J Periodontal Implant Sci. 2025 Feb;55(1):72-84
https://doi.org/10.5051/jpis.2303580179
pISSN 2093-2278·eISSN 2093-2286

JPIS
Journal of Periodontal & Implant Science

Research Article
Implant Science

Check for updates

Immediate implant placement in the premolar maxillary area: a cone-beam computed tomography study

Ali Najm [1,†], Amer Bihorac [1,†], Vinícius de Carvalho Machado [2], Bruno Ramos Chrcanovic [3,*]

[1]Faculty of Odontology, Malmö University, Malmö, Sweden
[2]Slice Diagnóstico Volumétrico por Imagem, Belo Horizonte, Brazil
[3]Department of Oral and Maxillofacial Surgery and Oral Medicine, Faculty of Odontology, Malmö University, Malmö, Sweden

Received: Sep 4, 2023
Revised: May 17, 2024
Accepted: Jul 10, 2024
Published online: Aug 26, 2024

***Correspondence:**
Bruno Ramos Chrcanovic
Department of Oral and Maxillofacial Surgery and Oral Medicine, Faculty of Odontology, Malmö University, Carl Gustafs väg 34, SE-214 21 Malmö, Sweden.
Email: bruno.chrcanovic@mau.se
Tel: +46-725541545

†Ali Najm and Amer Bihorac contributed equally to this work.

ORCID iDs
Bruno Ramos Chrcanovic
https://orcid.org/0000-0002-3460-3374

Conflict of Interest
No potential conflict of interest relevant to this article was reported.

Author Contributions
Conceptualization: Ali Najm, Amer Bihorac, Vinícius de Carvalho Machado, Bruno Ramos Chrcanovic; Formal analysis: Bruno Ramos Chrcanovic; Investigation: Ali Najm, Amer Bihorac; Methodology: Ali Najm, Amer Bihorac, Vinícius de Carvalho Machado, Bruno Ramos Chrcanovic; Project administration: Bruno Ramos Chrcanovic; Writing – original draft: Ali Najm, Amer Bihorac, Bruno Ramos

ABSTRACT

Purpose: This research aimed to investigate potential factors associated with the risk of perforation of the labial bone plate, nasal floor, or maxillary sinus floor during immediate implant placement (IIP) in the maxillary premolar area, utilizing a cone-beam computed tomography (CBCT) virtual study.
Methods: CBCT exams from 179 eligible participants, encompassing 716 teeth, were included. Implants were virtually positioned in 2 orientations: along the long axis of the tooth (the prosthetically-driven position) and in an optimal position relative to adjacent anatomical structures (the bone-driven position). Binary logistic regression analysis was employed to assess potential associations between perforation or invasion and various covariates, including sex, age, tooth region, the distance from the tooth apex to the nasal floor or maxillary sinus floor, the angle between the prosthetically- and bone-driven positions (implant-line A angle [ILAA]), and the labial concavity angle (LCA).
Results: The mean ILAA was 18.3°±8.0°, and the angle was significantly larger for the second premolar compared to the first premolar. The mean minimum implant length was 13.0±2.1 mm, with a bone anchorage of 4 mm. The incidence of perforation was 84.1% for the prosthetically-driven position and 40.5% for the bone-driven position. Factors associated with a higher risk of cortical bone wall perforation or invasion of the 2-mm safety margin from surrounding anatomical structures (in the bone-driven position) included female sex, older age, shorter distance from the tooth apex to the nasal cavity/maxillary sinus, and smaller LCA.
Conclusions: A high prevalence of cortical bone wall perforation or invasion of the 2-mm safety margin is anticipated when performing IIP in the maxillary premolar region.

Keywords: Cone-beam computed tomography; Dental implants; Immediate placement; Maxillary premolars

INTRODUCTION

According to the original Brånemark protocol, a dental implant should be placed at the planned surgical site only after several months of healing of the extraction alveolar socket, ensuring that an adequate amount of bone is available at the implant site [1]. However, not

JPIS Journal of Periodontal & Implant Science

Chrcanovic; Writing – review & editing: Ali Najm, Amer Bihorac, Vinícius de Carvalho Machado, Bruno Ramos Chrcanovic.

long after that protocol was suggested, others proposed that implants could be installed directly into the alveolar dental socket immediately following tooth extraction [2]. This method was termed immediate implant placement (IIP).

IIP offers several advantages over the initial protocol, including shorter treatment time through fewer surgical sessions, diminished resorption of the alveolar bone after tooth extraction, improved psychological outcomes for the patient, and the ability to position the implant in a more ideal axial inclination, more closely resembling that of the natural tooth previously occupying the socket [3]. However, as the alveolar socket is empty, this method may compromise the primary stability of the implant due to the reduced volume of surrounding bone [4].

Provided that proper care is taken, IIP represents a viable option even in alveolar sockets with existing endodontic and/or periodontal lesions [5]. A recent systematic review, which compiled data from 163 clinical studies, found that implants placed in fresh extraction sockets had a failure rate of 3.60% (622 failures among 17,278 implants). This contrasts with a failure rate of 2.87% (1,113 of 38,738 implants) for implants placed in healed sites. However, the meta-analysis indicated a higher risk of failure for implants placed in extraction sockets [6].

