

# Frequency of Buccal Bone Fenestration in Anterior maxilla: A Virtual Implant Placement Study

Zainab Naqvi\*, Muhammad Haseeb, Sittara Javed, Obaid Bajwa, Maqbool Ahmed

University College of Dentistry,  
University of Lahore, Lahore,  
Pakistan

\*Corresponding Author

Zainab Naqvi  
zainabnaqvi050@gmail.com

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## Abstract

**Objective:** To determine the occurrence of buccal bone fenestration of the anterior maxilla and its relationship with the type of prosthesis (screw-retained or cement-retained) and the labial concavity angle (LCA) based on virtual placement of the implants.

**Methodology:** A Cone-Beam Computed Tomography (CBCT)-based virtual implant simulation study was conducted over 6 months from May to October, 2025 at the Department of Periodontology, University Dental Hospital, University of Lahore. Two hundred anonymized CBCT images for patients over the age of 20 years were analyzed using BlueSky Plan software. Virtual placement of implants was done based on the type of prosthesis- screw retained and cement retained. Buccal bone thickness, presence of fenestration and LCA were documented. Data were analyzed based on the Mann Whitney U test and Fisher's exact test with SPSS at a significance level of  $p < 0.05$ .

**Results:** The average age of patients was  $39.7 \pm 10.9$  years. The mean coronal bone-to-implant distance was significantly greater in cement-retained implants ( $2.33 \pm 0.93$  mm) compared with screw-retained implants ( $1.52 \pm 0.48$  mm) ( $p < 0.05$ ). The distance b/w the bone and the implant significantly differed at the middle ( $1.61 \pm 0.48$  mm) and apical ( $1.40 \pm 0.59$  mm) levels for cement-retained implants as compared to screw-retained implants ( $1.03 \pm 0.62$  mm and  $0.67 \pm 0.88$  mm, respectively;  $p < 0.05$ ). The average LCA was  $154.7^\circ \pm 7.1^\circ$ . A statistically significant association between prosthesis type and fenestration was identified using Fisher's exact test. In addition, the LCA showed a positive correlation, with significant differences observed between genders ( $p < 0.05$ ).

**Conclusion:** Screw-retained virtual implant positions demonstrated a higher likelihood of buccal bone fenestration compared to cement-retained positions. Labial concavity angle differed significantly between genders, suggesting anatomical variability may influence fenestration risk.

**Keywords:** Buccal bone fenestration, anterior maxilla, CBCT, virtual implant placement, screw-retained prosthesis, cement-retained prosthesis

## Introduction

Dental implants are now a highly accepted and predictable treatment option for partially or fully edentulous patients.<sup>1</sup> Modern surgical and restorative methods currently emphasize shortening treatment time while maintaining the best esthetic and functional outcomes.<sup>1</sup> Immediate implant placement, especially with simultaneous bone augmentation, has demonstrated the ability to develop and/or maintain the natural periodontal architecture and minimize bone resorption after tooth extraction.<sup>1</sup> However, implant placement in the anterior maxilla has its unique challenges due to proclined antero-inferior angle of the alveolar bone and the presence of a prominent buccal concavity, both of which increase the potential for labial bone fenestration.<sup>2</sup> The thin buccal cortical plate is vulnerable to fenestration and dehiscence, which may negatively impact primary stability and consequently require additional grafting procedures.

Sagittal root positioning (SRP) can further complicate implant placement in this esthetic zone. A study established that approximately 85% of maxillary incisors have Class I SRP with the root positioned near the labial cortical plate.<sup>3</sup> To preserve sufficient buccal bone in such cases, implant placement is recommended 0.5-1.0 mm towards the palatal side.

