-49-year-old age group (Figure 5B). A significant positive correlation was found between age and LUD ( $r = 0.172$ ,  $p < 0.001$ ). Significant differences were also detected among tooth types ( $p < 0.001$ ), with the highest values observed in lateral incisors.

LCA values were significantly higher in male patients ( $p < 0.001$ ; Figure 5C). Significant differences were observed among age groups ( $p < 0.001$ ), with the highest values in the 30-39-year age group. No significant correlation was found between age and LCA ( $p > 0.05$ ; Figure 5D).

Mesiodistal measurements were higher in male patients ( $p < 0.05$ ) (Figure 6A) and differed significantly

among age groups ( $p = 0.001$ ) (Figure 6B). Significant differences were also observed among tooth types ( $p < 0.001$ ) (Figure 6C). Faciopalatal width was significantly greater in male patients across all analyses ( $p < 0.001$ ) (Figure 7A). A weak negative correlation was found between age and FP ( $r = -0.253$ ,  $p < 0.001$ ) (Figure 7B). FP measurements differed significantly among maxillary anterior teeth ( $p < 0.001$ ; Figure 7C).

In VIP-t, a significant sex-related difference was observed ( $p < 0.001$ ), with a higher proportion of Class A among female patients and of Class C among male patients. In VIP-b, most cases were classified as Class C (95.3%). Significant differences were observed among age groups for both VIP-t ( $p < 0.001$ ) and VIP-b ( $p < 0.05$ ), with more favorable placement patterns observed in older age groups. No location-related effect was observed ( $p > 0.05$ ).

The mean VIP-angle was approximately  $10^\circ$ – $11^\circ$  and was positively correlated with age ( $r = 0.183$ ,  $p < 0.001$ ) (Figure 8B). No significant differences were observed by sex or tooth type (Figure 8A and Figure 8C).