Some minor adjustments to the IIP approach are necessary, depending on the jaw region involved. The roots of the first maxillary premolar (1PM) are typically found at the lowest part of the anterior maxillary buttress, while those of the second maxillary premolar (2PM) are generally located beneath the anterior maxillary sinus. The anterior maxillary buttress originates around the alveolus of the maxillary canines, and its triangular lower portion is situated between the maxillary sinus and the nasal cavity [7]. Consequently, an adequate evaluation of the local anatomical structures is necessary when considering IIP as a treatment option [8,9].

The aim of this study was to explore potential factors associated with the risk of perforating the labial bone plate, nasal floor, or maxillary sinus floor during IIP in the maxillary premolar area, utilizing a cone-beam computed tomography (CBCT) virtual study. This represents the first investigation into the risks of IIP in the maxillary premolar region.

MATERIALS AND METHODS

Objectives

The objectives of the present study were as follows: a) To determine the risk of perforation of the labial bone plate, the nasal floor, or the maxillary sinus floor when implants are virtually planned for placement either along the longitudinal axis of the tooth (the prosthetically-driven ideal position) or in the bone-driven position, for IIP in the maxillary premolar area; b) To ascertain the minimum feasible implant length in the specified region that avoids perforation of the surrounding cortical bone, while also maintaining a safety margin from adjacent anatomical structures; c) To determine the angle between the 2 described positions; and d) To investigate the associations between the covariates and cortical bone perforation for the ideal bone-driven position.

JPIS Journal of Periodontal & Implant Science

Hypothesis

The null hypothesis posited that the prevalence of cortical bone perforation would not differ significantly between the bone-driven and prosthetically-driven ideal positions for IIP in the maxillary premolar area.

Participants

The present retrospective analysis was based on maxillary scans performed at Slice Diagnóstico Volumétrico por Imagem in Belo Horizonte, Brazil, during the last quarter of 2014. The scans utilized in this study were selected from the CBCT database and were not specifically acquired for this publication.

Ethical considerations

The study was approved by the Institutional Review Board (or Ethics Committee) of Centro de Pesquisas Odontológicas São Leopoldo Mandic, Campinas, Brazil (protocol code CAAE 51387215.5.0000.5374). Patients were contacted via telephone, and each provided written informed consent, authorizing the use of their scans. The patients were not identifiable in the published data, and a decoding list that linked patient names to numbers was maintained by the principal investigator and destroyed after completion of the study. The research adhered to the principles set forth in the 1964 Helsinki Declaration for biomedical research involving human participants, as revised in 2013.

Inclusion and exclusion criteria

The following inclusion criteria were applied for the scans: a) the patients consented to their use; b) the scans comprised CBCT examinations of the maxilla; c) fully erupted bilateral maxillary premolars were present; d) each tooth had fully formed apices; and e) each tooth was normally positioned and aligned.

CBCT examinations were excluded based on the following criteria: a) the presence of technical artifacts that compromised the evaluation of the targeted structures; b) images that included an implant, a pathological lesion, obvious root resorption, or a missing tooth; and c) examinations from patients with a history of orthognathic surgery, grafted alveolar ridge, supernumerary or impacted teeth, preexisting alveolar bone destruction, perforation, dehiscence, or a combination thereof resulting from periodontal disease or traumatic injury in the area under investigation.

Selection of cases

In the last quarter of 2014, a total of 574 CBCT exams of the maxilla were performed at Slice Diagnóstico Volumétrico por Imagem in Belo Horizonte, Brazil. Of these, 387 exams were initially excluded for the following reasons: missing maxillary premolars, the presence of an implant in the premolar region, misalignment of teeth, or radiological artifacts that compromised the evaluation of the targeted structures. Of the remaining 187 exams, 8 were further excluded due to the presence of periapical bone destruction in a premolar. Consequently, 179 CBCT exams were included in the study.

Hardware and software

CBCT scanning was conducted using an i-CAT CBCT system (Imaging Sciences International, Hatfield, PA, USA). The scans, which included the entire maxilla, were acquired with the i-CAT 3D Imaging System (i-CAT Vision Software, Imaging Sciences International). The following CBCT parameters were consistently applied for all patients: a tube voltage of 120 kV, a current of 3 to 5 mA, X-ray emission over a 40-second interval, and an effective dose of 136 μSv. Measurements were taken from the transverse sections of the selected teeth using computer software (DeltalSlice Navegação Virtual version 2021, Bioparts, Brasília, Brazil). The thickness of the transverse sections was set at 1.0 mm. A standard field of view (medium; 6×14 cm) was used to capture the entire maxilla.

Sample size calculation

The sample size was computed using ClinCalc.com and was based on research by Botermans et al. [8]. That study observed an incidence of approximately 5% for fenestration (labial cortical bone perforation) when IIP was performed at the bone-driven ideal location in the anterior maxilla. We hypothesized that prosthetically-driven IIP in the maxillary premolar sockets would yield a 4-fold increase in cortical bone perforation compared to IIP with bone-driven ideal placement, with expected rates of 20% versus 5%. Accordingly, a total of 150 cases were required, with an alpha of 5% and a power of 80%.

