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Research Article

Evaluation of Alveolar Bone Loss around Immediate and Delayed Dental Implantation in the Posterior Mandible Using Cone-Beam Computed Tomography

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Abstract

Introduction: Alveolar bone loss is one of the primary determinants of long-term success in dental implant therapy. This study aimed to evaluate and compare alveolar bone loss around immediate and delayed dental implantation in the posterior mandible using Cone-Beam Computed Tomography (CBCT). **Materials and Methods:** A comparative cross-sectional study was conducted at Khyber College of Dentistry (KCD), Peshawar, over an 18-month period from July 2022 to December 2023. A total of 82 patients requiring single-tooth implants in the posterior mandible were enrolled and equally assigned to two groups: Immediate Dental Implantation (n = 41) and Delayed Dental Implantation (n = 41). Marginal bone levels on the mesial and distal surfaces were assessed using CBCT at baseline and at the 12-month follow-up. Data analysis was performed using SPSS version 26, applying independent t-tests, paired t-tests, and chi-square tests with a significance level of $p < 0.05$. **Results:** The mean mesial and distal alveolar bone loss in the immediate group was 1.31 ± 0.33 mm and 1.27 ± 0.32 mm, respectively, whereas in the delayed group it was 0.99 ± 0.28 mm and 1.02 ± 0.29 mm, respectively ($p < 0.001$). A significantly higher proportion of patients in the immediate group experienced moderate to severe bone loss. Insertion torque demonstrated a significant inverse correlation with bone loss ($p = 0.004$). **Conclusion:** Delayed dental implantation in the posterior mandible was associated with significantly reduced alveolar bone loss compared to immediate implantation. These findings support delayed protocols as a more favorable strategy for preserving marginal bone over a 12-month period.

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Introduction

Because they provide a dependable and long-lasting way to replace lost teeth, dental implants have completely transformed the restorative dentistry industry [1]. Because of their excellent success rates and capacity to restore function, aesthetics, and patient confidence, Osseo integrated implants in particular have become more well-known [2]. However, maintaining peri-implant bone, especially marginal bone, is crucial for long-term implant stability and function and is directly related to the success of dental implants [3]. The timing of implant placement—whether immediate (at the time of tooth extraction) or delayed (after a healing period)—has drawn a lot of interest in clinical research as one of the factors influencing marginal bone loss (MBL).

A few benefits of immediate implant placement are shorter recovery times, fewer surgical procedures, and the possibility of alveolar bone preservation. Immediate implant placement is the process of inserting an implant straight into the extraction socket [4]. Nevertheless, immediate placement presents challenges such as potential soft tissue complications, inadequate primary stability, and greater risk of marginal bone remodeling [5]. In contrast, delayed implant placement, performed several weeks or months after tooth extraction, allows for soft and hard tissue healing prior to surgery and is traditionally believed to result in more predictable Osseo integration [6]. However, it may be associated with increased crestal bone resorption due to the absence of functional stimulation during the healing phase [7].

The posterior mandible presents its own set of anatomical and biomechanical considerations, including limited visibility, reduced bone density compared to the anterior mandible, and high occlusal loading forces [8]. These factors make the evaluation of implant outcomes in this region particularly important. Marginal bone loss in the posterior mandible can compromise not only the longevity of the implant but also the prosthetic rehabilitation and patient satisfaction [9].

Because Cone Beam Computed Tomography (CBCT) can provide high-resolution, three-dimensional pictures with low radiation exposure [10], it has become a vital diagnostic and evaluating tool in implant dentistry. For comparing the results of immediate vs delayed implant insertion, CBCT is absolutely helpful as it permits exact and consistent measurements of marginal bone levels [11]. While several studies have explored the impact of timing on implant success, few have specifically focused on marginal bone loss in the posterior mandible using CBCT [12].

Despite the growing body of literature on implant timing, there remains a lack of consensus regarding which placement protocol yields better marginal bone preservation in the posterior mandible. This study aims to fill that gap by using CBCT to evaluate and compare marginal bone loss around immediately placed versus delayed implants in this region.

Materials and Methods

Study Design and Setting

This comparative cross-sectional study was conducted at the Department of Oral and Maxillofacial Surgery, Khyber College of Dentistry (KCD), Peshawar, over a period of 18 months, from July 2022 to December 2023. The study aimed to evaluate and compare the marginal bone loss surrounding immediate and delayed implant placement in the posterior mandible using Cone Beam Computed Tomography (CBCT).

