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Surgical Management of Deficient Implant Sites and Its Influence on Subsequent Prosthetic Rehabilitation

¹Vikas B. Kamble, ²Akansh Datta, ³Purva Singla, ⁴Omkar Krishna Shetty, ⁵Rahul Maurya, ⁶Mrinalini Jaichander

¹Professor & Head, Department of Prosthodontics and Crown & Bridge, PMNM Dental College & Hospital, Bagalkot, Karnataka, India drvikaskamble2002@yahoo.co.in

²Professor, Department of Oral & Maxillofacial Surgery, Uttaranchal Dental & Medical Research Institute, Dehradun, Uttarakhand, India dr.akanshdatta@gmail.com

³Post Graduate, Department of Oral & Maxillofacial Surgery, Post Graduate Institute of Dental Sciences, Pt B D Sharma University of Health Sciences, Rohtak, Haryana, India purvasingla4@gmail.com

⁴Principal & Professor, Department of Prosthodontics and Crown & Bridge, ITS Dental College, Hospital & Research Centre, Greater Noida, Uttar Pradesh, India oshetty123@gmail.com

⁵Junior Resident, Department of Periodontology, Uttar Pradesh University of Medical Sciences, Saifai, Etawah, Uttar Pradesh, India, drrahulmauryario13@gmail.com

⁶Senior Lecturer, Department of Conservative Dentistry & Endodontics, Dayananda Sagar College of Dental Sciences, Bengaluru, Karnataka, India mrinalinij@dscds.edu.in
Corresponding author: Vikas B. Kamble, drvikaskamble2002@yahoo.co.in

ABSTRACT:

Aim:

To compare ridge augmentation, implant stability, peri-implant tissue health, prosthetic outcomes, implant survival, and patient satisfaction between conventional site management and surgical augmentation in patients with deficient implant sites.

Materials and Methods:

A total of 60 patients with deficient implant sites were included and equally allocated to Group I (conventional site management, n = 30) and Group II (surgical augmentation, n = 30). Baseline ridge dimensions, horizontal and vertical ridge gain, insertion torque, implant stability quotient (ISQ), healing and loading intervals, prosthetic complications, peri-implant clinical parameters, marginal bone loss, patient satisfaction, implant survival, and prosthetic success were evaluated. Intergroup comparisons were performed using appropriate statistical tests, with $p < 0.05$ considered statistically significant.

Results:

Baseline ridge width and height were comparable between the groups. At implant placement, Group II demonstrated greater ridge width (6.72 ± 0.61 vs. 5.01 ± 0.58 mm), horizontal ridge gain (2.63 ± 0.55 vs. 0.89 ± 0.42 mm), and vertical ridge gain (2.18 ± 0.63 vs. 0.91 ± 0.48 mm), with all differences statistically significant ($p < 0.001$). Insertion torque and ISQ values were also higher in Group II at placement and at 3 months. Group II showed lower marginal bone loss at 6 and 12 months and more favourable peri-implant clinical parameters at 6 months. Patient satisfaction at 12 months was significantly higher in Group II for overall satisfaction, chewing comfort, and esthetics. Prosthetic complications were less frequent in Group II, although the difference was not statistically significant. Implant survival (96.7% vs. 93.3%) and prosthetic success (93.3% vs. 86.7%) were numerically higher in Group II but did not

differ significantly between groups.

Conclusion:

Surgical augmentation provided greater ridge enhancement, improved early implant stability, favourable peri-implant tissue outcomes, reduced marginal bone loss, and higher patient satisfaction compared with conventional site management. However, implant survival and prosthetic success were comparable between the groups at 12 months.

INTRODUCTION

Dental implants have become an established treatment modality for the rehabilitation of partially and completely edentulous patients, offering predictable restoration of function, comfort, and esthetics [1]. However, successful implant-supported rehabilitation depends not only on osseointegration but also on the availability of adequate hard and soft tissues at the proposed implant site [2]. Following tooth loss, progressive resorption of the alveolar ridge may result in reduced ridge width and height, unfavorable three-dimensional (3D) anatomy, inadequate keratinized mucosa, and compromised peri-implant soft-tissue contours [3]. These deficiencies can make ideal implant placement difficult and may adversely affect the emergence profile, cleansability, esthetics, and long-term biological stability of the definitive prosthesis [4].

Surgical management of deficient implant sites aims to restore the anatomical conditions required for prosthetically driven implant placement. Depending on the nature and severity of the defect, treatment may include guided bone regeneration (GBR), particulate or block grafting, ridge-splitting procedures, vertical augmentation, sinus floor elevation, or soft-tissue augmentation [5]. Hard-tissue procedures are primarily intended to increase the volume of bone available for implant placement, whereas soft-tissue procedures can improve mucosal thickness, keratinized tissue dimensions, and peri-implant tissue architecture [6]. The selection of an appropriate technique is influenced by the defect morphology, residual bone dimensions, anatomical limitations, patient-related factors, and the intended prosthetic outcome [7].

The relationship between surgical site development and prosthetic rehabilitation is particularly important because implant surgery and prosthetic treatment are interdependent stages of a single restorative process. Implant position, angulation, depth, surrounding bone volume, and peri-implant soft-tissue architecture directly influence prosthetic space, crown emergence, restoration contours, interproximal contact, occlusal relationships, and overall esthetic integration [8]. Conversely, inadequate consideration of the definitive prosthetic design during surgical planning may result in implants being positioned in locations that are biologically acceptable but prosthetically compromised. Therefore, contemporary implant treatment increasingly emphasizes prosthetically driven planning, in which the anticipated restoration serves as a reference for determining the optimal implant position and the need for site-development procedures [9].

Despite advances in regenerative materials, surgical protocols, and digital planning technologies, deficient implant sites continue to present clinical challenges. Variations in augmentation techniques, healing responses, defect characteristics, implant positioning, and prosthetic protocols can influence treatment duration and the predictability of the final rehabilitation. Furthermore, the success of site augmentation should not be evaluated solely by the amount of regenerated tissue or implant survival; the resulting anatomical conditions must also facilitate fabrication of a functional, hygienic, and esthetically appropriate prosthesis. Evaluating the prosthetic consequences of surgical site development therefore provides a broader perspective on the clinical effectiveness of implant-site management.

Accordingly, the present study was undertaken to evaluate the surgical management of deficient implant sites and to assess its influence on subsequent prosthetic rehabilitation. The study focuses on the relationship between correction of site deficiencies and clinically relevant prosthetic outcomes, with the objective of determining whether appropriate surgical site development facilitates more predictable and favorable restorative rehabilitation.

MATERIALS & METHODS

Study Design and Participants

This comparative clinical study at a single tertiary care centre from October 2024 to March 2026 evaluated the outcomes of two approaches for the management of deficient implant sites. A total of 60 patients requiring implant rehabilitation at sites with inadequate alveolar ridge dimensions were included. The participants were equally divided into two groups of 30 patients each. Group I underwent conventional site management, whereas Group II received surgical augmentation before or in conjunction with implant placement, according to the clinical requirements of the deficient site.