Ideally, implants should be prosthetically driven to maximize esthetics, force distribution, and hygiene; however, anatomical restrictions dictate practicing the positioning of implants bone-driven. Cone-beam computed tomography (CBCT) plays an important role in the pre-operative evaluation process to understand bone morphology and implant positioning in 3D. A study identified a significant number of labial perforations, mainly in the apical and middle third, based on the implant design and angulation.<sup>4,5</sup> A study conducted by Anna and coworkers reported a higher percentage of perforation at prosthetically driven (80%) compared to bone-driven implants (5%) in central

incisors. It is thought that the differences in perforations about the location could be due to differences in SRP classes and differences, ethnicity in the morphology of the alveolar ridge.<sup>6</sup>

Previous CBCT-based investigations in the anterior maxilla have explored parameters such as screw-retained crown feasibility, ridge morphology, labial bone thickness, undercuts, and sagittal angulation. Across these studies, a consistent finding emerges—there is a substantial risk of labial bone perforation when planning implants in the esthetic zone.<sup>7</sup> However, to date, no study has specifically evaluated the risk of labial bone perforation in relation to screw-retained versus cement-retained implant restorations within the context of sagittal root positioning. However, unlike previous CBCT studies that focused primarily on bone morphology or implant angulation, this study uniquely integrates prosthetic orientation with labial concavity morphology to quantify fenestration risk in anterior maxillary implant planning. This study evaluates the frequency of buccal bone fenestration in screw-retained vs. cement-retained implant positions. This study also investigates the labial concavity angle in our population and its possible association with gender variation and fenestration of buccal bone.

## Methodology

Following ethical approval from the Institutional Review Board (Ref No: UCD/ERCA/279; Approved on 17-06-2023), A CBCT-based virtual implant simulation study was conducted over 6 months at the Department of Periodontology. It was conducted over six months from May 15<sup>th</sup> 2025 to Oct 15<sup>th</sup> 2025 in the Department of Periodontology, University Dental Hospital, University of Lahore, using non-probability consecutive sampling.

The sample size comprised 200 virtual implant simulations, which were enough to provide the statistical power needed to check the relation between the type of prosthesis and the buccal bone fenestration. OpenEpi (Version 3.01) was used for the priori determination of the necessary sample size. Fenestration rates mentioned in earlier CBCT-based virtual placement studies were the basis for this determination. A total sample size of 200 virtual implant stimulations was calculated with 100 in each group (screw-retained versus cement-retained position). The sample size was calculated using a 95% confidence level and 80% power, based on an expected buccal bone fenestration prevalence of approximately 15.5% for screw-retained implant positions at tooth #21, as reported in previous CBCT-based studies.<sup>6</sup>

Inclusion criteria comprised patients older than 20 years who were medically suitable for implant therapy, presented with bilateral maxillary anterior teeth, sagittal root positioning (SRP) Class I, and Type I extraction sockets. Only those requiring CBCT scans for posterior implant planning and providing informed consent were included. Exclusion criteria included the presence of periodontal disease, a history of radiotherapy or chemotherapy, psychological impairment, unclear or artifact-distorted CBCT images, Type II or III extraction sockets, and pathology affecting the maxillary anterior region.

To minimize selection bias, one maxillary anterior tooth (right or left central or lateral incisor) was randomly selected per

scan using a computer-generated randomization sequence. The allocation of each tooth was thus purely random and not affected by the researchers. CBCT scans were obtained using a Planmeca Romexis unit (Planmeca, Helsinki, Finland) with a voxel size of 0.2mm, 90 kV at 10 mA, and a field of view of 8 × 8 cm. The DICOM datasets were then imported into BlueSky Plan software (Version 4.8, BlueSkyBio, USA) for virtual simulation.

Within the BlueSky Plan software, standard cross-sectional slices were utilized. The labial concavity angle was measured on cross-sectional CBCT images at each implant site to assess the curvature of the labial cortical plate. Three reference points were identified for this measurement (Figure 2):

- Point C: the most coronal external point of the labial plate,
- Point I: the most internal point of the labial concavity, and
- Point A: the most external apical point of the labial plate, located superior to Point I.

