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CBCT-guided risk analysis for labial cortical plate perforation in virtual immediate implant placement of the anterior mandible

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Abstract:
Immediate anterior mandibular implant placement after extraction risks labial bone perforation (LBP), yet CBCT-based anatomical predictors remain insufficiently quantified for pre-operative risk assessment. Therefore, it is of interest to analyze the 100 subjects (300 sites), evaluating sagittal root position, dentoalveolar phenotype, concavity depth/angle, torque and deep bone thickness (DBT) at 0/5/10 mm via virtual implant simulation. LBP occurred in 19.0% (57/300 sites), with perforation sites showing reduced concavity angle (138.75±8.17° versus 145.11±8.49°; P<0.0001) and DBT at 0 mm (7.00±1.45 vs 8.73±1.66 mm; P<0.0001). Multivariable regression identified concavity angle (OR=0.879), torque (OR=1.064), crestal DBT (OR=0.512) and concavity depth (OR=0.641) as independent LBP predictors (all P<0.01). Thus, data shows that CBCT virtual planning is essential for identifying high-risk morphology, enabling perforation prevention through precise implant angulation and site selection.

Keywords: Alveolar bone, cone-beam computed tomography (CBCT), dental implants, mandible, risk assessment, tooth socket

Background:

Over the years, placing an implant immediately following extraction has gained acceptance as it diminishes the overall treatment time and helps in preserving the architectural framework of the alveolar bone **[1]**. However, achieving an optimal implant positioning in the anterior lower jaw remains challenging due to anatomical unpredictability. Among the potential complications, labial bone perforation (LBP) is a noteworthy concern as it can jeopardize both functional and aesthetic outcomes **[2].** Pre-operative assessment of risk is indispensable to reduce surgical complications and ensure predictable outcomes. Appropriate understanding of anatomical factors such as bone thickness, root position and concavity morphology is vital in determining implant angulation and positioning **[3]**. There has been various advances in imaging over the years, but still there is a dearth of proper guidelines to evaluate the risk of LBP in the anterior region **[2]**. Conventional radiographs, despite its extensive usage have intrinsic limitations in assessing bone volume and morphological characteristics, owing to its two-dimensional visualisation **[4]**. These limitations can result in erroneous treatment planning, especially in the zone concerned with aesthetics. Consequently, cone-beam computed tomography (CBCT) has become a preferred imaging modality, offering three-dimensional picturing and improved diagnostic accuracy **[2, 5]**. When anatomical parameters like root position in the sagittal direction, concavity in the labial direction, dentoalveolar bone phenotype and thickness of the bone; are not favourable, immediate implant placement may result in complications or demand supplemental augmentation procedures **[6]**. Therefore, it is of interest to evaluate multiple anatomical parameters and their association with LBP using CBCT-based virtual implant placement.

Materials and Methods:

Study design:

The present study followed an observational design using CBCT images, which was conducted to evaluate anatomical risk factors associated with LBP in the anterior mandibular region.

Sample selection:

Based on the defined inclusion and exclusion criteria, 100 CBCT scans were chosen. The dataset consisted of anterior mandibular teeth, namely central incisors, lateral incisors and canines. The scans were obtained from patients reporting to the Department of Prosthodontics and Crown & Bridge at the Dental Institution.

Parameters evaluated:

The following anatomical parameters were assessed: Sagittal Root Position (SRP), Crestal and Radicular Dentoalveolar Bone Phenotype (CRDAP), Concavity Depth (CD), Concavity Angle (CA), Torque (T), Deep Bone Thickness (DBT) at 0 mm, 5 mm and 10 mm. The above-mentioned parameters were evaluated for their association with LBP during virtual implant placement.

Virtual implant placement:

Virtual implant positioning was performed using CBCT images, simulating immediate implant placement in the mandibular anterior region. The occurrence of LBP was assessed based on implant positioning relative to the cortical plate.

Statistical analysis:

Analysis was carried out using IBM SPSS Statistics for Windows, Version 27.0 (IBM Corp., Armonk, NY, USA). Shapiro–Wilk test was used to test normality and confirmed a normal distribution. Quantifiable variables were compared using Welch's t-test and Brown-Forsythe ANOVA to account for unequal sample sizes. Independent predictors of labial bone perforation were assessed using multivariable logistic regression, with adjustments made for anatomical and classification variables. Adjusted odds ratios (ORs) with 95% confidence intervals (CI) were calculated. A P value < 0.05 was considered statistically meaningful.