Definitions and measurements

Safety margin from the implant to the adjacent anatomical structures

Implants were placed to maintain a predefined distance from adjacent anatomical structures. In the maxillary premolar region, these structures included the adjacent teeth, the floors of the nasal and maxillary sinuses, and the labial and palatal cortical bone plates. For 1PM and 2PM, the distance between the implant and these structures was defined as extending from the closest point of the implant to the structure in question. The minimum distance between the implant and an adjacent tooth was set at 2 mm, adhering to recommendations that this distance should be no less than 1.5 to 2 mm [10]. Similarly, a minimum distance of 2 mm was maintained between the implant apex and the floor of the nasal or maxillary sinus. Additionally, a 2-mm clearance was preserved from all external cortical bone plates.

Implant simulation

The center of the implant platform was positioned buccolingually along an imaginary line that extended along the long axis of the tooth. For virtual IIP, a parallel implant with a diameter of 3.75 mm was selected. The implant was placed 1 mm subcrestally to account for the anticipated approximated marginal bone loss after 12 months after IIP [11]. To ensure primary stability, a minimum of 4 millimeters of bone was required to exist apically to the apex of the alveolar socket [12,13].

In each tooth site, implants were positioned in 2 ways.

a) Prosthetically-driven ideal position: this placement involved positioning the implant along the palatal slope of the tooth root being investigated, with the crown aligned along line A as depicted on the sagittal section. Line A represented the line that best connected the occlusal central developmental fossa with the root apex of the tooth, bisecting the labial and palatal halves. The implant was required to be anchored in at least 4 mm of native bone. Depending on the case, this positioning may result in either the absence of bone plate perforation (**Figure 1**) or its occurrence (**Figure 2**). In cases not exhibiting perforation, the examiner also noted whether the implant maintained the minimum distance of 2 mm from adjacent anatomical structures. Additionally, the correct mesiodistal angulation was confirmed in the panoramic view (**Figure 3**).

https://doi.org/10.5051/jpis.2303580179

JPIS Journal of Periodontal & Implant Science

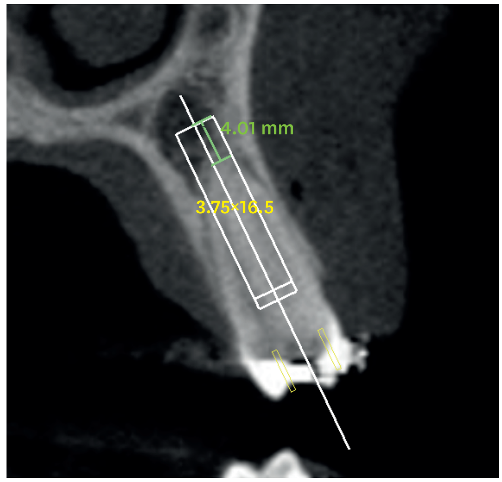

Figure 1. Absence of bone plate perforation when the implant is positioned in the prosthetically-driven ideal position and anchored with at least 4 mm of native bone.

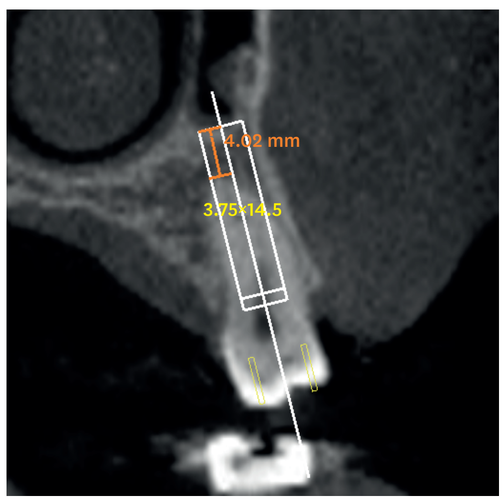

Figure 2. Occurrence of bone plate perforation when the implant is positioned in the prosthetically-driven ideal position and anchored with at least 4 mm of native bone.

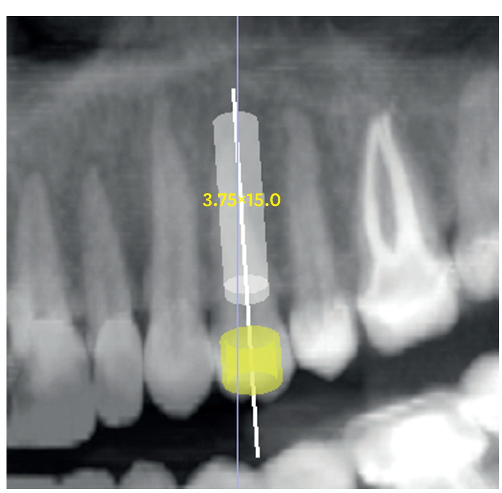

Figure 3. Proper mesiodistal angulation verified in the panoramic view.

JPIS Journal of Periodontal & Implant Science

b) Bone-driven ideal position: this refers to the shortest possible implant length that can be achieved without perforation, while ensuring that the implant apex is anchored in at least 4 mm of native bone. The minimum distance of 2 mm was similarly maintained from the nasal and/or maxillary sinus floor, as well as from the labial and palatal bone plates. Acceptable mesiodistal angulation was also confirmed in the panoramic view.

In certain cases, IIP is clearly not feasible, as shown in **Figure 4**.

Implant-line A angle (ILAA)

The angle formed by the implant in this position relative to the prosthetically-driven ideal position (line A) was measured and termed the ILAA (**Figure 5**).