A digital wax-up was obtained from the software's digital tooth library to produce crown contour and cemento-enamel junction (CEJ) contours, secured in position before implant simulation. The virtual bone-level tapered implants (4.1 × 13 mm) were positioned 4 mm apical to the mid-facial CEJ. A standardized implant length of 13 mm was selected to ensure a minimum apical anchorage of 4 mm, which is considered essential for immediate implant placement. Similarly, an implant diameter of 4.1 mm was used, as a 4 mm diameter is commonly regarded as a standard dimension for implants in this region.<sup>8</sup> Different angles were used for cement- and screw-retained implants to reflect clinical prosthetic requirements and assess their impact on buccal bone fenestration

Each site was planned in two orientations;

1. Screw-retained position: The implant was aligned such that the screw access hole emerged through the middle of the lingual groove near the cingulum.
2. Cement-retained position: The implant was aligned along the long axis of the tooth through the incisal edge of the diagnostic wax-up.

At both the positions, buccal bone thickness was measured from the implant shoulder to the outer buccal cortical plate at coronal, middle and apical third (Figure 1). The presence of fenestration (exposure of any implant thread beyond the buccal bone) was recorded at each level as present or absent. Data collection was preceded by the calibration of two operators who collectively assessed 10 CBCT scans and normalized their measuring protocols. The reliability testing showed a very good agreement, with the intra- and inter-observer ICC values both being more than 0.85, which meant that there was a high level of reliability in all the measurements taken.

Every virtual implant simulation, and not individual patients, was regarded as the unit of analysis, which guaranteed that the statistical tests took into account the independence of observations. One anterior tooth per scan was randomly chosen to obviate clustering effects, thus preventing unit-of-analysis errors and subsequently allowing for valid inference to be made.

The reliability was established by means of intra- and inter-observer ICC (intraclass correlation coefficients) which were greater than 0.85 indicating a very good agreement between the two trained operators. All measurements were carried out again on 10% of the sample in order to check the consistency thus ensuring robust and reproducible radiographic assessments. Normality of the data was assessed using the Shapiro–Wilk test. The labial concavity angle (LCA) showed a normal distribution ( $p > 0.05$ ) and was therefore analyzed using parametric independent-sample t-tests. Bone-to-implant distance did not follow a normal distribution and was analyzed using the non-parametric Mann–Whitney U test. Categorical variables, including the presence or absence of fenestration, were analyzed using Fisher’s exact test. Continuous variables were reported as mean  $\pm$  standard deviation, while categorical variables were presented as frequencies and percentages. A  $p$ -value  $< 0.05$  was considered statistically significant.

## Results

A descriptive analysis of a total of 200 virtual implant simulations demonstrated that, the average age of the patients was  $39.7 \pm 10.9$  years. Of the 100 patients included, 65 were female and 35 were male. The average labial concavity angle (LCA) was  $154.7^\circ \pm 7.1^\circ$ , which indicates a moderately convex labial plate contour.

**Bone to implant distance by prosthesis type:** The average distance from bone to implant in screw retained implants was  $1.07 \pm 0.66$  mm whereas the average distance for cement retained implants was  $1.78 \pm 0.66$  mm. Table I shows the comparison of the bone distance from the implant to the gingiva in more detail. The results reveal a significant difference between bone width at cement retained and screw retained positions at coronal, middle and apical levels.

**Table 1:** Comparison of radiographic bone-to-implant distance (mm) between cement-retained and screw-retained implant prosthesis

Distance	Cement-Retained (Mean $\pm$ SD)	Screw-Retained (Mean $\pm$ SD)	p-value
Bone-to-Implant (Coronal)	$2.33 \pm 0.93$	$1.52 \pm 0.48$	$<0.05$
Bone-to-Implant (Middle)	$1.61 \pm 0.48$	$1.03 \pm 0.62$	$<0.05$
Bone-to-Implant (Apical)	$1.40 \pm 0.59$	$0.67 \pm 0.88$	$<0.05$

Mann-Whitney U test was applied to evaluate the significance between the cement-retained and screw-retained position in table I. Table II shows the Fisher’s test for fenestration at different levels. It shows that there is significance difference between middle third and apical third.

