Horizontal Versus Vertical Ridge Augmentation For Implant Therapy: A Comparative Study

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HOW TO CITE:

Pratik Bhatnagar, Saranya Kodeboina, Sandhya Shroff, Sareen. Seelam, Shivendra Pal Singh, Madhuri Chinta (2026). Horizontal Versus Vertical Ridge Augmentation Therapy: A Comparative Study. International Journal of Special Education, 41(8s), 450-459

ABSTRACT:

Background:

Alveolar ridge deficiencies frequently compromise ideal dental implant placement and often necessitate ridge augmentation procedures. Horizontal and vertical ridge augmentation techniques are commonly employed to reconstruct deficient alveolar bone; however, their clinical predictability, complication rates, and implant-related outcomes differ.

Aim:

The present retrospective comparative study aimed to evaluate and compare the clinical and radiographic outcomes of horizontal and vertical alveolar ridge augmentation procedures performed prior to dental implant placement, with particular emphasis on bone gain, implant survival and success rates, complication rates, and healing duration.

Materials and Methods:

A retrospective analysis was conducted on patients who underwent alveolar ridge augmentation followed by implant placement between October 2009 and June 2025. Patients were categorized into two groups: Group I (horizontal ridge augmentation) and Group II (vertical ridge augmentation). Clinical records and radiographic data, including cone-beam computed tomography (CBCT) where available, were reviewed. Primary outcomes included horizontal and vertical bone gain (mm), while secondary outcomes comprised implant survival rate, implant success rate, postoperative complications, and healing duration. Statistical analysis was performed using SPSS version 25.0. Intergroup comparisons were carried out using the Independent Student's t-test for continuous variables, with statistical significance set at $p < 0.05$.

Results:

Vertical ridge augmentation demonstrated significantly greater mean bone gain (5.8 ± 1.4 mm) compared with horizontal ridge

augmentation (4.2 ± 1.1 mm) (p = 0.010). However, horizontal ridge augmentation showed significantly higher implant survival rates (97.8 ± 1.8%) than vertical ridge augmentation (95.2 ± 2.9%) (p = 0.029), as well as superior implant success rates (95.6 ± 2.4% vs. 92.1 ± 3.7%; p = 0.021). The complication rate was significantly higher in the vertical ridge augmentation group (24.8 ± 8.6%) compared with the horizontal ridge augmentation group (11.4 ± 5.2%) (p < 0.001). Additionally, the healing duration was significantly longer following vertical ridge augmentation (8.3 ± 1.8 months) than horizontal ridge augmentation (5.4 ± 1.2 months) (p < 0.001).

Conclusion:

Vertical ridge augmentation procedures are effective in achieving greater bone gain and are particularly indicated for severe vertical deficiencies; however, they are associated with higher complication rates, longer healing periods, and comparatively lower implant survival and success rates. Horizontal ridge augmentation offers greater predictability, fewer complications, shorter healing duration, and more favorable implant-related outcomes. Appropriate case selection and individualized treatment planning are essential for optimizing clinical success in ridge augmentation prior to implant placement..

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Keywords: Bone regeneration, Guided bone regeneration, Implant dentistry, Ridge augmentation, Survival Rate.

Introduction

Adequate alveolar bone volume is a fundamental requirement for successful dental implant placement. However, following tooth extraction, the alveolar ridge undergoes physiological remodeling that often results in considerable bone loss. This reduction in ridge dimensions may limit the available bone necessary for ideal implant positioning, thereby affecting both functional outcomes and esthetic rehabilitation [1–3]. To overcome these deficiencies, various ridge augmentation procedures have been introduced to restore lost bone and create favorable conditions for implant-supported restorations [4, 5].

Alveolar ridge deficiencies are commonly classified as either horizontal or vertical defects. Horizontal defects involve a reduction in ridge width, whereas vertical defects are characterized by loss of ridge height. Each defect type presents distinct anatomical and biological challenges that require different surgical approaches for successful reconstruction [6].Over the years, several augmentation techniques have been developed, including guided bone regeneration (GBR), autogenous block grafting, ridge expansion procedures, distraction osteogenesis, and the application of allogenic, xenogenic, and synthetic bone substitutes [4,5,6].