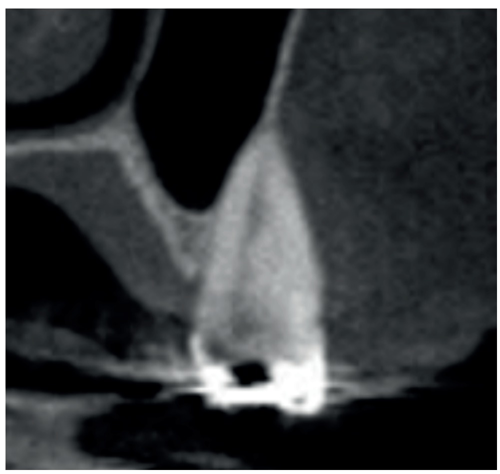

Figure 4. Lack of bone for sufficient apical anchorage, precluding immediate implant placement.

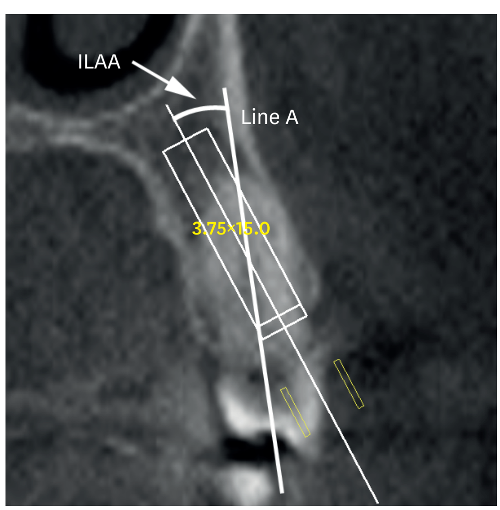

Figure 5. Graphic visualization of the ILAA.
ILAA: implant-line A angle.

https://doi.org/10.5051/jpis.2303580179

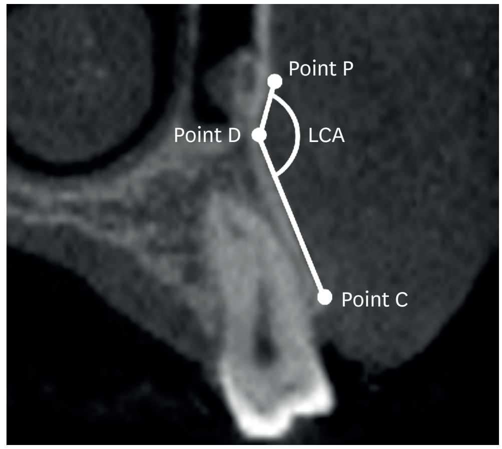

Figure 6. Graphic visualization of the LCA.
LCA: labial concavity angle.

Labial concavity angle (LCA)

The LCA was defined as the angle formed between line D-C and line D-P (**Figure 6**). Line D-C is drawn from point D to point C, with the latter denoting the most external point on the buccal plate. Line D-P connects points D and P, where point P indicates the most external point on the buccal plate superior to point D. The LCA was measured at the virtual buccal-palatal longitudinal middle section of each tooth.

Tooth apex distance

This measurement was taken from the apex of the tooth to the floor of the nasal cavity or maxillary sinus.

Angle measurement

The images produced were subsequently transferred to Image J (National Institutes of Health, Bethesda, MD, USA) for the measurement of the relevant angles.

Calibration

Prior to the study, calibration was performed among 3 authors (A.B., A.N., and B.R.C.) using 10 CBCT exams, focusing on the positioning of the implants and all associated measurements. Following this calibration, the first 2 authors of the manuscript (A.B. and A.N.) conducted the measurements.

Statistical analyses

The mean, standard deviation, minimum, and maximum for each measurement were calculated. Variations were assessed based on the tooth (1PM or 2PM) as the predictor variable. Additional variables included the maxillary side (left or right), age, and sex. The Kolmogorov–Smirnov test was used to assess the normality of the distribution. Homoscedasticity was evaluated using the Levene test. To compare the measurements of each tooth between the left and right maxilla, the paired *t*-test and the Wilcoxon test were applied as appropriate. When comparing independent groups (including tooth and sex), the Student *t*-test or the Mann-Whitney *U* test was used, depending on whether the data followed a normal distribution. The Pearson χ^2 test or the Fisher exact test was employed for categorical variables, with the choice of test based on the expected frequency of events in a 2×2 contingency table. To investigate the relationships of patient age with LCA, ILAA, and the

https://doi.org/10.5051/jpis.2303580179

minimal possible implant length, as well as the relationship between LCA and ILAA, Pearson correlation and linear regression analyses were conducted. Spearman correlation analysis was used to examine the relationships of sex with LCA, ILAA, minimal possible implant length, and distance from the tooth apex to the nasal cavity/maxillary sinus.

Univariate and multivariate binary logistic regression analyses were employed to evaluate potential associations between the covariates and perforation of the labial bone plate when implants were positioned in the prosthetically-driven ideal location. Odds ratios (ORs) and 95% confidence intervals were derived from these regression models.

The final multivariate regression model included only those variables that demonstrated a moderate association (P<0.10) with labial bone plate perforation while exhibiting no multicollinearity. To assess multicollinearity, a correlation matrix of all predictor variables that displayed a significant OR (P value threshold=0.1), as identified in the univariate models, was reviewed to check for high correlations among the predictors. Additionally, collinearity diagnostics were performed using the variance inflation factor and the tolerance statistic to detect subtler forms of multicollinearity.