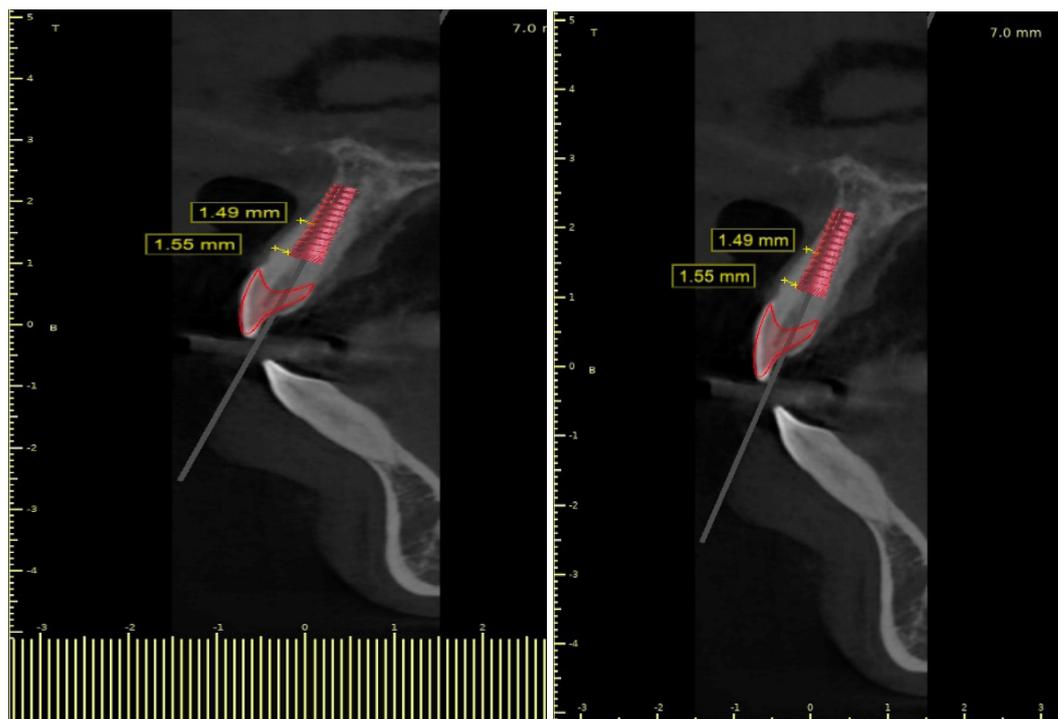
In our analysis, the overall prevalence of buccal bone fenestration across both groups was 67% (55 cases in screw retained, 1 in cement retained and 11 in common). The Fisher’s exact test indicated a statistically significant correlation between the prosthesis type and the presence of fenestration. Fenestration was analyzed per level, and a single implant could exhibit fenestration at more than one level

**Table 2:** Frequency of buccal bone fenestration in cement-retained versus screw-retained prosthesis n (%)

Presence of fenestration	Cement-Retained n(%)	Screw-Retained n(%)	p-value
Coronal third	0 (0%)	0 (%)	-
Middle third	3 (3%)	16 (16%)	$<0.05$
Apical third	10 (10%)	50 (50%)	$<0.05$