Among these treatment options, horizontal ridge augmentation is generally considered more predictable and clinically manageable. Favorable blood supply, improved graft stabilization, and reduced surgical complexity often contribute to consistent increase in ridge width and high treatment success rates [7, 8]. In contrast, vertical ridge augmentation remains a technically demanding procedure. Achieving stable vertical bone gain is complicated by factors such as restricted vascularity, increased soft tissue tension, risk of wound dehiscence, and graft exposure [9, 10]. As a result, greater variability in clinical outcomes and higher complication rates has been reported for vertical augmentation procedures [11].

The increasing use of implant-supported prostheses has highlighted the importance of identifying the most effective methods for alveolar ridge reconstruction. Although

numerous investigations have evaluated horizontal and vertical augmentation techniques separately, studies directly comparing their clinical performance remain relatively scarce. Differences in research methodology, grafting materials, surgical protocols, and outcome assessment methods have further contributed to variations in the published evidence [12].

A systematic comparison of horizontal and vertical ridge augmentation procedures is therefore important for understanding their relative effectiveness and predictability. Evaluating parameters such as the amount of bone gain achieved, implant survival, postoperative complications, and overall treatment success can provide clinicians with valuable guidance when selecting an appropriate treatment strategy. Such information is essential for optimizing patient outcomes and ensuring evidence-based clinical decision-making.

The objective of the present study is to perform a statistical comparison of horizontal and vertical ridge augmentation therapies by analyzing clinical and radiographic outcomes. Through the assessment of treatment efficacy, complication incidence, and implant-related success measures, this investigation aims to provide a clearer understanding of the strengths and limitations of each approach in contemporary implant reconstructive dentistry.

Materials and Methods

Study Design

This study was designed as a retrospective comparative analysis to evaluate and compare the clinical outcomes of horizontal and vertical alveolar ridge augmentation procedures performed prior to dental implant placement. The study assessed treatment efficacy, complication rates, and implant-related outcomes associated with both augmentation modalities.

Study Population

Patients who underwent alveolar ridge augmentation followed by implant placement at the Department of Prosthodontics and Crown & Bridge, the Department of Oral and Maxillofacial Surgery, and the Department of Periodontology between October 2009 and June 2025 were included in the study. Clinical records and radiographic data were reviewed after obtaining approval from the Institutional Ethics Committee.

Inclusion and Exclusion Criteria

Patients included in this study were those aged 18 years or older presenting with horizontal or vertical alveolar ridge deficiencies requiring augmentation prior to implant placement. Only patients who had undergone documented ridge augmentation procedures with a minimum follow-up period of 12 months after implant placement were considered eligible. In addition, inclusion required the availability of complete clinical records along with preoperative and postoperative radiographic investigations, including cone-beam computed tomography (CBCT) scans where applicable.

Patients were excluded from the study if they had uncontrolled systemic diseases known to affect bone healing, were heavy smokers consuming more than 10 cigarettes per day, or had a history of radiotherapy in the head and neck region. Individuals with untreated periodontal disease were also excluded. Furthermore, cases with incomplete clinical documentation or missing radiographic records were not considered for analysis.

Group Allocation

The study population was divided into two groups:

Group I – Horizontal Ridge Augmentation

Patients undergoing augmentation procedures aimed primarily at increasing alveolar ridge width.

Group II – Vertical Ridge Augmentation

Patients undergoing augmentation procedures aimed primarily at increasing alveolar ridge height.

Surgical Procedures

Horizontal ridge augmentation procedures included guided bone regeneration (GBR), ridge splitting, particulate grafting, and autogenous block grafting. Vertical ridge augmentation procedures included GBR, onlay block grafting, and distraction osteogenesis when indicated.

All procedures were performed under local anesthesia by experienced clinicians following standard surgical protocols. Bone graft materials included autogenous, allogenic, xenogenic, or synthetic grafts according to clinical requirements. Barrier membranes were utilized whenever indicated.