Sample Size Calculation

The WHO sample size calculator was used to determine the sample size. The minimum needed sample size was found to be 82 individuals, with a 95% confidence level, 80% power, and an estimated mean difference in marginal bone loss of 0.5 mm between the two groups. This estimate was based on previously published studies that reported clinically significant differences of approximately 0.5 mm between immediate and delayed implant placement groups [13]. (With a standard deviation of 0.8 mm). Group A (Immediate Implant Placement, n = 41) and Group B (Delayed Implant Placement, n = 41) were each equally split into these.

Inclusion and Exclusion Criteria

Participants included adult patients aged between 20 and 60 years, requiring a single-tooth implant in the posterior mandible, with adequate bone volume confirmed through CBCT. Inclusion criteria required good oral hygiene, no signs of acute infection, and no history of systemic conditions known to impair bone healing. Patients were excluded if they had a history of periodontal disease, smoking, bruxism, systemic disorders like uncontrolled diabetes, or were on medications such as bisphosphonates or corticosteroids. Cases requiring bone grafting prior to implant placement were also excluded.

Surgical Protocol

All implant placements were carried out by trained oral surgeons under strict aseptic conditions following a standardized surgical protocol. In Group A (Immediate Placement), implants were inserted into freshly extracted sockets at the time of tooth removal. In Group B (Delayed Placement), implants were placed after a healing period of 8 to 12 weeks post-extraction. All patients received implants from the Straumann® SLA system, with standard dimensions of 4.1 mm in diameter and 10 mm in length. The implants featured a sandblasted, large-grit, acid-etched (SLA) surface treatment to enhance osseointegration.

The same implant system and dimensions were used across all cases to minimize variability. Insertion torque was measured digitally using a calibrated electronic torque wrench (e.g., Osstell ISQ device), ensuring standardized assessment across all procedures. Primary implant stability was evaluated intraoperatively using insertion torque values. Postoperative care included a course of antibiotics, analgesics, and chlorhexidine mouthwash. Patients were instructed to follow standard postoperative care guidelines and were monitored regularly throughout the healing period.

Radiographic Evaluation

To assess marginal bone loss, Cone Beam Computed Tomography (CBCT) images were performed immediately following implant placement and again at the 12-month follow-up. Standardized sagittal and coronal images were used to measure each implant's mesial and distal features. Marginal bone preservation was assessed based on vertical bone height, defined as the distance from the implant shoulder to the most coronal bone-to-implant contact point on both mesial and distal surfaces. The vertical distance between the implant shoulder and the most coronal bone-to-implant contact point was used to determine marginal bone loss.

All radiographic assessments were performed by two independent radiologists who were blinded to the group allocations. In cases where discrepancies occurred between observers, a third radiologist was consulted to reach consensus. Calibration exercises were conducted prior to data collection to ensure measurement consistency and reliability.

Data Analysis

All data were entered and analyzed using SPSS version 26. Mean marginal bone loss was reported as mean ± SD. Comparative analyses between groups were conducted using independent t-tests, with paired t-tests used for within-group comparisons across timepoints. Chi-square tests evaluated categorical variables. A p-value < 0.05 was considered statistically significant.

Ethical Considerations

The Declaration of Helsinki's ethical standards were followed in the conduct of this inquiry. The Institutional Review Board (IRB) of the College provided ethical approval prior to the Commencement of the study. After being educated about the purpose, nature, and procedures of the study, each participant completed an informed consent form.

Results

With 41 participants in each of Group A (Immediate Implant Placement) and Group B (Delayed Implant Placement), the study had 82 patients overall split evenly in both groups. The participants' mean age overall was 43.6 ± 10.2 years, falling between 22 and 60 years. Group A had a somewhat higher mean age of 44.1 ± 10.6 years; Group B had a mean age of 43.0 ± 9.8 years. The study population consisted of 45 men (54.9%) and 37 women (45.1%). Regarding gender distribution, Group A contained 24 men (58.5%) and 17 women (41.5%; Group B comprised 21 men (51.2%) and 20 women (48.8%). This more exact comparison between the two implant placement techniques can aid to reduce bias by means of a more even population (as Table 1 illustrates).