Patients were assessed clinically and radiographically from the initial site-management stage through implant placement, prosthetic rehabilitation, and follow-up. The study evaluated changes in ridge dimensions, implant stability, healing and prosthetic timelines, peri-implant clinical health, marginal bone changes, prosthetic complications, patient satisfaction, implant survival, and prosthetic success.

Inclusion Criteria

Participants were eligible for inclusion if they met the following criteria:

- Adults requiring implant-supported prosthetic rehabilitation
- Presence of a clinically diagnosed deficient implant site requiring site management
- Inadequate ridge dimensions requiring either conventional management or surgical augmentation
- Availability of baseline clinical and radiographic records for assessment of ridge dimensions
- Adequate general condition to undergo implant placement and prosthetic rehabilitation
- Willingness to undergo the planned treatment and attend scheduled follow-up assessments
- Availability for follow-up evaluations through at least 12 months after prosthetic rehabilitation

Exclusion Criteria

Patients were excluded if they met any of the following criteria:

- Presence of uncontrolled systemic conditions that could adversely affect surgical healing or implant therapy
- Active infection or untreated pathological lesions at the proposed implant site
- Previous implant placement at the same site
- History of radiotherapy involving the proposed implant region
- Conditions or medications known to substantially compromise bone healing
- Inability to maintain adequate oral hygiene or comply with postoperative instructions
- Insufficient clinical or radiographic records for outcome assessment
- Failure to attend the scheduled follow-up evaluations
- Requirement for additional treatment that could substantially influence the outcomes being investigated

Clinical and Radiographic Evaluation

At baseline, all participants underwent a standardized clinical examination and radiographic evaluation of the proposed implant site. The assessment included evaluation of the residual ridge, available bone dimensions, soft-tissue condition, adjacent teeth or implants, occlusal relationships, and prosthetic requirements. Radiographic assessment was performed to determine the available vertical bone height and to evaluate the anatomical characteristics relevant to implant placement. The same diagnostic principles were applied to both groups. Baseline measurements were documented before initiation of site-management procedures.

The implant position and dimensions were subsequently planned according to the available anatomy and the prosthetic requirements. The records obtained at baseline served as the reference for subsequent assessment of ridge dimensional changes.

Group Allocation and Site Management

Following baseline assessment, patients were assigned to one of the two treatment groups.

Group I: Conventional Site Management

Patients in Group I were managed using a conventional approach without a formal ridge augmentation procedure. Site preparation was performed according to the existing ridge anatomy and the requirements of implant placement. Where clinically appropriate, minor site modifications required for implant placement were performed without undertaking a dedicated surgical augmentation procedure intended to increase ridge volume.

Group II: Surgical Augmentation

Patients in Group II underwent guided bone regeneration (GBR) for correction of deficient alveolar ridge anatomy. The procedure was selected according to the extent and morphology of the horizontal and/or vertical ridge deficiency and the prosthetically planned implant position. After administration of local anesthesia, a full-thickness mucoperiosteal flap was reflected to expose the deficient ridge. The recipient site was carefully debrided and prepared to provide a clean vascularized bony surface. For horizontal and/or localized vertical deficiencies, a particulate bone graft was placed over the deficient ridge to restore the required 3D contour. The graft was stabilized and covered with a resorbable collagen membrane, which was extended beyond the margins of the defect to provide adequate containment and guided bone regeneration. Where primary implant placement was feasible, the implant was inserted simultaneously with the augmentation procedure; in sites requiring staged reconstruction, augmentation was performed first and implant placement was undertaken after the prescribed healing period. The augmented site was closed using interrupted or mattress sutures to achieve tension-free primary closure. Patients received routine postoperative instructions and institutional postoperative care, including maintenance of oral hygiene and monitoring for signs of infection, wound dehiscence, membrane exposure, graft-related complications, or other adverse events. Patients undergoing staged augmentation were reviewed periodically during the healing phase. The interval between augmentation and implant placement was recorded in months. At the time of implant placement, the ridge dimensions were reassessed, and the implant was positioned according to the prosthetically planned 3D position. In cases involving simultaneous augmentation and implant placement, ridge measurements were recorded before and after the augmentation procedure according to the study assessment protocol.

Assessment of Ridge Dimensions

Ridge dimensions were assessed at baseline and again at the time of implant placement. Measurements were obtained using standardized clinical and/or radiographic methods appropriate for the anatomical parameter being evaluated.

Ridge width represented the available horizontal dimension of the alveolar ridge and was recorded in millimetres. Ridge height represented the available vertical bone dimension relevant to implant placement and was similarly recorded in millimetres.

The following parameters were calculated:

- **Horizontal ridge gain (mm):** post-management ridge width – baseline ridge width
- **Vertical ridge gain (mm):** post-management ridge height – baseline ridge height
- **Percentage dimensional change:** calculated where appropriate by comparing the change from baseline with the corresponding baseline measurement.

The measurements obtained at implant placement were compared with the baseline values to quantify the dimensional changes associated with the respective treatment approaches. Intergroup comparisons were subsequently performed for horizontal and vertical ridge changes.

Implant Placement and Implant Stability

Implant placement was performed after adequate site preparation and healing, according to the treatment protocol and individual anatomical requirements. The implant dimensions and position were selected based on the available bone and planned prosthetic restoration. Primary implant stability was assessed immediately following implant placement. Insertion torque was recorded in Ncm as an indicator of mechanical stability at the time of implant insertion. In addition, implant stability was evaluated using the implant stability quotient (ISQ) obtained through resonance frequency analysis (RFA). ISQ measurements were recorded at implant placement and repeated at the 3-month follow-up. The change in ISQ between the two assessment points was used to evaluate the development of implant stability during the early healing period. Where applicable, implant placement and stability measurements were performed using the same clinical protocol and measurement principles for both groups to minimize procedural variability.

Healing and Treatment Timeline

The major treatment intervals were documented prospectively for comparison between groups.

The site-management-to-implant-placement interval was recorded from the date of completion of site management to the date of implant insertion. For patients undergoing surgical augmentation, this represented the healing period following augmentation before implant placement. Following implant placement, the implant-to-prosthetic-loading interval was recorded from implant placement to definitive prosthetic loading. These intervals were expressed in months and compared between the two treatment groups. Any clinically relevant delays caused by inadequate healing, surgical complications, or prosthetic requirements were documented.

Prosthetic Rehabilitation

After completion of the appropriate implant healing period, patients underwent definitive prosthetic rehabilitation. The definitive restoration was fabricated and delivered according to the planned implant position, occlusal requirements, and restorative protocol. The interval between implant placement and definitive prosthetic loading was recorded for each participant. Following delivery of the definitive restoration, patients were evaluated clinically for function, occlusion, prosthetic adaptation, and complications.

Prosthetic complications occurring during the follow-up period were recorded systematically.

Complications were categorized into clinically relevant groups, including:

- Requirement for occlusal adjustment
- Crown-related complications
- Abutment-related complications
- Other prosthetic events requiring clinical intervention

The number and proportion of patients experiencing each complication were recorded and compared between the groups.

Peri-Implant Clinical Evaluation

Peri-implant clinical health was evaluated at 6 months following prosthetic loading using a standardized clinical assessment protocol. The same examiner or standardized examination procedure was used, wherever feasible, to maintain consistency between groups.