P values of less than 0.05 were considered to indicate statistical significance. The data were statistically analyzed using SPSS version 28 (IBM Corp., Armonk, NY, USA).

RESULTS

Participant cohort

The details of the patient cohort are presented in **Table 1**. The data indicate a higher number of examinations from women compared to men, with women displaying a slightly higher mean age.

Measurements

The mean values representing the minimum length of the planned implants in the bone-driven position, positioned to maintain a safety margin (>2 mm) from surrounding structures, were slightly higher for 1PM than for 2PM (**Table 2**). However, the difference in mean values was not statistically significant (P=0.127, Mann-Whitney U test).

Table 1. Description of the cohort group by sex

Sex	Total (n=179)	Age (yr)	Range (min–max)
Male	83 (332)	45.0±15.2	14.2–73.0
Female	96 (384)	47.6±15.1	16.1–78.1

Values are presented as mean ± standard deviation or number of patient (teeth).

Table 2. Minimum implant length for bone-driven positioning

Tooth	Mean ± SD	Range (min–max)	No.
15	12.7±2.2	6.5–18.5	75
14	13.3±2.1	7.0–19.0	132
24	13.1±2.2	6.5–19.0	135
25	12.8±2.1	8.5–17.0	85
Global	13.0±2.1	6.5–19.0	427

SD: standard deviation.

https://doi.org/10.5051/jpis.2303580179

Table 3. LCA values, globally and by sex

Tooth	Global (n=179)		Male (n=83)		Female (n=96)		*P* value[a)]
	Mean ± SD	Range (min–max)	Mean ± SD	Range (min–max)	Mean ± SD	Range (min–max)	
15	154.5±10.8	110.5–173.5	156.4±10.8	110.5–173.5	153.3±9.9	131.4–170.1	0.014
14	158.3±9.7	115.2–176.5	159.8±9.3	121.1–176.5	157.1±9.8	115.2–173.6	0.055
24	158.9±8.3	112.6–177.1	160.0±8.5	122.6–177.1	158.0±7.9	135.9–171.9	0.064
25	154.4±11.2	112.0–173.7	156.5±11.2	112.0–173.7	152.6±11.0	120.2–170.9	0.010
All teeth	156.5±10.3 (n=716)	110.5–177.1 (n=716)	158.2±10.1 (n=332)	110.5–177.1 (n=332)	155.3±10.0 (n=384)	115.2–173.6 (n=384)	<0.001

LCA: labial concavity angle, SD: standard deviation.
[a)]The mean LCA values were compared between male and female patients using the Mann-Whitney *U* test.

Table 4. Frequency of cortical bone perforation for prosthetically- and bone-driven positions, along with ILAA

Tooth	Prosthetically-driven			ILAA		Bone-driven		
	No perforation	<2 mm	Perforation	Mean ± SD	Range (min–max)	No perforation	<2 mm	Perforation
15	3 (1.7)	15 (8.4)	161 (89.9)	20.6±8.5	0–40.1	29 (16.2)	46 (25.7)	104 (58.1)
14	5 (2.8)	26 (14.5)	148 (82.7)	17.5±7.4	0–38.7	51 (28.5)	81 (45.2)	47 (26.3)
24	5 (2.8)	39 (21.8)	135 (75.4)	16.7±7.8	0–34.3	54 (30.2)	81 (45.2)	44 (24.6)
25	3 (1.7)	18 (10.0)	158 (88.3)	20.3±8.2	0–37.1	30 (16.7)	54 (30.2)	95 (53.1)
Total	16 (2.2)	98 (13.7)	602 (84.1)	18.3±8.0	0–40.1	164 (22.9)	262 (36.6)	290 (40.5)

Values are presented as number (%).
ILAA: implant-line A angle, SD: standard deviation.

The mean value of the LCA differed significantly between men and women (P<0.001, Mann-Whitney U test) when all measurements were considered (**Table 3**). A weak correlation was observed between LCA and sex (r_s=−0.160, P<0.001; Spearman correlation).

The frequency of perforation was greater among implants with prosthetically-driven placement compared to those in bone-driven positions (**Table 4**). A highly significant difference was noted in the prevalence of cortical bone perforation between prosthetically- and bone-driven ideal positions (P<0.001, Pearson χ^2 test). Of the 716 prosthetically-driven implants, only 16 exhibited no perforation. The mean ILAA angle was 18.3°±8.0°, with a higher average ILAA for 2PM than for 1PM. A statistically significant difference in mean ILAA values was observed between the 1PM and 2PM teeth (P<0.001, Mann-Whitney U test) (**Table 4**).

The correlation between the ILAA and the LCA was weak (r=−0.149, P=0.002; Pearson correlation). Similarly, weak correlations were found between ILAA and sex (r_s=0.160, P<0.001; Spearman correlation) and between the distance from the tooth apex to the nasal cavity/maxillary sinus and sex (r_s=0.183, P<0.001; Spearman correlation). The correlation between age and ILAA was very weak (r=0.023, P=0.636; Pearson correlation), as were the correlations between age and LCA (r=−0.183, P<0.001; Pearson correlation), between age and minimal implant length (r=−0.049, P=0.313; Pearson correlation), and between sex and minimal implant length (r_s=0.022; P=0.649; Spearman correlation).