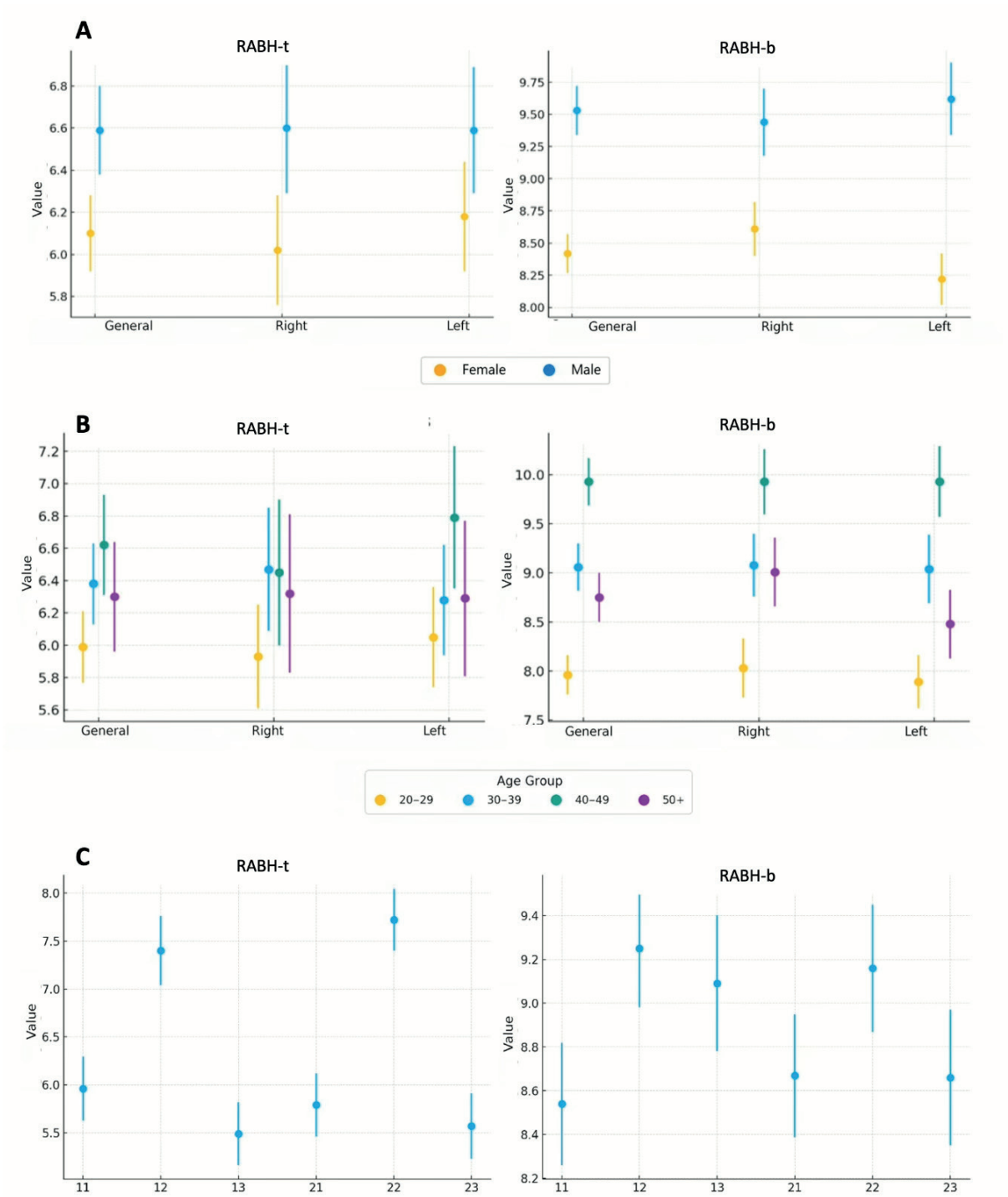


**Figure 4.** A. Distribution of RABH-t/RABH-b measurements by gender B. Association between RABH-t/RABH-b measurements and age groups C. Distribution of RABH-t/RABH-b measurements across teeth in the maxillary anterior region.

RABH-t: linear distance between the root apex and the relevant anatomical landmark, RABH-b: linear distance between the virtual implant apex and the same landmark.