The following clinical parameters were assessed:

Probing Depth

Peri-implant probing depth was measured in millimetres using a periodontal probe. Measurements were obtained at standardized sites around the implant, and the recorded values were used to calculate the patient/implant-level mean according to the study protocol.

Plaque Index

Plaque accumulation around the implant-supported restoration was assessed using the designated plaque index. The scores were recorded according to the predefined scoring criteria, and the resulting values were used for comparison between the treatment groups.

Bleeding on Probing

Bleeding on probing was assessed following gentle probing of the peri-implant sulcus. The presence or absence of bleeding at the examined sites was recorded, and the result was expressed as a percentage of bleeding sites.

Width of Keratinized Mucosa

The width of keratinized mucosa surrounding the implant was measured in millimetres. The measurement was obtained from the mucosal margin to the mucogingival junction using a standardized clinical technique. All peri-implant measurements were performed using the same assessment protocol to facilitate reliable comparison of peri-implant soft-tissue health between Group I and Group II.

Radiographic Assessment of Marginal Bone Loss

Marginal bone levels were evaluated radiographically at 6 and 12 months following implant rehabilitation. Standardized radiographic images were obtained using a reproducible technique to permit comparison of crestal bone levels over time. The marginal bone level was measured in millimetres from a predefined implant reference point to the most coronal level of the marginal bone adjacent to the implant. The reference level established at the time of implant restoration was used as the baseline for subsequent evaluation.

Marginal bone loss was calculated as the change in crestal bone level between the restoration baseline and each subsequent follow-up examination.

Measurements were recorded separately at:

- 6 months after rehabilitation
- 12 months after rehabilitation

The mean marginal bone loss was calculated for each group and compared to identify differences in radiographic peri-implant bone stability.

Patient-Reported Satisfaction

Patient-reported satisfaction was evaluated at the 12-month follow-up using a numerical rating scale ranging from 0 to 10, with higher values indicating greater satisfaction.

Three domains were assessed:

1. Overall treatment satisfaction
2. Chewing comfort
3. Esthetic satisfaction

Patients were asked to independently rate each domain based on their experience with the completed implant-supported rehabilitation. The individual scores were recorded and summarized as mean values for each treatment group. The three satisfaction domains were analyzed separately to determine whether the treatment approach was associated with differences in perceived overall outcome, functional comfort, or esthetic acceptance.

Implant Survival

Implant survival was assessed at the 12-month follow-up. An implant was considered to have survived when it remained in situ and functional without removal during the observation period. Implants that required removal because of failure or other

implant-related complications were considered non-surviving implants. The number of surviving implants and the corresponding percentage were calculated for each group.

Implant survival was expressed as:

Implant survival (%) = (Number of surviving implants / Total number of implants placed) × 100

Prosthetic Success

Prosthetic success was evaluated at 12 months after definitive rehabilitation. Prosthesis was considered successful when it remained clinically functional without an event requiring replacement or resulting in definitive prosthetic failure during the observation period. Prosthetic events requiring adjustment or repair were documented separately from definitive prosthetic failure. The number and percentage of successful prostheses were calculated for each treatment group.

Follow-up Protocol

Participants were followed systematically from the initial site-management stage through implant placement and prosthetic rehabilitation. Clinical and radiographic assessments were performed at predefined time points.

Data Recording and Quality Control

All clinical, radiographic, surgical, prosthetic, and patient-reported observations were entered into a structured data-recording format. Patient identifiers were replaced with study-specific codes for analysis. Measurements were recorded in their respective standard units, and follow-up observations were linked to the corresponding baseline records. Radiographic and clinical measurements were reviewed for completeness before statistical analysis. Where repeated measurements were required, the same measurement protocol was followed at each assessment point to reduce measurement variability.

Statistical Analysis

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS), IBM SPSS Statistics for Windows, version 29.0 (IBM Corp., Armonk, NY, USA). Appropriate descriptive and inferential statistical methods were applied according to the type and distribution of the data. Continuous variables such as ridge dimensions, ridge gain, insertion torque, ISQ, healing interval, implant-to-loading interval, peri-implant probing depth, plaque index, bleeding on probing, keratinized mucosa width, marginal bone loss, and patient satisfaction scores were expressed as mean ± standard deviation (SD). Between-group comparisons for continuous variables were performed using the independent-samples Student's t-test, as the comparisons involved two independent groups.

Categorical variables, including sex, successful implant placement, prosthetic complications, implant survival, and prosthetic success, were summarized as frequencies and percentages. Between-group differences in categorical variables were assessed using the Chi-square test or Fisher's exact test, as appropriate, particularly where expected cell frequencies were small. Implant stability was evaluated using insertion torque and ISQ measurements at implant placement and at 3 months. Between-group comparisons demonstrated statistically significant differences for insertion torque and ISQ at both assessment points. A two-sided p-value < 0.05 was considered statistically significant. Results with p-values < 0.001 were reported as p < 0.001. The analysis was designed to assess differences between conventional site management and surgical augmentation across anatomical, implant stability, prosthetic, peri-implant, radiographic, and patient-reported outcomes.

RESULTS

Table 1 & Figure 1 illustrate the baseline demographic characteristics of the 60 patients with deficient implant sites included in the simulated analysis. The participants were equally divided into two groups, with 30 patients in Group I (conventional site management) and 30 in Group II (surgical augmentation). The mean age was 42.6 ± 8.1 years in Group I and 43.1 ± 7.6 years in Group II. Group I consisted of 17 males (56.7%) and 13 females (43.3%), while Group II included 16 males (53.3%) and 14 females (46.7%).

Table 1: Participant characteristics

Variable	Group I (n=30)	Group II (n=30)
Age (years), mean $\pm$ SD	42.6 $\pm$ 8.1	43.1 $\pm$ 7.6
Male, n (%)	17 (56.7)	16 (53.3)
Female, n (%)	13 (43.3)	14 (46.7)

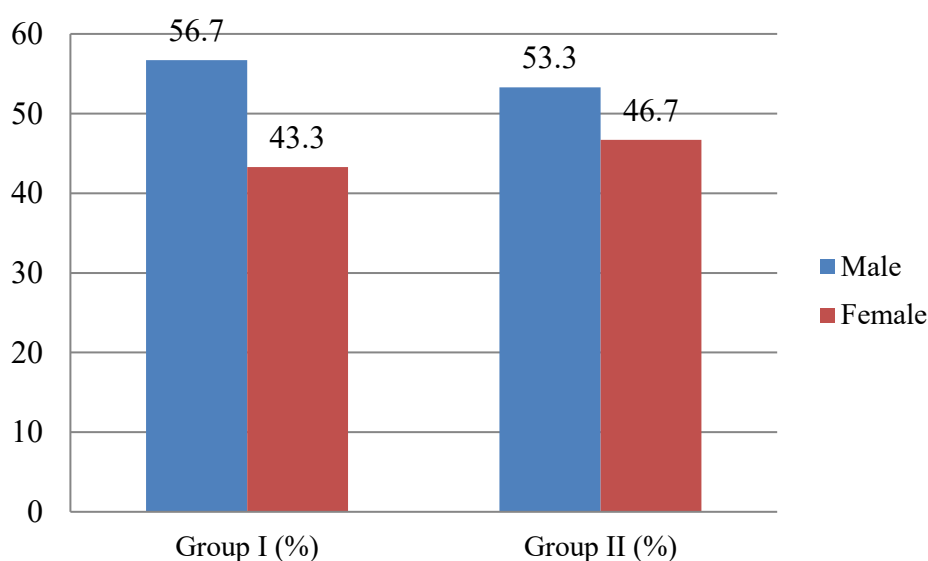


Figure 1: Distribution of participants according to age and gender in the conventional site management (Group I) and surgical augmentation (Group II) groups