Data Collection

The following variables were recorded in this study. Demographic data included patient age and gender. Clinical variables comprised the type of defect (horizontal or vertical), the augmentation technique employed, the type of graft material used, and the healing duration prior to implant placement. Outcome measures were categorized into primary and secondary parameters. The primary outcomes included horizontal bone gain (mm) and vertical bone gain (mm). The secondary outcomes assessed implant survival rate, implant success rate, and postoperative complications such as wound dehiscence, membrane exposure, graft infection, partial graft loss, and total graft failure. Radiographic evaluation was performed to assess preoperative and postoperative bone dimensions and to support clinical outcome measurements.

Preoperative and postoperative CBCT scans or standardized radiographs were evaluated. Bone dimensions were measured using calibrated digital software. Measurements were recorded at baseline and immediately before implant placement.

Follow-Up Assessment

Patients were followed clinically and radiographically for a minimum period of 12 months after implant loading. Implant survival and biological complications were documented during the follow-up period.

Statistical Analysis

Data collected from the selected studies were compiled and analyzed using Statistical Package for the Social Sciences (SPSS) software version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables, including mean bone gain, implant survival rate, implant success rate, complication rate, and healing duration, and were expressed as mean ± standard deviation (SD) and standard error (SE). The normality of data distribution was assessed using the Shapiro–Wilk test.

Intergroup comparisons between horizontal ridge augmentation and vertical ridge augmentation were performed using the Independent Student's t-test for normally distributed continuous variables. The calculated t-values, mean differences, and corresponding p-values were recorded. Categorical variables, where applicable, were presented as frequencies and percentages and compared using the Chi-square test

For all statistical analyses, a two-tailed p-value < 0.05 was considered statistically significant.

Results

Table 1 & Figure 1 present the comparison of mean bone gain achieved following horizontal and vertical ridge augmentation procedures. The mean bone gain observed in the horizontal ridge augmentation group was 4.2 ± 1.1 mm (SE = 0.35), whereas the vertical ridge augmentation group demonstrated a significantly greater mean bone gain of 5.8 ± 1.4 mm (SE = 0.44). Intergroup comparison using the Independent Student's t-test revealed a statistically significant difference between the two groups ($t = 2.86$, $p = 0.010$). These findings indicate that vertical ridge augmentation procedures are capable of achieving significantly greater bone augmentation compared to horizontal ridge augmentation procedures, making them particularly useful in cases with severe vertical

bone deficiencies requiring substantial reconstruction of alveolar ridge height.

Table 1: Comparison of Mean Bone Gain Between Horizontal and Vertical Ridge Augmentation

Group	Mean (mm)	SD	SE	t-value	p-value
Horizontal Ridge Augmentation	4.2	1.1	0.35	2.86	0.010
Vertical Ridge Augmentation	5.8	1.4	0.44		

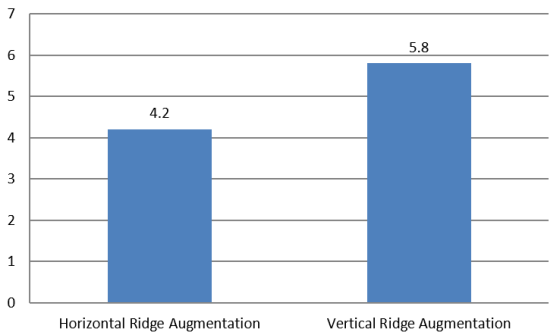

Figure 1: Graphical comparison of the mean bone gain achieved following horizontal and vertical alveolar ridge augmentation procedures

Table 2 & Figure 2 present the comparison of implant survival rates between horizontal and vertical ridge augmentation procedures. The horizontal ridge augmentation group demonstrated a mean implant survival rate of 97.8 ± 1.8% (SE = 0.57), while the vertical ridge augmentation group exhibited a mean implant survival rate of 95.2 ± 2.9% (SE = 0.92). Intergroup comparison using the Independent Student's t-test revealed a statistically significant difference between the two groups (t = 2.38, p = 0.029). The findings indicate that implants placed in horizontally augmented ridges exhibited a significantly higher survival rate compared to those placed in vertically augmented ridges. Although both augmentation approaches achieved high implant survival rates exceeding 95%, the superior survival observed in the horizontal augmentation group suggests greater predictability and long-term stability of implant-supported restorations in sites reconstructed primarily for ridge width enhancement.