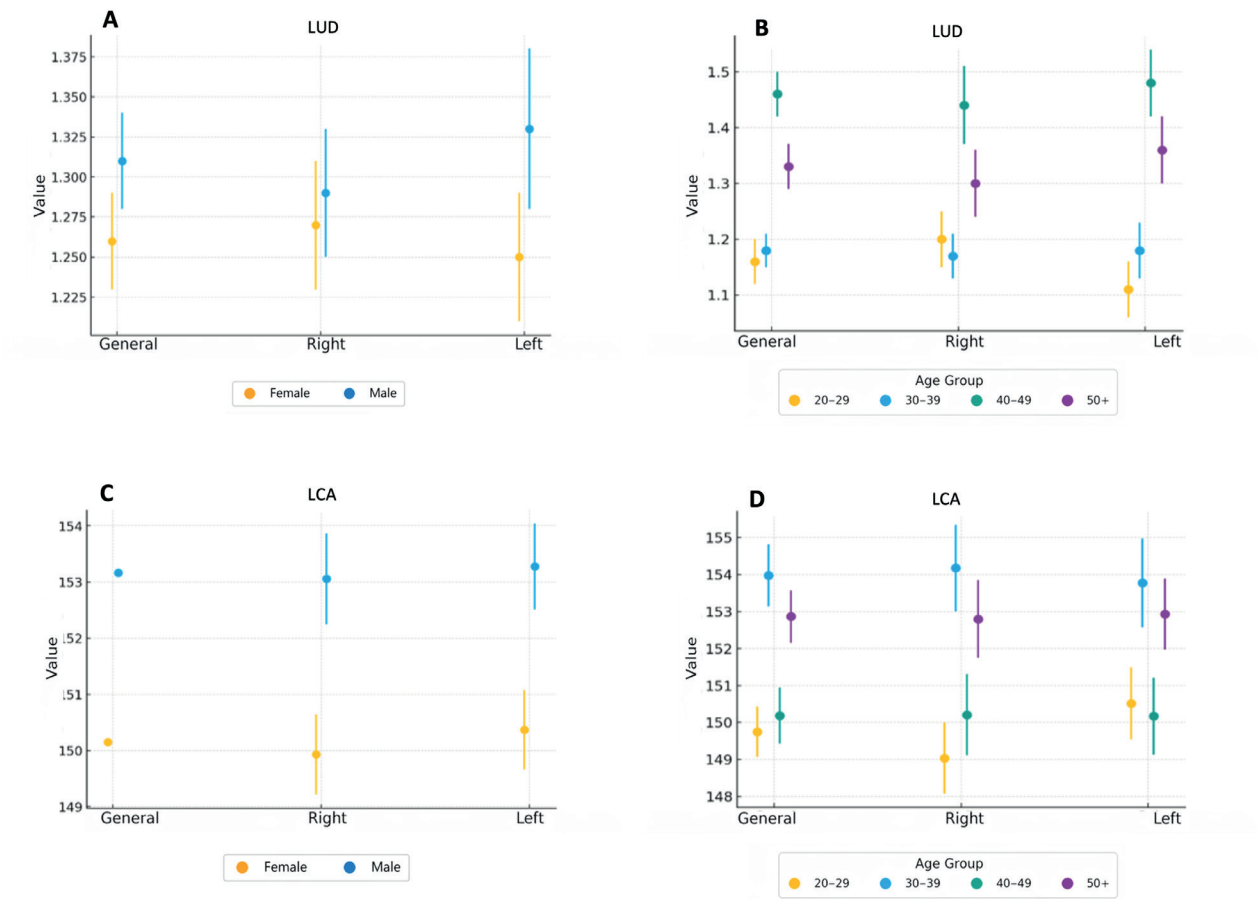


**Figure 5.** A. Distribution of LUD measurements by gender B. Association between LUD measurements and age groups. C. Distribution of LCA measurements by gender D. Association between LCA measurements and age groups. LUD: Labial undercut depth, LCA: Labial concavity angle.

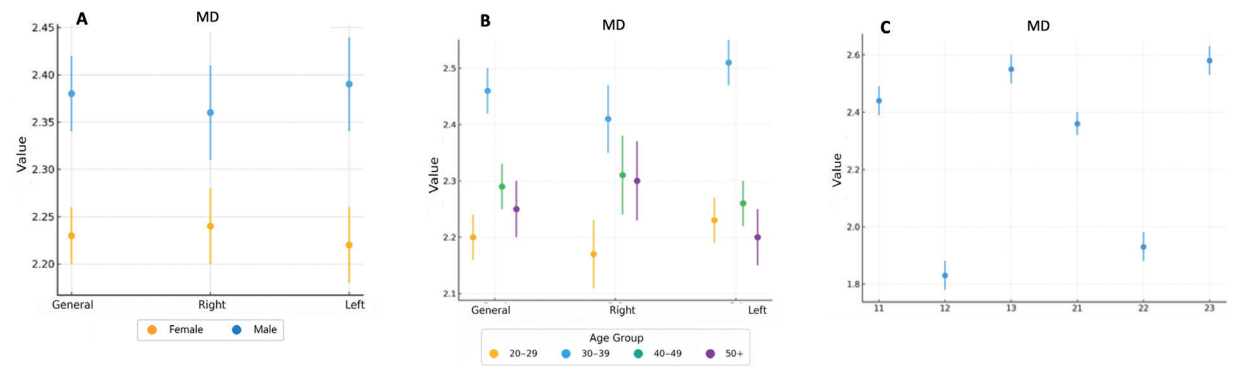


**Figure 6.** A. Distribution of MD measurements by gender B. Association between MD measurements and age groups C. Distribution of MD measurements across teeth in the maxillary anterior region MD: mesiodistal distance between adjacent root surfaces.