According to the univariate binary logistic regression model (**Table 5**), several factors influenced the occurrence of cortical bone perforation or the invasion of the 2-mm safety margin from surrounding anatomical structures by the planned implant. These included sex, age, tooth region, distance from the tooth apex to the nasal cavity/maxillary sinus, and LCA. In the multivariate model, all factors except tooth region remained statistically significant. Specifically, female sex, older age, shorter distance from the tooth apex to the nasal cavity/maxillary sinus, and smaller LCA were associated with greater risk of perforation or invasion (**Table 6**).

JPIS Journal of Periodontal & Implant Science

Table 5. Univariate binary logistic regression for cortical bone perforation or invasion within the 2-mm safety margin from surrounding anatomical structures (relative to no perforation), for bone-driven implant position

Factor	OR (95% CI)	*P* value
Sex		<0.001
Male	1	
Female	3.526 (2.411–5.155)	
Age	1	0.084
1-year increase	1.010 (0.999–1.022)	
Tooth region		<0.001
First premolar	1	
Second premolar	2.031 (1.407–2.930)	
Tooth apex distance	1	<0.001
1-mm increase	0.705 (0.664–0.750)	
ILAA	1	0.211
1° increase	1.016 (0.991–1.041)	
LCA	1	<0.001
1° increase	0.946 (0.926–0.967)	

OR: odds ratio, CI: confidence interval, ILAA: implant-line A angle, LCA: labial concavity angle.

Table 6. Multivariate binary logistic regression for cortical bone perforation or invasion within the 2-mm safety margin from surrounding anatomical structures (relative to no perforation), for bone-driven implant position

Factor	OR (95% CI)	*P* value
Sex		<0.001
Male	1	
Female	2.358 (1.492–3.725)	
Age	1	<0.001
1-year increase	1.034 (1.018–1.049)	
Tooth region		0.750
First premolar	1	
Second premolar	0.925 (0.571–1.497)	
Tooth apex distance	1	<0.001
1-mm increase	0.697 (0.650–0.747)	
LCA	1	0.008
1° increase	0.964 (0.938–0.990)	

OR: odds ratio, CI: confidence interval, LCA: labial concavity angle.

DISCUSSION

The present findings indicate a highly significant difference in the prevalence of cortical bone perforation between the prosthetically- and bone-driven ideal positions for IIP in the maxillary premolar region. Consequently, the null hypothesis was rejected.

The regression model identified 4 variables as factors that increase the risk of cortical bone perforation or invasion of the 2-mm safety margin from adjacent anatomical structures when the implant is virtually placed in the bone-driven position. These were female sex, older age, shorter distance from the tooth apex to the nasal cavity/maxillary sinus, and smaller LCA.

Relative to men, women were nearly 2.4 times more likely to exhibit perforation of the cortical bone plate. This disparity may relate to the mean volume difference in facial bones typically observed between sexes, with women exhibiting smaller average dimensions than men [14-17].

A 3.4% increase in the risk of perforation or invasion of the 2-mm safety margin was observed for each additional year of patient age. This phenomenon may be attributed to the pneumatization of the sinuses. Notably, however, pneumatization of the maxillary sinuses beginning in young adulthood is predominantly linked to the extraction of posterior maxillary teeth [18,19]. A computed tomography study involving adolescents and adults revealed no significant correlation between age and sinus pneumatization [20]. Nonetheless, the aging process in the maxilla is associated with bone resorption [21,22]. This concept could partially explain the observed decrease in the feasibility of IIP in this region, as the volume of available maxillary bone tends to diminish with patient age.

The study revealed an increase in perforation risk with a decreasing distance between the tooth apex and the nasal cavity or maxillary sinus. This finding is reasonable, as a reduction in the available bone apical to the tooth apex may limit the opportunity to maintain a 4-mm minimum for implant anchorage.

Furthermore, for every 1° increase in the LCA, the probability of perforation decreased by 3.6%. This may stem from the fact that a smaller LCA creates a deeper buccal concavity, resulting in a smaller volume of bone in the buccal-palatal dimension at the angle's tip. This diminishes the likelihood of repositioning the implant without perforating the surrounding anatomical structures. The mean LCA was approximately 156°, although a considerable range of 67° was noted between the maximum and minimum values observed among study participants.

Most implants that were virtually planned for placement in the prosthetically-driven position either perforated adjacent cortical bone (84.1%) or encroached upon the minimum safety distance of 2 mm from adjacent structures (13.7%). Consequently, it was often necessary to tilt the implant away from the tooth's long axis. Thus, implants intended for fresh extraction sockets of maxillary premolars will likely require the coronal portion to be tilted buccally to ensure sufficient bone is available apical to the alveolar socket for anchorage. From a prosthetic perspective, this indicates that most implant-supported single crowns in this region would need to be cemented onto a custom-made prosthetic abutment, with an average buccal-palatal angulation of 18°, mirroring the mean ILAA (18.3°±8.0°). Individualized abutments with an angled screw channel could represent a prosthetic alternative for this issue [23], allowing the implant to be restored with a screw-retained crown. However, research has suggested that variations in the angulation of dental implants in the maxilla may influence implant survival [24], a factor that should also be considered.