Results:

A total of 300 tooth sites in 100 subjects were analysed. The study population had a mean age of 33.06 ± 8.82 years, with 156 females (52.0%) and 144 males (48.0%). Class IV SRP was the most common present in 141 subjects (47.0%), while Class IV CRDAP also predominated among other CRDAP subtypes, occurring in 217 subjects (72.3%). Overall, LBP was noted in 57 subjects (19.0%), whereas 243 (81.0%) showed no perforation (*P* < 0.0001). Anatomical parameters varied significantly across demographic and clinical groups. It was found that CA was inversely related with age (*P* = 0.0034), with younger individuals exhibiting higher values. Sex-based comparison showed that males had a notably higher mean CA (145.18 ±10.09°) in comparison to females (142.72±7.20°; *P*=0.02). DBT at 0 mm was also higher in males (8.67±1.91 mm) than females (8.16±1.56 mm; *P* = 0.01). By tooth type, the highest concavity depth was noted in the lateral incisors (3.68±1.18 mm), whereas canines showed significantly more DBT at 0 mm (8.96±1.94 mm; *P* =0.0005). The distribution of perforation varied significantly across SRP categories (*P* =0.001), with Class IV SRP being most frequent among perforation cases (40(28.4%)), whereas Class I SRP was predominantly associated with non-perforation (114(91.2%)). Similarly, CRDAP classifications showed a significant association with perforation (*P* =0.014), with Class II being more frequent in perforation cases (22(32.4%)) and Class IV predominating in non-perforation (184(84.8%)). Although lateral incisors had the highest perforation incidence (22(22.0%)), followed by central incisors (19(19.0%)) and canines (16 (16.0%)), differences across tooth types were not statistically significant (P = 0.557). A lower concavity angle marked out perforation sites (138.75±8.17°), in contrast to the higher values observed in non-perforation sites (145.11±8.49°; P <0.0001).DBT was significantly greater in the non-perforation group at all levels: 0 mm (8.73±1.66 mm versus 7.00±1.45 mm; *P* < 0.0001), 5 mm (10.41±1.80 mm vs. 8.71±1.73 mm; *P* <0.0001) and 10 mm (11.43±2.40 mm vs. 10.60±2.17 mm; *P* =0.01). Concavity depth (*P*=0.20) and torque (*P* =0.14) did not show significant differences on univariate comparison **(Table 1)**. The crucial predictors of LBP were recognized using multivariable logistic regression analysis. Increasing concavity angle significantly reduced the odds of perforation (adjusted OR = 0.879, 95% CI: 0.825–0.937, P < 0.001). Greater torque was associated with a higher probability of perforation (adjusted OR = 1.064, 95% CI: 1.021–1.109, *P* = 0.003). Increased DBT at 0 mm demonstrated a significant protective effect (adjusted OR = 0.512, 95% CI: 0.310–0.847, *P* = 0.009). Additionally, concavity depth was significantly associated with reduced perforation risk after adjustment (adjusted OR = 0.641, 95% CI: 0.464–0.887, *P* = 0.007) **(Table 2 and Figure 1)**.

Table 1: Association of tooth type, sagittal root position (SRP) and crestal and radicular dentoalveolar phenotype (CRDAP) with labial bone perforation (LBP).

Variable	Category	Non-Perforation n (%)	Perforation n (%)	*P* value[§]
Tooth	Central	81 (81)	19 (19)	0.557 (NS)
	Lateral	78 (78)	22 (22)	
	Canine	84 (84)	16 (16)	
SRP	Class I	114 (91.2)	11 (8.8)	0.001*
	Class II	26 (83.9)	5 (16.1)	
	Class III	2 (66.7)	1 (33.3)	
	Class IV	101 (71.6)	40 (28.4)	
CRDAP	Class I	10 (83.3)	2 (16.7)	0.014*
	Class II	46 (67.6)	22 (32.4)	
	Class III	3 (100)	0	
	Class IV	184 (84.8)	33 (15.2)	

Table 2: Multivariable logistic regression analysis showing predictors of labial bone perforation (LBP)

Variable	Non-Perforation (n=243)	Perforation (n=57)	Adjusted Odds ratio	95% Confidence Interval	*P* value
Concavity Angle	145.11 ± 8.49	138.75 ± 8.17	0.879	0.825–0.937	<0.001*
Concavity Depth	3.38 ± 1.26	3.68 ± 1.65	0.641	0.464–0.887	0.007*
Torque	149.67 ± 9.74	151.79 ± 9.72	1.064	1.021–1.109	0.003*
DBT at 0 mm	8.73 ± 1.66	7.00 ± 1.45	0.512	0.310–0.847	0.009*
DBT at 5 mm	10.41 ± 1.80	8.71 ± 1.73	0.968	0.619–1.513	0.886 (NS)
DBT at 10 mm	11.43 ± 2.40	10.60 ± 2.17	0.891	0.724–1.095	0.273 (NS)

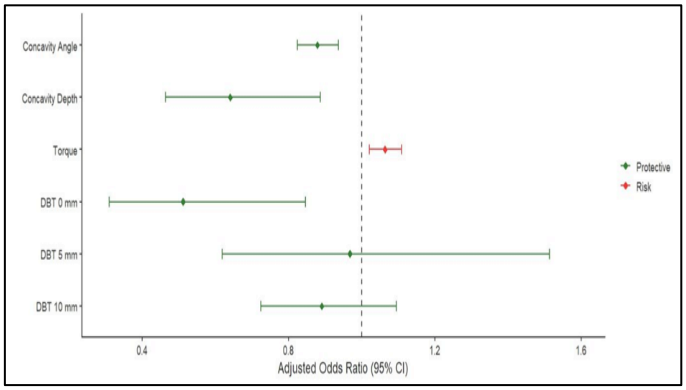

Figure 1: Forest plot showing adjusted odds ratios (OR) with 95% confidence intervals (CI) for anatomical predictors of labial bone perforation.