Table 2 & Figure 2 illustrate the baseline ridge dimensions in the two study groups. The mean ridge width was 4.12 ± 0.56 mm in Group I and 4.09 ± 0.59 mm in Group II, with no statistically significant intergroup difference ($p = 0.840$). Similarly, the mean ridge height was 7.21 ± 0.74 mm in Group I and 7.18 ± 0.71 mm in Group II, with the difference also being statistically insignificant ($p = 0.873$). The comparable baseline measurements indicate that both groups had similar initial ridge dimensions before intervention, allowing subsequent outcomes to be evaluated under comparable conditions.

Table 2: Baseline ridge dimensions

Parameter	Group I	Group II	Mean Difference	p-value
Ridge width (mm)	4.12 $\pm$ 0.56	4.09 $\pm$ 0.59	0.03	0.840
Ridge height (mm)	7.21 $\pm$ 0.74	7.18 $\pm$ 0.71	0.03	0.873

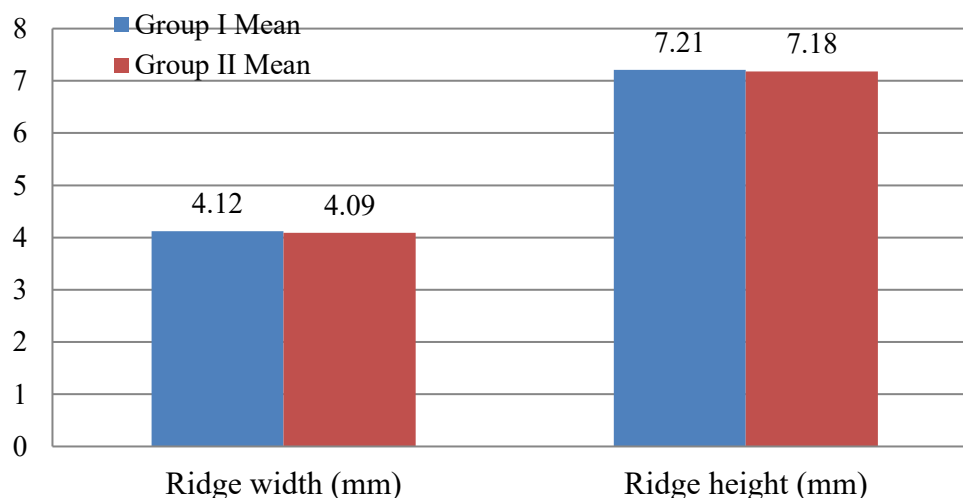


Figure 2: Comparison of baseline ridge width and ridge height between conventional site management (Group I) and surgical augmentation (Group II) groups

Table 3 & Figure 3 illustrate the changes in alveolar ridge dimensions following the management of deficient implant sites. Group II exhibited greater improvements in ridge dimensions than Group I after surgical intervention. At the time of implant placement, the mean ridge width was 5.01 ± 0.58 mm in Group I and 6.72 ± 0.61 mm in Group II, with a statistically significant difference between the groups ($p < 0.001$). The mean horizontal ridge gain was 0.89 ± 0.42 mm in Group I, compared with 2.63 ± 0.55 mm in Group II, indicating significantly greater horizontal augmentation in the latter group ($p < 0.001$). Similarly, the mean vertical ridge gain was 0.91 ± 0.48 mm in Group I and 2.18 ± 0.63 mm in Group II, with the intergroup difference being statistically significant ($p < 0.001$). These findings demonstrate that surgical augmentation was associated with greater horizontal and vertical ridge enhancement than conventional site management.

Table 3: Change in ridge dimensions following site management

Outcome	Group I	Group II	Mean Difference	p-value
Ridge width at implant placement (mm)	5.01 ± 0.58	6.72 ± 0.61	1.71	<0.001
Horizontal gain (mm)	0.89 ± 0.42	2.63 ± 0.55	1.74	<0.001
Vertical gain (mm)	0.91 ± 0.48	2.18 ± 0.63	1.27	<0.001

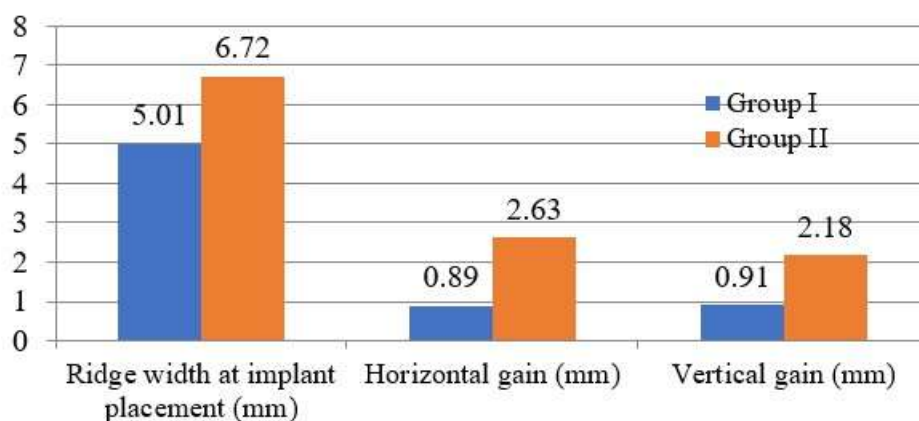


Figure 3: Intergroup comparison of ridge width at implant placement and horizontal and vertical ridge gain following conventional site management and surgical augmentation

Table 4 & Figure 4 illustrate the intergroup comparison of implant stability parameters, revealing statistically significant differences between the two groups. The mean insertion torque at the time of implant placement was 31.4 ± 5.8 Ncm in Group I and 38.7 ± 6.1 Ncm in Group II, with a statistically significant difference ($p < 0.001$). Similarly, the mean ISQ at placement was 67.3 ± 5.2 in Group I and 72.8 ± 4.7 in Group II, demonstrating significantly higher initial stability in Group II ($p < 0.001$). At the three-month follow-up, the mean ISQ increased to 73.6 ± 4.8 in Group I and 76.9 ± 4.2 in Group II, with the difference remaining statistically significant ($p = 0.006$). Overall, Group II exhibited higher insertion torque and ISQ values at implant placement, along with greater stability measurements during the early follow-up period.