Table 1: Demographic Distribution of Study Participants

Variable	Group A (Immediate)	Group B (Delayed)	Total (N = 82)
Mean Age (years)	44.1 ± 10.6	43.0 ± 9.8	43.6 ± 10.2
Age Range (years)	23 – 60	22 – 59	22 – 60
Male (n, %)	24 (58.5%)	21 (51.2%)	45 (54.9%)
Female (n, %)	17 (41.5%)	20 (48.8%)	37 (45.1%)

At the end of the 12-month follow-up, marginal bone loss was evaluated using CBCT scans at both mesial and distal implant surfaces. The findings showed that Group A (Immediate Implant Placement) exhibited greater bone resorption compared to Group B (Delayed Implant Placement). Specifically, the mean mesial bone loss in Group A was 1.28 ± 0.34 mm, while in Group B it was significantly lower at 0.96 ± 0.30 mm. Similarly, distal bone loss was higher in the immediate group (1.34 ± 0.31 mm) compared to the delayed group (1.02 ± 0.27 mm). The overall mean marginal bone loss was 1.31 ± 0.33 mm in Group A and 0.99 ± 0.28 mm in Group B. These differences were statistically significant, as confirmed by independent samples t-tests ($p < 0.001$ for all comparisons), indicating that delayed implant placement resulted in significantly better bone preservation over the 12-month period (table 2).

Table 2: Mean Marginal Bone Loss at 12 Months (in mm)

Site of Measurement	Group A (Immediate) (Mean ± SD)	Group B (Delayed) (Mean ± SD)	p-value (t-test)
Mesial	1.28 ± 0.34	0.96 ± 0.30	< 0.001
Distal	1.34 ± 0.31	1.02 ± 0.27	< 0.001
Average Total	1.31 ± 0.33	0.99 ± 0.28	< 0.001

When stratified by gender, the analysis revealed that both male and female participants in Group A (Immediate Implant Placement) experienced greater marginal bone loss compared to their counterparts in Group B (Delayed Implant Placement). Among male participants, the mean marginal bone loss in Group A was 1.29 ± 0.32 mm, whereas it was significantly lower in Group B at 1.00 ± 0.27 mm ($p = 0.001$). Similarly, female participants in Group A showed a mean bone loss of 1.33 ± 0.35 mm, while females in Group B had a mean loss of 0.97 ± 0.29 mm ($p = 0.002$). These statistically significant differences across both genders reinforce the trend that delayed implant placement is associated with reduced marginal bone loss, regardless of gender. As shown in table 3.

Table 3: Distribution of Marginal Bone Loss by Gender

Gender	Group A (Mean ± SD)	Group B (Mean ± SD)	p-value
Male	1.29 ± 0.32 mm	1.00 ± 0.27 mm	0.001
Female	1.33 ± 0.35 mm	0.97 ± 0.29 mm	0.002

Categorizing patients based on the range of marginal bone loss revealed notable differences between the two groups. In Group A (Immediate Implant Placement), a significant proportion of patients experienced higher bone loss, with 17 individuals (41.5%) falling within the 1.3–1.6 mm range and 6 patients (14.6%) exhibiting bone loss greater than 1.6 mm. In contrast, Group B (Delayed Implant Placement) had a greater number of patients with minimal bone loss, with 22 patients (53.7%) in the 0.8–1.2 mm range and 10 patients (24.4%) with bone loss less than 0.8 mm. Only 8 patients (19.5%) in Group B experienced bone loss between 1.3–1.6 mm, and just 1 patient (2.4%) had bone loss exceeding 1.6 mm. These findings further emphasize the trend that delayed implant placement is associated with more favorable bone preservation outcomes (as illustrated in Figure 1).