Discussion:

The present study evaluated multiple anatomical parameters influencing LBP in the anterior mandible evaluated with the help of CBCT-based virtual implant placement. The findings emphasise the need for a through pre-operative assessment to lessen surgical complications. One of the key findings of this study is the significant role of SRP. In determining the risk of LBP. The result agrees with the findings from earlier research which showed that certain SRP classes are more prone to perforation due to unfavourable root alignment within the alveolar encasement **[7–10]**. Evidence from previous studies specifies that SRP classification is a significant determining factor of LBP, with specific classes allied with a considerably increased risk **[2, 11 and 12].** Perforation was most often noted with Class IV SRP (n=40; 28.4%), while Class I SRP corresponded primarily to non-perforation (n=114, 91.2%). Yet, once the regression model accounted for other anatomical factors, SRP itself lost statistical importance, hinting that its predictive strength may be confounded in multivariable settings. The effect of dentoalveolar bone phenotype and concavity morphology found in this study is also helmed by previous research. Tsai *et al.* confirmed that parameters such as concavity angle, depth and bone thickness are key determinants in safe placing of an implant **[6]**. Chances of perforation increases with an increased concavity depth and lesser concavity angle as the available bone volume becomes less, as found in this study. The multivariable analysis reinstated concavity angle as a meaningful predictor. Curiously, concavity depth, despite its eminence in prior literature, failed to reach significance in the univariate comparison but gained importance after adjustment, implying that its influence is allied with other anatomical variables. Apical Bone thickness was acknowledged as another decisive factor. The anterior mandible often showed a reduced buccolingual width at the alveolar crest, creating a "bottleneck" effect that raises the prospect of perforation during implant placement. In line with previous studies by Lee *et al.* **[13]** and Sheerer *et al.* **[14]**, the present study showed significantly greater bone thickness in non-perforation sites, particularly at the crestal level. Multivariable analysis reaffirmed the importance of DBT at 0 mm as being a significant independent predictor. In contrast to previous studies showing both crestal and apical bone thickness, DBT at 5 mm and 10 mm, following adjustment, no longer showed significance. Lateral incisors were the most perforated teeth (22(22%)), followed by central incisors (19(19%)) and canines (16(16%)). This difference is not statistically significant though (P =0.557). This finding is in opposition to previous studies that have proposed an increased risk associated with certain tooth types with LBP and implies that localized anatomical morphology rather than tooth type may be more important in affecting the risk of perforation. The study highlights the importance of 3D imaging, which is supported by literature. Conventional radiographs can hide information about bone morphology, which may result in diagnostic errors and a greater possibility of complications **[15]**. But CBCT enables accurate assessment of anatomical structures which assists in better treatment planning. However, the role of individual parameters is not well established in the literature. Some authors consider SRP as the most important factor, while others focus on the implant positioning strategy. Botermans *et al.* **[16]** found a lower risk of perforation when the placement was aligned to the available bone, compared to the placement based on the prosthetic considerations only, suggesting that the surgical technique can modulate the anatomical risk factors. The study found that higher torque values increased the risk of LBP, besides emphasizing the importance of implant angulation. Although a handful of studies have examined torque as an independent predictor, the findings align with previous research on implant positioning and cortical plate perforation. However, univariate analysis showed no significant results, indicating that torque may interact with other anatomical factors or may be influenced by the small sample size. Differences in population characteristics can be attributed for the variability seen across previous studies. Reports of variation in ethnicities in LBP prevalence propose that anatomy itself may lead to alteration in the risk profiles, underscoring the need for population-specific analyses such as the present one **[1]**. Equally critical is the surgical approach. Freehand placement tends to produce more deviations, amplifying perforation risk, whereas guided techniques provide control that can render safer outcomes **[17]**. The study provides useful insight but has limitations, including the virtual setting, which may not accurately represent the clinical conditions that affect treatment outcomes, such as bone density and surgical technique. The sample size was also considered adequate, although population variability may limit applicability to a broader population. Nevertheless, the present study reaffirms the necessity of a through pre-operative evaluation using CBCT and highlights the collated influence of multiple anatomical factors on the risk of LBP, for better predictable outcomes.

Conclusion:

LBP in the anterior mandibular zone depends on a multitude of anatomical factors, notably SRP, dentoalveolar phenotype, concavity morphology and bone thickness. A pre-operative

CBCT evaluation proves fundamental in divulging these risks and refining placement strategies.

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