Table 4: Implant Stability

Parameter	Group I	Group II	Mean Difference	p-value
Insertion torque (Ncm)	31.4 ± 5.8	38.7 ± 6.1	7.3	<0.001
ISQ at placement	67.3 ± 5.2	72.8 ± 4.7	5.5	<0.001
ISQ at 3 months	73.6 ± 4.8	76.9 ± 4.2	3.3	0.006

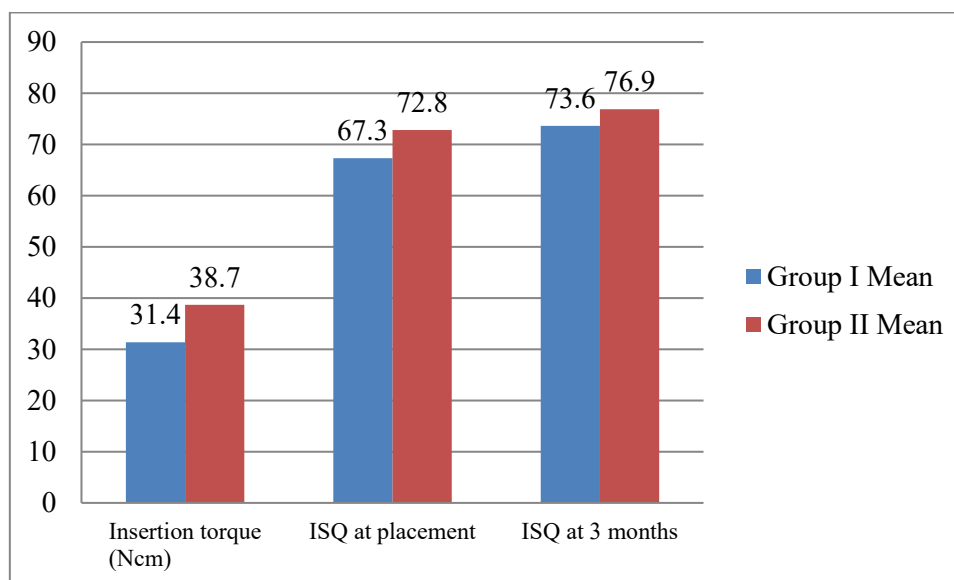


Figure 4: Intergroup comparison of insertion torque and ISQ at implant placement and three-month follow-up

Table 5 & Figure 5 present the mean interval between site management and implant placement was 5.8 ± 1.1 months in Group I and 5.2 ± 0.9 months in Group II. This difference was statistically significant ($p = 0.021$), indicating a shorter mean healing interval before implant placement in Group II. Following implant placement, the mean interval to prosthetic loading was 3.4 ± 0.7 months in Group I and 3.1 ± 0.6 months in Group II. Although the interval was shorter in Group II, the difference did not reach statistical significance ($p = 0.071$).

Table 5: Prosthetic rehabilitation

Outcome	Group I	Group II	Mean Difference	p-value
Healing interval (months)	5.8 ± 1.1	5.2 ± 0.9	0.6	0.021
Implant-to-loading interval (months)	3.4 ± 0.7	3.1 ± 0.6	0.3	0.071

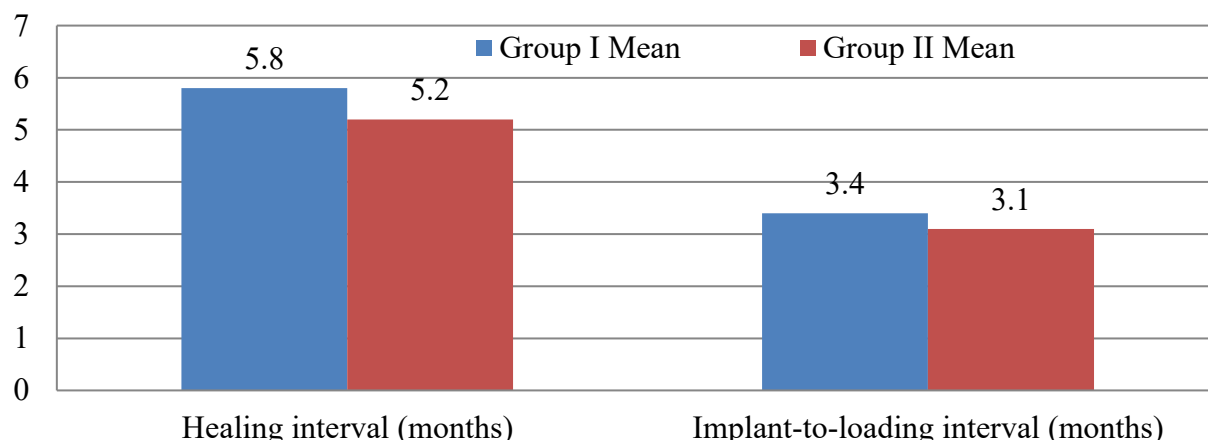


Figure 5: Intergroup comparison of healing interval before implant placement and time from implant placement to prosthetic loading

Table 6 & Figure 6 present the distribution of prosthetic complications observed in the two study groups. Prosthetic complications occurred in 6 patients (20.0%) in Group I and 2 patients (6.7%) in Group II. Although complications were less frequent in Group II, the difference between the groups was not statistically significant ($p = 0.129$). In Group I, occlusal adjustment was required in 4 patients (13.3%), while crown- or abutment-related complications occurred in 2 patients (6.7%). In Group II, 1 patient (3.3%) required occlusal adjustment and 1 patient (3.3%) experienced a crown- or abutment-related complication. Overall, the absence of prosthetic complications was recorded in 24 patients (80.0%) in Group I and 28 patients (93.3%) in Group II during the assessment period.

Table 6: Prosthetic complications

Outcome	Group I n (%)	Group II n (%)	p-value
No prosthetic complication	24 (80.0)	28 (93.3)	0.129
Occlusal adjustment	4 (13.3)	1 (3.3)	
Crown/abutment complication	2 (6.7)	1 (3.3)	

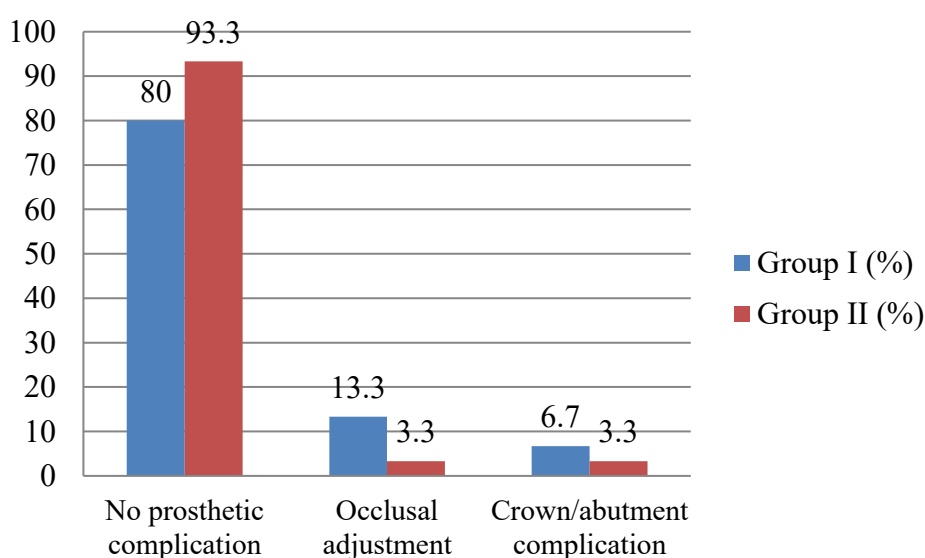


Figure 6: Distribution and comparison of prosthetic complications between Group I and Group II during the assessment period