Table 2: Comparison of Implant Survival Rate Between Horizontal and Vertical Ridge Augmentation

Group	Mean (mm)	SD	SE	t-value	p-value
Horizontal Ridge Augmentation	97.8	1.8	0.57	2.38	0.029
Vertical Ridge Augmentation	95.2	2.9	0.92		

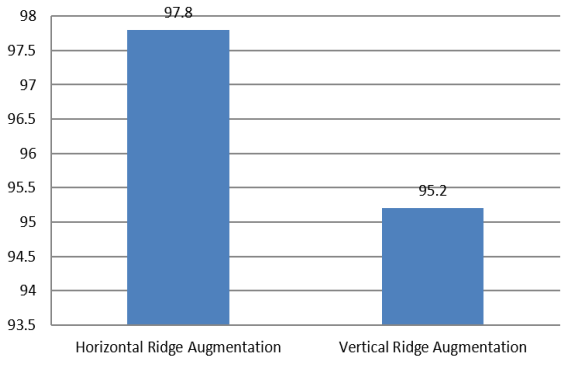

Figure 2: Implant Survival Outcomes After Horizontal Versus Vertical Ridge Augmentation

Table 3 & Figure 3 present the comparison of implant success rates between horizontal and vertical ridge augmentation procedures. The mean implant success rate in the horizontal ridge augmentation group was 95.6 ± 2.4% (SE = 0.76), whereas the vertical ridge augmentation group demonstrated a mean implant success rate of 92.1 ± 3.7% (SE = 1.17). Intergroup comparison using the Independent Student's t-test revealed a statistically significant difference between the two groups (t = 2.52, p = 0.021). The results indicate that implants placed in horizontally augmented ridges achieved a significantly higher success rate than those placed in vertically augmented ridges. Although both treatment modalities demonstrated favorable clinical outcomes with success rates

exceeding 90%, horizontal ridge augmentation exhibited superior predictability and treatment success.

Table 3: Comparison of Implant Success Rate Between Horizontal and Vertical Ridge Augmentation

Group	Mean (mm)	SD	SE	t-value	p-value
Horizontal Ridge Augmentation	95.6	2.4	0.76	2.52	0.021
Vertical Ridge Augmentation	92.1	3.7	1.17		

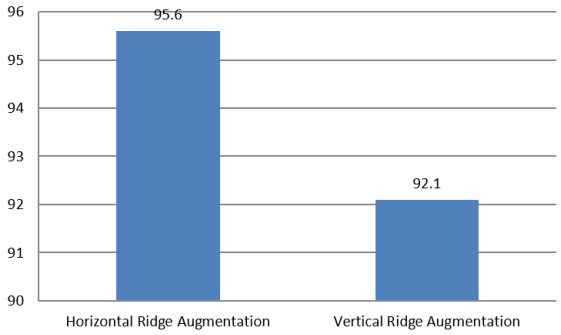

Figure 3: Implant Success Outcomes After Horizontal Versus Vertical Alveolar Ridge Augmentation

Table 4 & Figure 4 present the comparison of complication rates between horizontal and vertical ridge augmentation procedures.

The mean complication rate observed in the horizontal ridge augmentation group was 11.4 ± 5.2% (SE = 1.64), whereas the vertical ridge augmentation group demonstrated a significantly higher complication rate of 24.8 ± 8.6% (SE = 2.72). Intergroup comparison using the Independent Student's t-test revealed a highly statistically significant difference between the two groups ($t = 4.22$, $p < 0.001$). The findings indicate that vertical ridge augmentation procedures were associated with a significantly greater incidence of postoperative complications compared to horizontal ridge augmentation procedures.