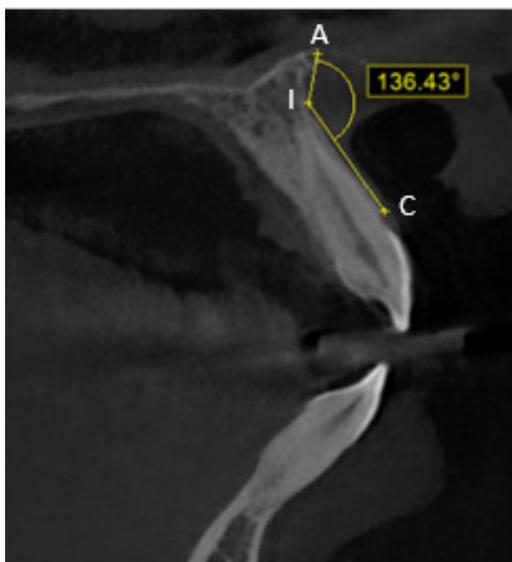
In our analysis, the overall prevalence of buccal bone fenestration across both groups was 67% (55 cases in screw retained, 1 in cement retained and 11 in common). The Fisher’s exact test indicated a statistically significant correlation between the prosthesis type and the presence of fenestration. Fenestration was analyzed per level, and a single implant could exhibit fenestration at more than one level

**Correlation of Labial Concavity Angle with gender:** The mean value of LCA in females was  $151^\circ \pm 6.01^\circ$ , signifying a more pronounced buccal concavity compared to males, in whom the angle was  $156.52^\circ \pm 6.96^\circ$ . Significant differences were observed between male and female mean labial concavity angles ( $p < 0.01$ ) using the independent sample t-test. Figure 2 shows the measurement of LCA as described.



**Figure 1:** Implant placement in the (a) cement-retained (b) screw-retained position with buccal bone thickness at coronal, middle and apical third

The labial concavity angle (LCA) was measured between the coronal external I, internal concavity (I), and apical external (A) points.



**Figure 2:** Labial concavity angle

## Discussion

The screw-retained position is widely regarded as the optimal choice due to its superior esthetic results but the results of our study show that there is an increased and thread exposure. In such cases, the clinician has to perform guided bone regeneration (GBR) procedures to overcome the defect and implant thread exposure.<sup>9</sup> However, in cases where the bone thickness is not favorable, a cement-retained position is preferred to minimize the risk of perforation and reduce additional cost of the bone graft and membrane. Although

it does save the cost, the esthetics is compromised. While this option may offer a cost advantage, it often compromises esthetics, particularly in the anterior maxilla.<sup>10,11</sup>

The mean value of LCA (Figure 2) in females was  $151^{\circ} \pm 6.01^{\circ}$  signifying a more pronounced buccal concavity as compared to males in which the angle was  $156.52^{\circ} \pm 6.96^{\circ}$ . The present study found that females exhibited a higher incidence of labial cortical bone perforation compared to males, consistent with the findings of Ikbal et al., (2023).<sup>12</sup> This discrepancy may be attributed to inherent anatomical variations between genders, particularly the generally smaller facial bone volume and thinner cortical plates in women. Such factors should be carefully considered during immediate implant placement (IIP), as they may predispose to labial bone perforation even with optimal virtual implant positioning.<sup>13,14</sup>

In our analysis, we discovered that the prevalence of fenestration was 67%, which is comparable with the previous CBCT evaluations done by Sayer et al. showing a wide range of 50% – 70% in the anterior maxilla area.<sup>15</sup> This again underlines the need for the clinical use of pre-operative assessment for the risk of fenestration using CBCT or virtual planning tools.<sup>16</sup>

The bone-to-implant distances were considerably higher in the cement-retained group at the middle ( $1.61 \pm 0.48$  mm vs.  $1.03 \pm 0.62$  mm,  $p < 0.05$ ) and apical levels ( $1.40 \pm 0.59$  mm vs.  $0.67 \pm 0.88$  mm,  $p < 0.05$ ) (Table 1). Anna et al. compared buccal plate perforation between prosthetically driven and bone-driven implant positions, reporting a significantly higher incidence of perforation in the former (80%) than in the latter (5%) which is in agreement with our study.<sup>5</sup> Screw-retained prosthesis does provide the benefit that it is easy to retrieve due to the presence of an access channel

and provides better hygiene however it requires very precise implant angulation.<sup>17</sup>