Table 7 & Figure 7 summarize the peri-implant clinical parameters assessed six months after prosthetic loading. Statistically significant differences were observed between the groups across all evaluated parameters. The mean probing depth was 2.71 ± 0.42 mm in Group I and 2.38 ± 0.36 mm in Group II ($p = 0.002$). Similarly, the mean plaque index was 0.54 ± 0.22 in Group I and 0.39 ± 0.18 in Group II ($p = 0.006$). Bleeding on probing was recorded at $25.8 \pm 11.2\%$ in Group I and $16.7 \pm 9.4\%$ in Group II, with a statistically significant difference ($p = 0.001$). The mean width of keratinized mucosa was 2.72 ± 0.51 mm in Group I compared with 3.18 ± 0.48 mm in Group II ($p = 0.001$). Overall, Group II showed more favourable peri-implant clinical measurements at the six-month follow-up.

Table 7: Peri-implant clinical parameters

Parameter at 6 months	Group I	Group II	Mean Difference	p-value
Probing depth (mm)	2.71 ± 0.42	2.38 ± 0.36	0.33	0.002
Plaque index	0.54 ± 0.22	0.39 ± 0.18	0.15	0.006
Bleeding on probing (%)	25.8 ± 11.2	16.7 ± 9.4	9.10	0.001
Keratinized mucosa width (mm)	2.72 ± 0.51	3.18 ± 0.48	-0.46	0.001

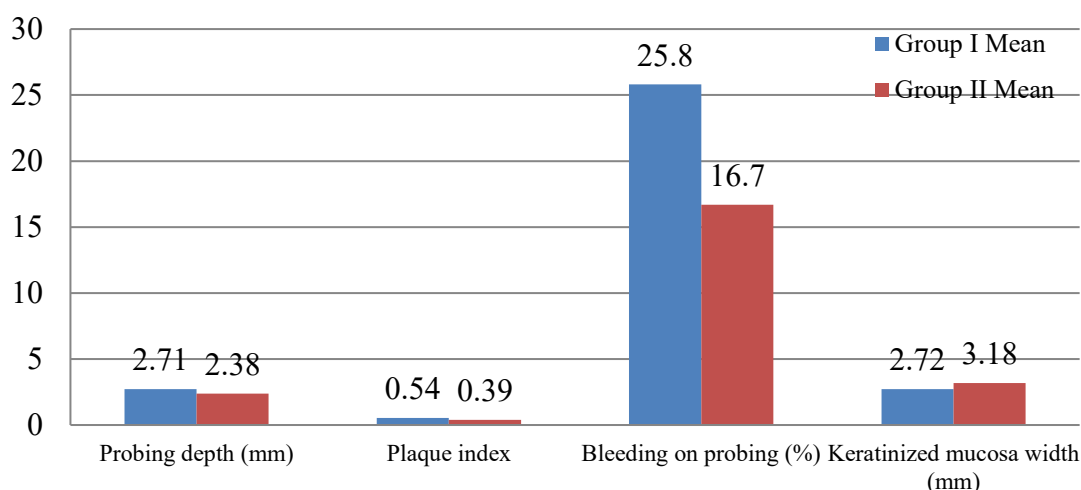


Figure 7: Comparison of peri-implant clinical parameters between Group I and Group II at six months following prosthetic loading.

Table 8 & Figure 8 present the intergroup comparison of marginal bone loss at the 6 and 12-month follow-up assessments. At 6 months, the mean marginal bone loss was 0.71 ± 0.24 mm in Group I and 0.48 ± 0.19 mm in Group II, with a statistically significant difference between the groups ($p < 0.001$). At 12 months, mean marginal bone loss increased to 0.93 ± 0.31 mm in Group I and 0.64 ± 0.25 mm in Group II, and the intergroup difference remained statistically significant ($p < 0.001$). Overall, Group II showed lower mean marginal bone loss at both follow-up time points.

Table 8: Marginal bone changes

Time point	Group I (mm)	Group II (mm)	Mean Difference	p-value
6 months	0.71 ± 0.24	0.48 ± 0.19	0.23	<0.001
12 months	0.93 ± 0.31	0.64 ± 0.25	0.29	<0.001

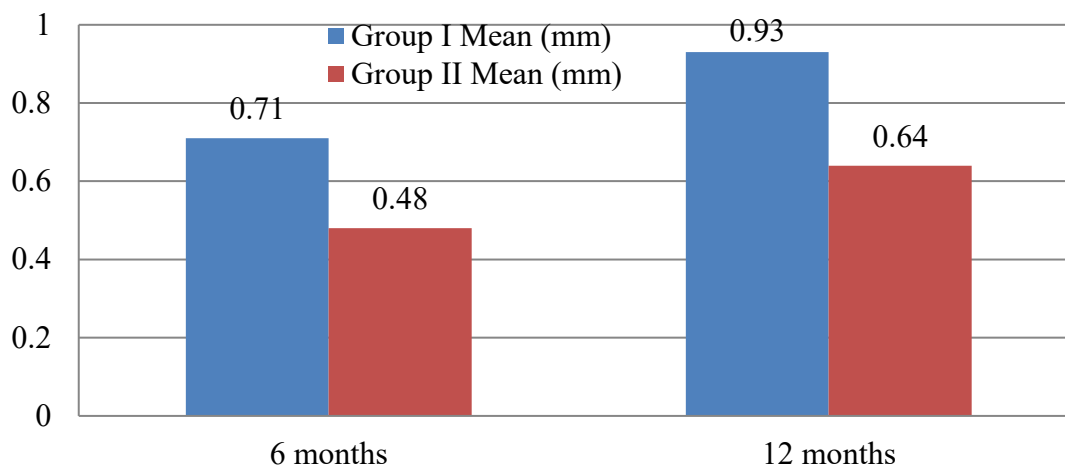


Figure 8: Intergroup comparison of mean marginal bone loss at 6 and 12 months of follow-up

Table 9 & Figure 9 present the patient-reported satisfaction scores assessed 12 months after prosthetic rehabilitation using a 0–10 rating scale. The mean overall satisfaction score was 7.8 ± 1.1 in Group I and 8.6 ± 0.9 in Group II, with a statistically significant difference between the groups ($p = 0.004$). Satisfaction with chewing comfort was also significantly higher in Group II (8.5 ± 0.9) than in Group I (7.6 ± 1.2 ; $p = 0.002$). Likewise, the mean esthetic satisfaction score was 8.6 ± 0.8 in Group II and 8.0 ± 1.0 in Group I, with a statistically significant intergroup difference ($p = 0.011$). Overall, the Group II participants reported higher satisfaction across the evaluated domains at the 12-month assessment.