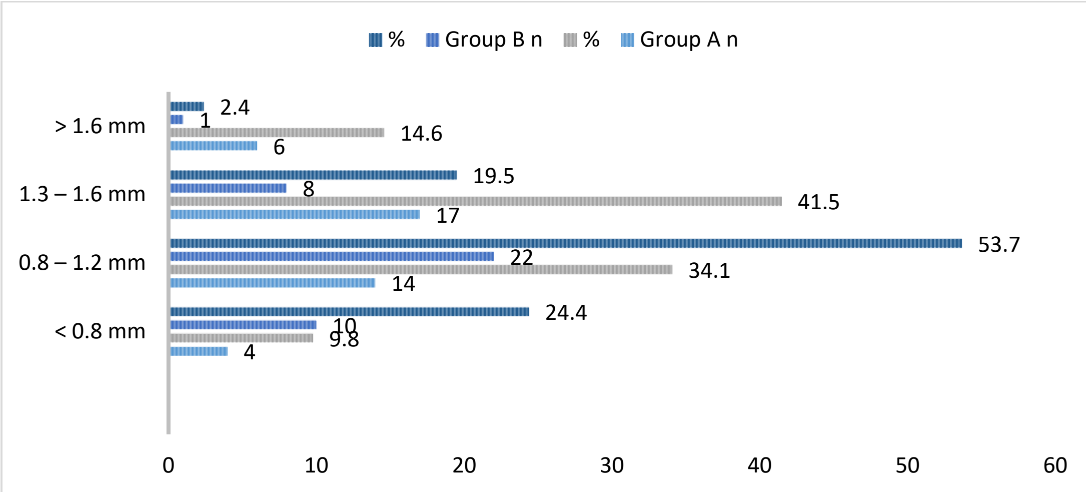

Figure 1: Frequency Distribution of Patients by Range of Bone Loss (mm)

Insertion torque was also evaluated in relation to marginal bone loss, revealing a clear inverse correlation in both implant groups. In Group A (Immediate Implant Placement), patients with an insertion torque of ≤35 Ncm showed an average bone loss of 1.42 ± 0.29 mm, whereas those with higher torque values (>35 Ncm) experienced significantly lower bone loss at 1.20 ± 0.35 mm ($p = 0.012$). Similarly, in Group B (Delayed Implant Placement), patients with insertion torque ≤35 Ncm had a mean bone loss of 1.08 ± 0.25 mm, while those with torque >35 Ncm exhibited reduced bone loss at 0.92 ± 0.26 mm ($p = 0.021$). These findings suggest that achieving a higher insertion torque during implant placement may contribute to better preservation of marginal bone, regardless of timing. As shown in table 4.

Table 4: Insertion Torque and Marginal Bone Loss Correlation

Insertion Torque (Ncm)	Group A Avg Bone Loss (mm)	Group B Avg Bone Loss (mm)
≤ 35	1.42 ± 0.29	1.08 ± 0.25
> 35	1.20 ± 0.35	0.92 ± 0.26
p-value (within group)	0.012	0.021

The categorization of patients by severity of marginal bone loss further highlighted the advantages of delayed implant placement. In Group A (Immediate Implant Placement), 56.1% of patients experienced moderate to severe bone loss (≥1.3 mm), with 17 patients (41.5%) falling into the moderate range (1.3–1.6 mm) and 6 patients (14.6%) in the severe category (>1.6 mm). In contrast, only 21.9% of patients in Group B (Delayed Implant Placement) exhibited bone loss in these higher categories, with 8 patients (19.5%) showing moderate loss and just 1 patient (2.4%) showing severe loss. Conversely, mild bone loss (<1.3 mm) was far more prevalent in the delayed group, affecting 78.1% (n = 32) of patients compared to only 43.9% (n = 18) in the immediate group. These findings suggest that delayed implant placement is more consistently associated with minimal bone resorption over the follow-up period (as illustrated in Figure 2).