Table 4: Comparison of Complication Rate Between Horizontal and Vertical Ridge Augmentation

Group	Mean (mm)	SD	SE	t-value	p-value
Horizontal Ridge Augmentation	11.4	5.2	1.64	4.22	<0.001
Vertical Ridge Augmentation	24.8	8.6	2.72		

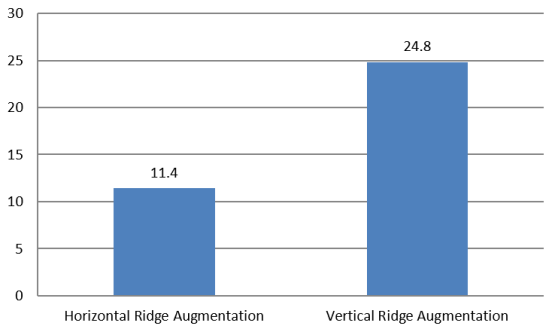

Figure 4: Comparative Analysis of Postoperative Complication Rates Following Horizontal and Vertical Ridge Augmentation

Table 5 presents the comparison of healing duration between horizontal and vertical ridge augmentation procedures. The mean healing duration in the horizontal ridge augmentation group was 5.4 ± 1.2 months (SE = 0.38), whereas the vertical ridge augmentation group demonstrated a significantly longer healing duration of 8.3 ± 1.8 months (SE = 0.57). Intergroup comparison using the Independent Student's t-test revealed a highly statistically significant difference between the two groups ($t = 4.25$, $p < 0.001$).

The results indicate that patients undergoing horizontal ridge augmentation required a significantly shorter healing period prior to implant placement compared with those undergoing vertical ridge augmentation.

Table 5: Comparison of Healing Duration Between Horizontal and Vertical Ridge Augmentation

Group	Mean (mm)	SD	SE	t-value	p-value
Horizontal Ridge Augmentation	5.4	1.2	0.38	4.25	<0.001
Vertical Ridge Augmentation	8.3	1.8	0.57		

Discussion

The present study evaluated and compared the clinical and radiographic outcomes of horizontal and vertical alveolar ridge augmentation procedures performed prior to implant placement. The results demonstrated clear differences between the two approaches in terms of predictability, complication rates, and overall treatment outcomes.

Horizontal ridge augmentation showed more favorable and consistent outcomes, with higher predictability and comparatively fewer postoperative complications. This may be attributed to more favorable anatomical and biological conditions, including better vascularization, improved graft stability, and reduced soft tissue tension. These factors support more efficient bone regeneration and long-term stability of the augmented ridge. Similar findings have been reported by Chiapasco M and colleagues, who emphasized that horizontal ridge augmentation technique generally, achieve reliable ridge width gain with a relatively low complication profile when appropriate surgical protocols are followed [4].

In contrast, vertical ridge augmentation demonstrated greater variability in outcomes and a higher incidence of complications such as graft exposure and soft tissue dehiscence. The difficulty in maintaining space, combined with limited blood supply and higher soft tissue tension, makes vertical bone regeneration biologically challenging. These observations are in agreement with the systematic review by Urban IA et al. (2019), which reported that vertical ridge augmentation remains one of the most technique-sensitive procedures in implant dentistry, with higher complication rates compared to horizontal augmentation [9].

Further support for these findings is provided by Aghaloo TL [5] and Moy PK [13], who highlighted that while various grafting and regenerative techniques can be used successfully, vertical augmentation procedures are associated with less predictable outcomes and require strict case selection and surgical expertise. Likewise, Jensen SS [6] and Sanz-Sánchez I [14] noted that bone augmentation in vertical defects often presents greater biological limitations compared to horizontal ridge reconstruction.

In the present study, implant survival and success rates were high in both groups, although slightly better outcomes were observed in horizontally augmented sites. This may be due to improved bone quality and stability in horizontally reconstructed ridges, which provide a more favorable environment for osseointegration. These findings are consistent with reports by Milinkovic I [11] and Cordaro L [15], who noted that while both horizontal and vertical augmentation can support successful implant placement, horizontal procedures generally demonstrate more predictable long-term outcomes.