Primary stability is considered a key factor for the success of dental implant treatment [25], and this is particularly relevant when an implant is placed immediately following tooth extraction. Often, the alveolar socket is wider than the implant, meaning that the implant may be primarily (or exclusively) anchorable apically within the socket, where some bone is present. This could compromise the implant's primary stability [26]. A minimum of 4 mm of apical anchorage has been recommended to improve the likelihood of achieving primary stability for planned IIP [12,13]. Consequently, a longer implant may be required for IIP compared to placement in a healed or pristine bone site. In the present study, the minimum implant length in the bone-driven position for maxillary premolar sockets ranged from 6.5 mm to 19.0 mm. The substantial range between the minimum and maximum values indicates variation among patients, necessitating a highly individualized approach to implant length determination. Although not statistically significant, 1PM demonstrated a slightly greater length than 2PM. This likely relates to the proximity of 1PM to the wall between the nasal cavity and the anterior maxillary sinus, which may offer marginally more available bone [7,27]. In contrast, the bone volume around the 2PM root can be compromised by the proximity of the maxillary sinus, and its extension toward the crown may reduce the available bone height [18]. One factor that exacerbates bone deficiency in the region of the 2PM (and

JPIS Journal of Periodontal & Implant Science

posterior areas) is the pneumatization of the maxillary sinus. While commonly recognized as a post-extraction occurrence, pneumatization begins at birth [28], with most of the maxillary sinus volume growth completed by young adulthood [29]. Sinus pneumatization is known to be triggered by tooth extraction [19], but other contributing factors include genetics, variations in craniofacial structure, growth hormone activity, bone density, and air pressure within the sinus cavity [30,31]. The anatomical complexities of this region may explain the high rate of implant perforation, even in the bone-driven position—40.5%, compared to a previously reported figure of 5.6% when IIP is planned in the anterior maxilla [8].

Regarding limitations, the validity of these results depends upon the accuracy of CBCT. Furthermore, the measurements were based on the virtual placement of single implants. Thus, the study did not consider the necessary spacing between implants when planning for the simultaneous placement of adjacent implants in the same area.

Implant placement in the bone-driven position is associated with markedly lower risk of cortical bone wall perforation compared to the prosthetically-driven position. Preoperative assessment of the anatomical characteristics of the planned implant site is crucial to individualize treatment plans and minimize potential surgical risk. Two-dimensional exams, such as orthopantomograms, are generally more accessible, are less expensive, and emit lower radiation doses. However, they offer limited radiological information about the risk of damage to adjacent anatomical structures. In contrast, exams like CBCT provide an accurate 3-dimensional view of the surrounding anatomy [32,33], which is vital for planning IIP in areas with a high risk of perforation, such as the maxillary premolar region.

In conclusion, the risk of perforating the cortical bone wall can be significantly reduced when employing a bone-driven rather than a prosthetically-driven implant position. Nevertheless, the likelihood of perforation occurring during IIP in the maxillary premolar region remains high.

REFERENCES

1. Brånemark PI, Hansson BO, Adell R, Breine U, Lindström J, Hallén O, et al. Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. Scand J Plast Reconstr Surg Suppl 1977;16:1-132. PUBMED
2. Schulte W, Kleineikenscheidt H, Lindner K, Schareyka R. The Tübingen immediate implant in clinical studies. Dtsch Zahnarztl Z 1978;33:348-59. PUBMED
3. Werbitt MJ, Goldberg PV. The immediate implant: bone preservation and bone regeneration. Int J Periodontics Restorative Dent 1992;12:206-17. PUBMED
4. De Rouck T, Collys K, Cosyn J. Single-tooth replacement in the anterior maxilla by means of immediate implantation and provisionalization: a review. Int J Oral Maxillofac Implants 2008;23:897-904. PUBMED
5. Chrcanovic BR, Martins MD, Wennerberg A. Immediate placement of implants into infected sites: a systematic review. Clin Implant Dent Relat Res 2015;17 Suppl 1:e1-16. PUBMED | CROSSREF
6. Ibrahim A, Chrcanovic BR. Dental implants inserted in fresh extraction sockets versus healed sites: a systematic review and meta-analysis. Materials (Basel) 2021;14:7903. PUBMED | CROSSREF
7. Peñarrocha M, Carrillo C, Boronat A, Peñarrocha M. Maximum use of the anterior maxillary buttress in severe maxillary atrophy with tilted, palatally positioned implants: a preliminary study. Int J Oral Maxillofac Implants 2010;25:813-20. PUBMED
8. Botermans A, Lidén A, de Carvalho Machado V, Chrcanovic BR. Immediate implant placement in the maxillary aesthetic zone: a cone beam computed tomography study. J Clin Med 2021;10:5853. PUBMED | CROSSREF
9. Chrcanovic BR, de Carvalho Machado V, Gjelvold B. Immediate implant placement in the posterior mandible: a cone beam computed tomography study. Quintessence Int 2016;47:505-14. PUBMED | CROSSREF