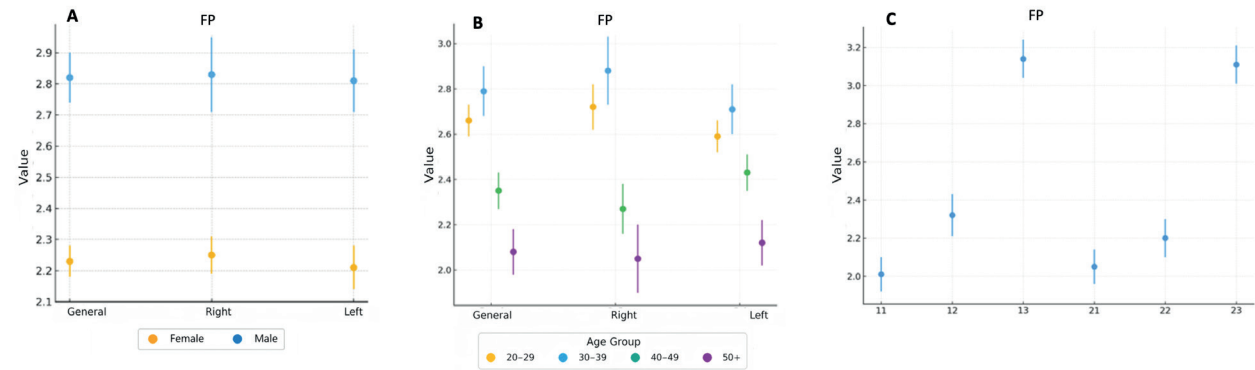


**Figure 7.** A. Distribution of FP measurements by gender B. Association between FP measurements and age groups C. Distribution of FP measurements across teeth in the maxillary anterior region  
FP: faciopalatal dimension on sagittal sections.

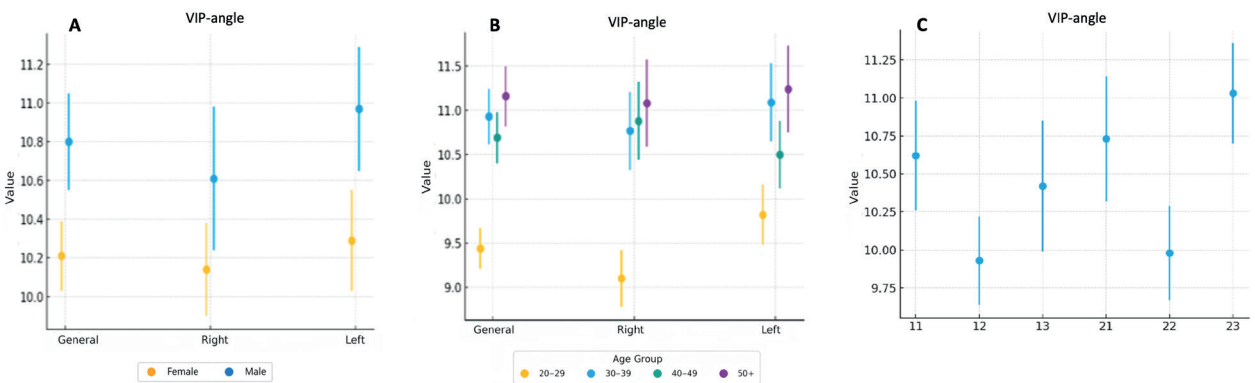


**Figure 8.** A. Distribution of VIP-angle measurements by gender B. Association between VIP-angle measurements and age groups C. Distribution of VIP-angle measurements across teeth in the maxillary anterior region.  
VIP-angle: angular difference between the two placement strategies.

## DISCUSSION

The maxillary anterior region is an anatomically demanding area where aesthetic and functional requirements must be precisely balanced, and the success of immediate implant placement in this region is largely governed by the three-dimensional morphological characteristics of the alveolar bone (3,6,27). The present findings demonstrate that implant placement in the anterior maxilla cannot be dictated solely by prosthetic requirements; rather, existing bone morphology acts as a decisive and often limiting factor.

A notable finding of this study is that labial bone thickness was predominantly  $<1$  mm. This observation is consistent with previous reports describing the inherently thin nature of the facial bone in the anterior maxilla (6,10,11,17). Such limited thickness predisposes the facial plate to early post-extraction resorption and consequently increases the risk of aesthetic complications following immediate implant placement (28,29). In this context, the frequently cited threshold of  $\geq 2$  mm facial bone thickness (30,31) appeared to be clinically unattainable in most cases within the sampled population. Accordingly, these findings support the frequent need for augmentation procedures in immediate implant therapy.

The predominance of Class III sagittal root position carries important clinical implications for implant planning. This distribution reflects a labially inclined root within the alveolar housing, thereby restricting prosthetically-driven implant placement in most cases. The consistency of similar findings across different populations (17,24,32) suggests that this is a reproducible anatomical pattern rather than a population-specific variation. A proclined root position increases the likelihood that the root will be close to the labial cortex and elevates the risk of cortical perforation; consequently, palatal implant placement often becomes necessary.