The distribution of buccal bone fenestration varied markedly between prosthetic designs (Table 2). Fenestrations were absent in the coronal third for both cement- and screw-retained positions, suggesting adequate coronal bone support in virtual implant placement. However, a significantly higher frequency of fenestration was observed in the middle and apical thirds in screw-retained implants compared to cement-retained implants ( $p < 0.05$ ). This finding indicates that the angulation required to achieve screw-access emergence may predispose implants to apical and mid-root buccal cortical perforation, particularly in anatomically concave labial plates.<sup>5</sup>

There was a statistically significant relationship between the type of prosthesis and the presence of a fenestration confirming the previously established effect of the restoration approach on peri-implant bone integrity. This is also supported by Severi et al. reporting the significance of surgical and prosthetic planning or coalescing buccal bone defects around anterior implants.<sup>18</sup>

The notable strengths of this study are the large sample size with 200 simulations, which allowed for a meaningful statistical comparison of prosthetic types, including the ability to examine bone morphology in three distinct levels (coronal, middle, apical). The use of virtual implant placement permitted standardized, isolated details in measuring bone-to-implant distance and fenestration risk, minimizing variability associated with clinical imaging methods. The measurement of the labial concavity angle as a morphological correlate is a unique approach and adds to the understanding of anatomical patterns that may predispose to the development of fenestrations.

### Limitations

Nevertheless, the study has several limitations. As the imaging modality was a virtual CBCT simulation, biological responses, including soft tissue remodeling, vascularization, and bone healing, during the process in vivo were not captured, nor were clinical implant placement procedural variances accounted for. Additionally, the CBCT scans were obtained for posterior implant planning, which is a consideration for sampling bias and circumvents the anatomical characteristics of patients requiring anterior maxillary rehabilitation. In addition, while intra- and inter-observer reliability was assessed using intraclass correlation coefficients ( $ICC > 0.85$ ), there are still concerns regarding the value associated with the lack of an independent external source to validate the measurements. Additionally, a single fixed implant size ( $4.1 \times 13$  mm) served as a limitation, and reconciling variability in bone morphology or risk of buccal fenestration with different dimensions or designs of implants was not transferable. Furthermore, clinical comparisons with actual implantation outcomes in vivo, including but not limited to survival rate or rates of marginal bone loss or soft tissue stability, were not possible through a virtual study. Finally, the nature of a cross-sectional design limits the study to an association versus causation of prosthesis type, angles of labial concavity, and buccal bone fenestration events.

### Conclusion

This research shows a statistically significant association between prosthesis type, labial concavity angle, and buccal bone fenestration in virtual implant placement in the anterior maxilla. Cement-retained prostheses provided decreased rates of fenestration and greater bone-to-implant distances when compared to screw retained prostheses, likely reflecting variation in surgical and prosthetic procedures. The angle of labial concavity emerged as an important morphological feature that influenced fenestration risk. Overall, these findings indicate a need for careful assessment of anatomical features and prosthetic planning of implant cases to decrease buccal bone fenestration while optimizing functional and esthetic results.

**Authors' Contribution:** Z.N. and M.H. contributed to the conception and design of the study. Z.N. conducted data acquisition and analysis and drafted the methodology. M.H. supervised the study and critically reviewed the manuscript. S.J. provided clinical input and verified data accuracy. O.B. performed statistical analysis and prepared figures and tables. M.A. and M.K. contributed to study design, manuscript revision, and coordination of the final submission. All authors approved the final manuscript and accept responsibility for the work.

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**Conflict of Interest:** The authors declare no conflict of interest related to this study.

**Data Availability Statement:** The data that support the findings of this study, apart from the data already presented in the results section, are available from the corresponding author upon reasonable request.

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