10. Buser D, Martin W, Belser UC. Optimizing esthetics for implant restorations in the anterior maxilla: anatomic and surgical considerations. Int J Oral Maxillofac Implants 2004;19 Suppl:43-61. PUBMED
11. Schropp L, Wenzel A, Kostopoulos L, Karring T. Bone healing and soft tissue contour changes following single-tooth extraction: a clinical and radiographic 12-month prospective study. Int J Periodontics Restorative Dent 2003;23:313-23. PUBMED
12. Fenner M, Vairaktaris E, Fischer K, Schlegel KA, Neukam FW, Nkenke E. Influence of residual alveolar bone height on osseointegration of implants in the maxilla: a pilot study. Clin Oral Implants Res 2009;20:555-9. PUBMED | CROSSREF
13. Froum SJ. Immediate placement of implants into extraction sockets: rationale, outcomes, technique. Alpha Omegan 2005;98:20-35. PUBMED
14. Chrcanovic BR, Custódio AL. Anatomical variation in the position of the greater palatine foramen. J Oral Sci 2010;52:109-13. PUBMED | CROSSREF
15. Chrcanovic BR, Abreu MH, Custódio AL. Morphological variation in dentate and edentulous human mandibles. Surg Radiol Anat 2011;33:203-13. PUBMED | CROSSREF
16. Chrcanovic BR, Abreu MH, Custódio AL. A morphometric analysis of supraorbital and infraorbital foramina relative to surgical landmarks. Surg Radiol Anat 2011;33:329-35. PUBMED | CROSSREF
17. Genç T, Duruel O, Kutlu HB, Dursun E, Karabulut E, Tözüm TF. Evaluation of anatomical structures and variations in the maxilla and the mandible before dental implant treatment. Dent Med Probl 2018;55:233-40. PUBMED | CROSSREF
18. Lim HC, Kim S, Kim DH, Herr Y, Chung JH, Shin SI. Factors affecting maxillary sinus pneumatization following posterior maxillary tooth extraction. J Periodontal Implant Sci 2021;51:285-95. PUBMED | CROSSREF
19. Sharan A, Madjar D. Maxillary sinus pneumatization following extractions: a radiographic study. Int J Oral Maxillofac Implants 2008;23:48-56. PUBMED
20. Marino MJ, Riley CA, Wu EL, Weinstein JE, Emerson N, McCoul ED. Variability of paranasal sinus pneumatization in the absence of sinus disease. Ochsner J 2020;20:170-5. PUBMED | CROSSREF
21. Pessa JE, Zadoo VP, Mutimer KL, Haffner C, Yuan C, DeWitt AI, et al. Relative maxillary retrusion as a natural consequence of aging: combining skeletal and soft-tissue changes into an integrated model of midfacial aging. Plast Reconstr Surg 1998;102:205-12. PUBMED | CROSSREF
22. Shaw RB Jr, Kahn DM. Aging of the midface bony elements: a three-dimensional computed tomographic study. Plast Reconstr Surg 2007;119:675-81. PUBMED | CROSSREF
23. Gjelvold B, Sohrabi MM, Chrcanovic BR. Angled screw channel: an alternative to cemented single-implant restorations--three clinical examples. Int J Prosthodont 2016;29:74-6. PUBMED | CROSSREF
24. Chrcanovic BR, Albrektsson T, Wennerberg A. Tilted versus axially placed dental implants: a meta-analysis. J Dent 2015;43:149-70. PUBMED | CROSSREF
25. Meredith N. Assessment of implant stability as a prognostic determinant. Int J Prosthodont 1998;11:491-501. PUBMED
26. Polizzi G, Grunder U, Goené R, Hatano N, Henry P, Jackson WJ, et al. Immediate and delayed implant placement into extraction sockets: a 5-year report. Clin Implant Dent Relat Res 2000;2:93-9. PUBMED | CROSSREF
27. Kopecka D, Simunek A, Streblov J, Slezak R, Capek L. Measurement of the interantral bone in implant dentistry using panoramic radiography and cone beam computed tomography: a human radiographic study. West Indian Med J 2014;63:503-9. PUBMED | CROSSREF
28. Ma YX, Zhang WJ, Yan ZH, He JW, Cheng XJ, Wang YJ, et al. Normal pneumatization time of paranasal sinuses in 799 children: evaluation with magnetic resonance imaging. Zhonghua Yi Xue Za Zhi 2013;93:816-8. PUBMED
29. Jun BC, Song SW, Park CS, Lee DH, Cho KJ, Cho JH. The analysis of maxillary sinus aeration according to aging process; volume assessment by 3-dimensional reconstruction by high-resolutional CT scanning. Otolaryngol Head Neck Surg 2005;132:429-34. PUBMED | CROSSREF
30. Nowak R, Mehlis G. Studies on the state of pneumatization of the sinus maxillaris. Anat Anz 1975;138:143-51. PUBMED
31. Thomas A, Raman R. A comparative study of the pneumatization of the mastoid air cells and the frontal and maxillary sinuses. AJNR Am J Neuroradiol 1989;10:S88. PUBMED
32. Machado VC, Chrcanovic BR, Felippe MB, Manhães Júnior LR, de Carvalho PS. Assessment of accessory canals of the canalis sinuosus: a study of 1000 cone beam computed tomography examinations. Int J Oral Maxillofac Implants 2016;45:1586-91. PUBMED | CROSSREF
33. Pinsky HM, Dyda S, Pinsky RW, Misch KA, Sarment DP. Accuracy of three-dimensional measurements using cone-beam CT. Dentomaxillofac Radiol 2006;35:410-6. PUBMED | CROSSREF