Overall, the results reinforce the importance of defect morphology as a key factor in treatment planning. As emphasized by Yu SH [7] and, selection of the appropriate augmentation technique should be based on anatomical conditions, surgical feasibility, and patient-related factors. A careful and individualized approach is essential to optimize clinical outcomes and minimize complications in implant site development. In conclusion, horizontal ridge augmentation appears to be more predictable and biologically favorable compared to vertical augmentation, which remains a challenging and technique-sensitive

procedure despite advances in regenerative materials and surgical techniques.

The findings of the present study are further substantiated by evidence from several key systematic reviews and clinical investigations focusing on both horizontal and vertical ridge augmentation techniques. In particular, the systematic review and meta-analysis by Sanz-Sánchez I et al. (2015) [16] demonstrated that horizontal bone augmentation procedures are highly effective in increasing alveolar crest width, with clinically significant and stable dimensional gains over time.

Their analysis highlighted predictable outcomes and acceptable complication rates when GBR principles are properly followed, which closely aligns with the superior predictability and consistency of horizontal augmentation observed in the present study. Similarly, Benic GI and Hämmerle CHF (2014) [17] emphasized that horizontal bone augmentation using GBR is a well-documented and biologically sound approach for implant site development. They reported that favorable vascular supply, improved wound stability, and effective membrane adaptation contribute to reliable ridge width enhancement and high implant survival rates. These biological advantages support the present study's observation that horizontally augmented sites provide a more stable and conducive environment for long-term implant success.

In contrast, the prospective case series by Urban IA et al. (2014) [18] on vertical ridge augmentation using titanium-reinforced d-PTFE membranes underscored the technical complexity of vertical bone regeneration. Although clinically relevant vertical bone gains were achieved, the authors reported a higher incidence of postoperative complications, including membrane exposure and soft tissue dehiscence. These findings corroborate the present study's results, which showed greater variability and increased complication rates in vertically augmented sites compared to horizontal augmentation.

Further reinforcing these observations, Urban IA et al. (2017) [19] outlined key principles for vertical ridge augmentation in the atrophic posterior mandible and described vertical augmentation as one of the most biologically demanding and technique-sensitive procedures in implant dentistry. The authors stressed the importance of meticulous surgical execution, rigid space maintenance, and stringent patient selection to achieve successful outcomes. Despite advancements in biomaterials and surgical protocols, they acknowledged that vertical augmentation remains less predictable than horizontal approaches, which is consistent with the conclusions of the present study. Collectively, these studies strengthen the evidence that horizontal ridge augmentation offers more predictable, biologically favorable, and clinically reliable outcomes, whereas vertical ridge augmentation, although feasible, is associated with increased technical demands and a higher risk of complications. Integrating these insights with the present findings further emphasizes the need for careful assessment of defect morphology and individualized treatment planning to optimize implant site development and long-term clinical success.

Limitations

This study has certain limitations that should be acknowledged. First, its retrospective design may introduce selection bias and limit control over confounding variables. Second, variations in surgical techniques, operator experience, and graft materials may have influenced the outcomes. Third, the sample size may not be large enough to generalize the findings to a broader population. Additionally, the follow-up period, although adequate for initial assessment, may not fully reflect long-term implant and graft stability. Finally, reliance on existing clinical records and radiographic data may have resulted in incomplete or inconsistent documentation in some cases.

Conclusion

Within the limitations of this study, it can be concluded that horizontal ridge augmentation procedures demonstrate more predictable outcomes and fewer complications compared to vertical ridge augmentation. Vertical augmentation, although clinically effective in selected cases, remains a more complex and technique-sensitive procedure with higher variability in results. Careful case selection, appropriate surgical planning, and adherence to established protocols are essential for achieving optimal outcomes in both treatment modalities. Further long-term prospective studies with larger sample sizes are recommended to validate these findings and enhance evidence-based decision-making in implant site development.

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