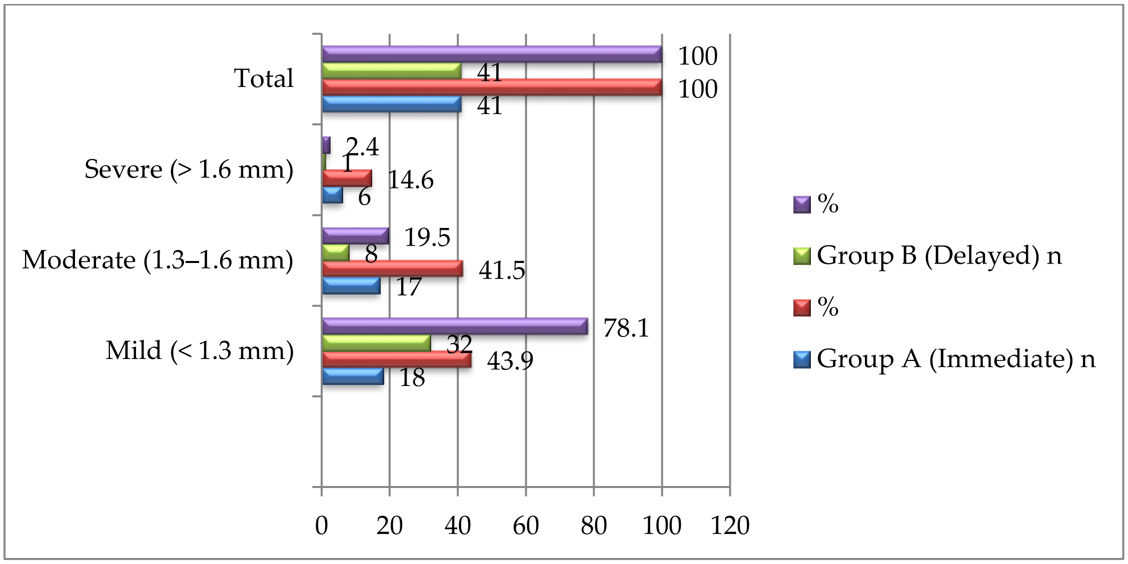

Figure 2: Severity of Marginal Bone Loss by Category with Percentage Distribution

Discussion

This study demonstrated a statistically significant difference in marginal bone loss between immediate and delayed implant placement in the posterior mandible over a 12-month follow-up period. Patients who received delayed implants exhibited significantly lower mean bone loss (0.99 ± 0.28 mm) compared to those with immediate implants (1.31 ± 0.33 mm). These findings were consistent across both mesial and distal sites and remained significant when stratified by gender and insertion torque.

The analysis further revealed that a greater proportion of patients in the delayed group had mild bone loss (<1.3 mm), whereas a majority of those in the immediate group fell into moderate to severe bone loss categories. This supports the notion that delayed implant placement may offer more favorable bone preservation outcomes, particularly in the early stages of osseointegration.

The present study's findings are aligned with existing literature, which suggests that immediate implant placement is associated with greater marginal bone remodeling due to the surgical trauma and healing demands placed on the peri-implant bone [14]. Delayed implant protocols, on the other hand, allow the extraction site to heal fully before implant placement, reducing early crestal bone changes and improving soft tissue stability [15].

Studies using CBCT have consistently shown that delayed implants exhibit better marginal bone maintenance, primarily due to a reduced inflammatory response and improved tissue integration [16]. Bone loss in immediate placement protocols has been attributed to the challenges of achieving primary stability in extraction sockets, as well as increased remodeling activity resulting from the simultaneous processes of socket healing and implants integration [17]. Additionally, soft tissue changes and loss of buccal plate support have been identified as contributing factors to early marginal bone loss in immediate placements [18].

The correlation between higher insertion torque and reduced bone loss observed in this study is also supported by literature, which emphasizes the importance of achieving optimal primary stability during implant placement [19]. Lower insertion torque values have been associated with micro-motion at the implant-bone interface, potentially resulting in fibrous encapsulation and bone resorption [20].

Overall, the current findings reinforce the biomechanical and biological advantages of delayed implant placement in preserving marginal bone, especially in the posterior mandible where bone quality may be more variable. While the current study focused on radiographic outcomes, soft tissue parameters such as keratinized tissue width and probing depth were not assessed. Additionally, patient-centered outcomes like postoperative comfort, satisfaction, and functional performance were not evaluated but are essential for a comprehensive understanding of implant success. Future studies should incorporate both clinical and subjective measures.

Limitations and Future Suggestions

Despite the valuable insights gained, the study had several limitations. The sample size, although statistically adequate, was limited to a single institution, affecting the broader generalizability. Soft tissue parameters (e.g., probing depth, keratinized tissue width) and patient-centered outcomes (comfort, satisfaction, function) were not evaluated. Moreover, multivariate regression analysis was not conducted to control for potential confounding variables such as age, gender, and bone density. Future multi-center studies with longer follow-up durations, inclusion of soft tissue and patient-reported metrics, and use of regression modeling are recommended for more robust findings.

Conclusion

This research emphasizes, in the posterior mandible, the notable variation in marginal bone loss between immediate and delayed implant implantation; delayed insertion produces less bone loss over a 12-month period. Particularly in the early phases of recovery, the results imply that delayed implant placement may provide improved preservation of bone. Although insertion torque was shown to contribute to bone loss, further long-term research is required to completely grasp how implant timing affects osseointegration and bone remodeling. These realizations may let doctors choose suitable implant techniques to maximize long-term results for individual patients.

Authors' contributions

Conceptualization and supervision: NK; Methodology: TN; Investigation, writing original draft and review: KI; Data collection: AZ; Data analysis: HPF; All authors approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Conflict of interest

The authors declared no conflict of interest.

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