Table 9: Patient satisfaction

Satisfaction outcome (0–10)	Group I	Group II	Mean Difference	p-value
Overall satisfaction	7.8 ± 1.1	8.6 ± 0.9	0.8	0.004
Chewing comfort	7.6 ± 1.2	8.5 ± 0.9	0.9	0.002
Esthetic satisfaction	8.0 ± 1.0	8.6 ± 0.8	0.6	0.011

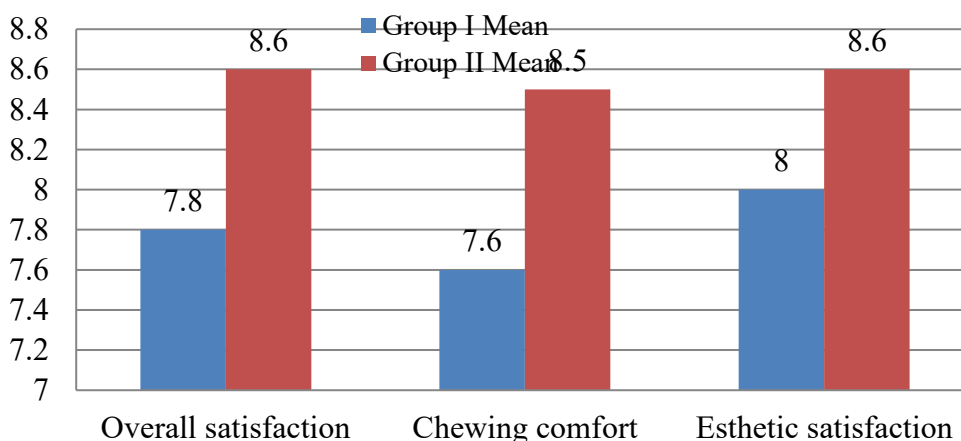


Figure 9: Intergroup comparison of patient-reported overall satisfaction, chewing comfort, and esthetic satisfaction at 12 months

Table 10 & Figure 10 present the intergroup comparison of implant survival and prosthetic success at the 12-month follow-up. Implant survival was 93.3% (28 of 30 implants) in Group I and 96.7% (29 of 30 implants) in Group II, with no statistically significant difference between the groups ($p = 0.554$). Similarly, prosthetic success was recorded in 26 patients (86.7%) in Group I and 28 patients (93.3%) in Group II. Although Group II demonstrated numerically higher rates of both implant survival and prosthetic success, the differences were not statistically significant ($p = 0.390$ for prosthetic success).

Table 10: Implant and prosthetic success

Outcome at 12 months	Group I n (%)	Group II n (%)	p-value
Implant survival	28 (93.3)	29 (96.7)	0.554
Prosthetic success	26 (86.7)	28 (93.3)	0.390

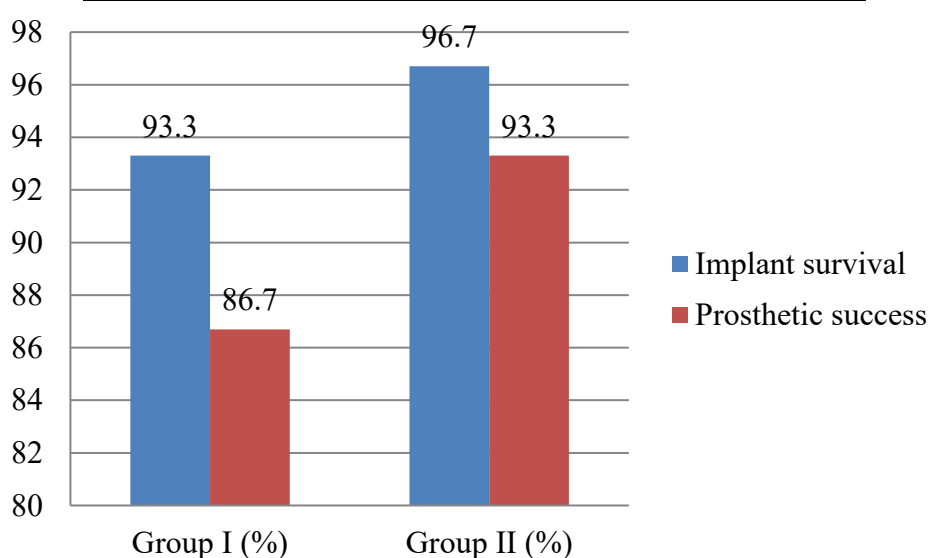


Figure 10: Intergroup comparison of implant survival and prosthetic success rates at the 12-month follow-up

DISCUSSION

The present findings can be interpreted in the context of established evidence on hard- and soft-tissue management, ridge preservation, and implant rehabilitation in anatomically compromised sites. Adequate peri-implant hard- and soft-tissue dimensions are fundamental for achieving favourable implant positioning, primary stability, long-term tissue health, and acceptable aesthetic outcomes. In the present study, surgical augmentation resulted in significantly greater horizontal and vertical ridge enhancement than conventional site management, accompanied by higher insertion torque and ISQ values. These findings support the clinical rationale for correcting deficient ridge anatomy before or during implant placement when the available tissue dimensions are inadequate for prosthetically appropriate implant positioning.

Aghaloo and Moy (2007) [10] reviewed different hard-tissue augmentation procedures used to provide adequate bone support for implant placement and highlighted that the predictability of augmentation techniques varies according to the clinical situation. Their review emphasized that the selection of an augmentation procedure should be based on the dimensions and location of the osseous defect rather than the universal application of a single technique. This concept is consistent with the present findings, in which surgical augmentation produced significantly greater ridge width, horizontal ridge gain, and vertical ridge gain at implant placement. The greater ridge dimensions achieved in Group II may have provided a more favourable 3D foundation for implant positioning and contributed to the higher primary stability observed in this group.

The improvement in ridge dimensions in Group II was accompanied by significantly higher insertion torque and ISQ values at implant placement. Insertion torque was 38.7 ± 6.1 Ncm in Group II compared with 31.4 ± 5.8 Ncm in Group I, while the corresponding ISQ values were 72.8 ± 4.7 and 67.3 ± 5.2 , respectively. The higher stability measurements remained evident

at 3 months, with ISQ values of 76.9 ± 4.2 in Group II and 73.6 ± 4.8 in Group I. These findings indicate that restoration of deficient ridge anatomy may facilitate improved mechanical conditions for implant placement. Nevertheless, implant stability is influenced by several factors, including bone quality, implant design, preparation of the osteotomy, implant dimensions, and surgical technique; therefore, the observed difference should not be attributed exclusively to ridge augmentation.

Soft-tissue conditions represent another important component of peri-implant site development. Ali and Kay (2020) [11] discussed the evidence supporting different approaches for increasing soft-tissue dimensions around dental implants and indicated that connective tissue-based procedures have an established role in improving peri-implant soft-tissue conditions, particularly when increased tissue thickness or enhancement of the peri-implant mucosal environment is required. In the present study, Group II demonstrated a significantly greater width of keratinized mucosa at 6 months, together with lower probing depth, plaque index, and bleeding on probing. These findings suggest that improved site development may have been associated with more favourable peri-implant tissue conditions during early functional follow-up. However, the contribution of patient-level oral hygiene and other biological factors should also be considered when interpreting these differences.