The present findings highlight the discrepancy between prosthetically-driven and bone-driven approaches in immediate implant planning. In most cases, LBT was <1 mm at all evaluated levels, indicating limited facial bone availability. Accordingly, implant placement along the prosthetic axis may increase the risk of facial bone perforation when it is incongruent with the existing bone morphology (20). Furthermore, the mean angular difference of approximately 10°–11° between prosthetically driven and bone-driven virtual implant positions demonstrates that the prosthetically determined implant position may not always be compatible with the available alveolar bone morphology. These findings emphasize the importance of considering both prosthetic requirements and individual bone morphology during immediate implant planning.

The observation that apical bone height was sufficient in most cases represents a favorable condition for immediate implant placement. Fulfillment of minimum apical bone requirements for primary stability, as emphasized in the literature (23,33,34), is a critical factor for successful osseointegration. This finding suggests that, in the anterior maxilla, anatomical limitations are primarily concentrated in the coronal and facial aspects, whereas the apical region generally provides adequate support.

Alveolar concavity and the presence of a labial undercut are key morphological determinants that directly influence implant angulation. A more pronounced concavity was observed in lateral teeth in the present study, suggesting increased technical complexity in this region and a potentially higher risk of perforation,

as also reported in the literature (19). These findings reinforce the importance of CBCT-based preoperative assessment and highlight the need for individualized surgical planning.

Mesiodistal distances exceeding the thresholds recommended in the literature ( $\geq 1.5$ –2 mm) (35–37) may be advantageous for papilla stability in the aesthetic zone. However, the predominance of faciopalatal width in favor of the palatal bone suggests that palatal implant positioning is not only necessary but also biomechanically advantageous (6,20,38). This supports the concept that implant placement strategies in the anterior maxilla should be guided by the distribution of available bone rather than prosthetic alignment alone.

A key strength of this study is the integrated assessment of multiple morphological parameters within the same population, together with the direct comparison of prosthetically-driven and bone-driven virtual implant positioning. CBCT-based three-dimensional planning may improve implant placement accuracy and help reduce potential bone-related risks by enabling detailed assessment of the available alveolar bone morphology (39). The present findings support this concept and indicate that bone-driven planning may provide greater morphological compatibility with the available alveolar bone in the anterior maxilla. Analysis of implant angulation revealed that implant positioning deviates from the prosthetic axis in most cases. This finding emphasizes the need to balance restorative objectives with anatomical constraints. The variability in angulation values reported across different populations (23) indicates that morphological variability plays a decisive role in clinical decision-making.

This study has certain limitations. The single-center dataset may limit the generalizability of the findings. Additionally, patient-related factors that may influence alveolar bone morphology were not evaluated. Furthermore, the absence of a direct correlation between morphological parameters and clinical outcomes necessitates cautious interpretation of their impact on treatment success. Prospective longitudinal studies are required to further elucidate the clinical relevance of these morphological factors.

Within the limitations of this study, immediate implant planning in the maxillary anterior region appears to be predominantly governed by alveolar bone morphology. The presence of a thin labial bone plate and the high prevalence of Class III sagittal root positions restrict prosthetically-driven implant placement in most cases and necessitate a bone-driven, palatally-oriented approach. These findings indicate that implant planning in the anterior region should be based on individualized morphological assessment. CBCT-based three-dimensional analysis, combined with a bone-driven placement strategy, should be considered a fundamental clinical approach for preserving facial bone integrity and achieving long-term aesthetic success.

### Ethical approval

The study was approved by the Non-Interventional Clinical Research Ethics Committee of Çanakkale Onsekiz Mart University (approval no: 2025-07/07-19; April 17, 2025) and conducted in accordance with the ethical principles of the Declaration of Helsinki.

### Author contribution

Concept: RA; Design: RA, BC; Data Collection or Processing: BC; Analysis or Interpretation: BC; Literature Search: BC; Writing: BC, RA; Critical Review: RA. All authors reviewed the results and approved the final version of the manuscript.

### Source of funding

The authors declare the study received no funding.

### Conflict of interest

The authors declare that there is no conflict of interest.

### Use of artificial intelligence

OpenAI ChatGPT (OpenAI, San Francisco, CA, USA) was used to improve the language and readability of the text. All AI-assisted outputs were critically reviewed, verified, and edited by the authors, who assume full responsibility for the presented work.

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