The management of anatomically compromised implant sites may also influence the duration of treatment. In the present study, the mean interval between site management and implant placement was significantly shorter in Group II than in Group I, whereas the interval between implant placement and prosthetic loading did not differ significantly between the groups. The shorter healing interval observed in Group II may reflect the clinical protocol used for augmented sites and the feasibility of implant placement once adequate ridge dimensions had been achieved. However, healing duration is dependent on defect morphology, augmentation technique, graft characteristics, implant stability, and individual healing response, and therefore should be interpreted in relation to the specific treatment protocol.

The management of the posterior atrophic maxilla is particularly challenging because reduced residual bone height and anatomical limitations may complicate conventional implant placement. Testori et al. (2024) [12], through a multidisciplinary modified Delphi consensus, emphasized that treatment planning in posterior maxillary atrophy should incorporate comprehensive assessment of residual anatomy, prosthetic requirements, patient-related factors, and available augmentation strategies. Their recommendations reinforce the importance of individualized treatment planning and multidisciplinary decision-making when conventional implant placement is limited by inadequate bone volume. Although the present study included deficient implant sites rather than focusing exclusively on posterior maxillary atrophy, the principle of tailoring site-development procedures to the anatomical defect is directly applicable.

Zafar et al. (2024) [13] systematically evaluated soft-tissue augmentation procedures aimed at increasing keratinized tissue around dental implants. Their findings support the clinical relevance of soft-tissue augmentation in situations where the quantity or quality of peri-implant keratinized tissue is inadequate. The evidence also indicates that different grafting approaches can produce varying degrees of improvement in tissue dimensions. In the present study, the greater keratinized mucosa width observed in Group II, together with the more favourable peri-implant clinical parameters, highlights the importance of considering the soft-tissue environment during implant-site development. Nevertheless, the present findings should not be interpreted as demonstrating that surgical augmentation alone was responsible for all observed soft-tissue improvements.

Marginal bone loss was also significantly lower in Group II at both 6 and 12 months. At 12 months, mean marginal bone loss was 0.64 ± 0.25 mm in Group II compared with 0.93 ± 0.31 mm in Group I. The lower radiographic bone changes in the augmented group may be related to improved peri-implant hard-tissue support and more favourable implant-site anatomy. In addition, the lower probing depth and bleeding on probing observed in Group II may indicate a more favourable peri-implant clinical environment. However, marginal bone stability is multifactorial and may also be influenced by implant positioning, prosthetic design, loading conditions, oral hygiene, and individual biological response.

More extensive vertical deficiencies may require techniques capable of producing substantial increases in available bone height. Manickavasagaswami et al. (2026) [14] compared the concepts of vertical alveolar distraction and autogenous bone ridge augmentation in the context of implant rehabilitation. Their review highlighted that both approaches can be used for the management of deficient alveolar ridges, although they differ in biological principles, technical requirements, treatment complexity, and clinical indications. These considerations support the principle that the severity and morphology of the defect should guide the choice of augmentation strategy. The significant vertical ridge gain observed in Group II in the present study

further emphasizes the potential value of surgical site development when vertical deficiency may compromise the intended implant position.

Alveolar ridge preservation also plays an important role in minimizing post-extraction dimensional changes. Yu et al. (2022) [15] systematically evaluated alveolar ridge preservation in comparison with immediate implant placement and demonstrated that the two approaches represent different strategies for managing the post-extraction socket. Their findings emphasize the importance of considering post-extraction remodeling when planning implant therapy. Preservation procedures may be particularly relevant when immediate implant placement is not feasible or when maintenance of ridge dimensions is an important treatment objective. In the context of the present study, these findings reinforce the broader principle that management of ridge dimensions should begin with recognition of the underlying anatomical deficiency and the anticipated restorative requirements.

The improved anatomical and clinical parameters observed in Group II were also reflected in patient-reported outcomes. At 12 months, overall satisfaction, chewing comfort, and aesthetic satisfaction were significantly higher in the surgical augmentation group. The higher satisfaction scores may be associated with the improved ridge dimensions, implant stability, peri-implant tissue conditions, and restorative outcomes observed in this group. In particular, improved ridge contour and soft-tissue architecture may facilitate more favourable prosthetic emergence and aesthetic integration. Nevertheless, patient satisfaction is subjective and can be influenced by expectations, previous treatment experience, functional demands, and individual perceptions.

Prosthetic complications were less frequent in Group II than in Group I, although the intergroup difference was not statistically significant. Similarly, implant survival and prosthetic success were numerically higher in Group II at 12 months, but neither difference reached statistical significance. Implant survival was 96.7% in Group II compared with 93.3% in Group I, while prosthetic success was 93.3% and 86.7%, respectively. These findings suggest that the improved anatomical and intermediate clinical outcomes associated with surgical augmentation did not translate into a statistically demonstrable difference in short-term implant survival or prosthetic success. The absence of statistical significance may also be related to the relatively small sample size and the limited 12-month observation period.

Collectively, evidence from various studies demonstrates that successful implant-site management requires a comprehensive approach involving both hard- and soft-tissue considerations. The findings of the present study indicate that surgical augmentation was associated with greater ridge enhancement, improved early implant stability, more favourable peri-implant clinical parameters, lower marginal bone loss, and higher patient satisfaction than conventional site management. However, the lack of a statistically significant difference in implant survival and prosthetic success indicates that these outcomes should be interpreted cautiously. The choice between ridge preservation, bone augmentation, soft-tissue augmentation, distraction procedures, or combinations of these approaches should be determined by the specific anatomical deficiency, biological considerations, and prosthetically driven implant position. Thus, contemporary implant rehabilitation should emphasize individualized 3D site development while considering both biological and restorative requirements.

LIMITATIONS

The present study had certain limitations that should be considered when interpreting the findings. The relatively small sample size of 60 patients, with 30 participants in each group, may limit the generalizability of the results to broader patient populations. The 12-month follow-up period was adequate for assessing early clinical, radiographic, and prosthetic outcomes but may not have captured long-term changes in marginal bone levels, implant stability, or prosthetic complications. Furthermore, the assessment was restricted to the specific site management approaches evaluated, and the findings may not be directly applicable to all types of deficient alveolar ridges or augmentation techniques. Variations in individual healing responses, bone quality, and anatomical characteristics may also have influenced the observed outcomes. In addition, patient-reported satisfaction was assessed using rating scales, which may be subject to individual perceptions and reporting variability. The study findings should therefore be interpreted within the context of the sample size, follow-up duration, and clinical parameters investigated.

CONCLUSION

Surgical augmentation demonstrated greater ridge augmentation, improved primary implant stability, more favourable peri-implant outcomes, lower marginal bone loss, fewer prosthetic complications, and higher patient satisfaction than conventional site management. Although implant survival and prosthetic success did not differ significantly between groups, surgical augmentation may offer clinically beneficial outcomes in deficient implant sites. Larger studies with longer follow-up are needed to confirm the long-term stability of these findings.

Conflicts of Interest: Nil

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