

Comparison of Titanium-Reinforced PTFE Membrane-Assisted Guided Bone Regeneration and Autogenous Ramus Block Grafting for Alveolar Ridge Augmentation: A Retrospective Study

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Abstract

Objectives

Guided bone regeneration (GBR) and autogenous block grafting are widely used for alveolar ridge augmentation; however, direct comparisons of their clinical and radiographic outcomes remain limited. This study compared PTFE membrane-assisted GBR and autogenous mandibular ramus block grafting for alveolar ridge reconstruction.

Methods

This retrospective cohort study included 60 patients treated with PTFE membrane-assisted GBR ($n = 30$) or ramus block grafting ($n = 30$). Horizontal and vertical bone gain was assessed using preoperative and approximately 6-month postoperative cone-beam computed tomography. Postoperative complications and implant-related outcomes were also evaluated. Logistic regression analyses were performed to identify factors associated with early and late complications.

Results

Horizontal bone gain was comparable between the PTFE and ramus groups (2.83 ± 1.19 mm vs. 2.86 ± 1.00 mm). In defects with a vertical component, vertical bone gain was significantly greater in the PTFE group (median, 3.3 vs. 2.0 mm). Treatment modality was not independently associated with early or late complications. Posterior localization was associated with early complications (OR = 10.059; $p = 0.012$), whereas smoking was associated with late complications (OR = 4.180; $p = 0.028$). Implant-related outcomes were comparable between the groups.

Conclusions

Both techniques provided effective alveolar ridge reconstruction with comparable horizontal bone gain, whereas PTFE-assisted GBR achieved greater vertical gain in vertically deficient sites. Treatment selection should consider defect morphology, reconstructive requirements, donor-site morbidity, and patient-related risk factors.

Introduction

Dental implant therapy has become an established treatment modality for restoring function and esthetics in partially and completely edentulous patients. Successful implant-supported rehabilitation, however, depends not only on osseointegration but also on the availability of an adequate three-dimensional volume of alveolar bone that permits implant placement in a prosthetically favorable position. Following tooth extraction, the alveolar process undergoes physiologic remodeling that results in progressive dimensional reduction of the residual ridge. These changes are most pronounced during the early healing period and generally affect ridge width to a greater extent than ridge height (1, 2). When

the residual bone volume is insufficient to accommodate implants in the desired position, reconstruction of the alveolar ridge may therefore be required before implant placement.

Several surgical approaches have been proposed for the reconstruction of horizontally and vertically deficient alveolar ridges, including guided bone regeneration (GBR), autogenous block grafting, ridge-splitting procedures, distraction osteogenesis, and combinations of particulate grafting techniques (3, 4). Among these approaches, GBR and intraoral autogenous block grafting are well-established treatment modalities for staged reconstruction of deficient implant sites. Selection of the augmentation technique is influenced by the morphology and extent of the defect, the amount and direction of bone gain required, the ability to maintain graft stability during healing, local soft-tissue conditions, and treatment-related morbidity (3–5).

GBR is based on the creation and maintenance of a protected regenerative compartment using a barrier membrane that limits soft-tissue ingrowth and provides an environment favorable for bone formation. Non-resorbable polytetrafluoroethylene (PTFE) membranes, particularly when reinforced with titanium, provide prolonged barrier function together with mechanical stability and space maintenance, which are important in the reconstruction of advanced horizontal and vertical ridge deficiencies (3, 6). When appropriately stabilized and combined with particulate grafting materials, PTFE membrane-assisted GBR can maintain the planned contour of the augmented site during healing. Nevertheless, the technique requires careful soft-tissue management, and membrane exposure or wound dehiscence remains a clinically relevant complication that may compromise the regenerative outcome (6, 7).

Autogenous block bone grafting represents another established approach for augmentation of deficient alveolar ridges. Intraoral donor sites allow harvesting of autogenous bone within the oral cavity, and the mandibular ramus provides predominantly cortical bone that can be adapted and rigidly fixed to the recipient site to restore deficient ridge contours (5, 8, 9). The structural stability of a fixed block graft facilitates maintenance of the reconstructed ridge during healing and has resulted in predictable bone augmentation before implant placement (5, 9, 10). However, the requirement for a separate donor site represents an inherent limitation of the technique and may be associated with postoperative morbidity, including discomfort and neurosensory disturbances (5, 11).

Both membrane-assisted GBR and autogenous block grafting have been successfully used for alveolar ridge reconstruction, and previous clinical investigations have demonstrated that both approaches can provide sufficient dimensional augmentation for subsequent implant placement (10, 12–14). Comparative studies have evaluated GBR-based procedures and autogenous block grafting using different grafting materials, membrane types, defect configurations, and measurement protocols; however, the available evidence remains heterogeneous, and direct comparisons between non-resorbable PTFE membrane-assisted GBR and autogenous mandibular ramus block grafting are limited (12–15). In particular, comparative clinical data simultaneously addressing horizontal and vertical dimensional changes together with treatment-related complications and subsequent implant rehabilitation remain scarce.

Therefore, the aim of this retrospective cohort study was to compare PTFE membrane-assisted guided bone regeneration and autogenous mandibular ramus block grafting for alveolar ridge augmentation by evaluating horizontal and vertical bone gain and associated clinical outcomes.

Materials and Methods

Study design and ethical approval

This retrospective cohort study was conducted at the Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Hatay Mustafa Kemal University, Türkiye. Clinical and radiographic records of patients who underwent alveolar ridge augmentation using either polytetrafluoroethylene (PTFE) membrane-assisted guided bone regeneration (GBR) or autogenous mandibular ramus block grafting between February 2024 and May 2026 were retrospectively reviewed.

Ethical approval

for the study was obtained from the Hatay Mustafa Kemal University Non-Interventional Clinical Research Ethics Committee (meeting no. 09, decision no. 69; July 1, 2026). Written informed consent for participation in the study and the use of clinical and radiographic data for research purposes was obtained from all included patients. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Study population and eligibility criteria

Patients were eligible for inclusion if they were ≥ 18 years of age, had undergone alveolar ridge augmentation using either PTFE membrane-assisted GBR or an autogenous mandibular ramus block graft for subsequent implant rehabilitation, and had adequate preoperative and postoperative CBCT examinations and clinical records available for evaluation. Patients were excluded in the presence of a history of radiotherapy to the head and neck region, systemic conditions contraindicating elective oral surgical procedures, uncontrolled periodontal disease, or the use of medications known to substantially interfere with bone metabolism or healing. Patients with incomplete clinical records, missing or diagnostically inadequate preoperative or postoperative CBCT examinations, or augmentation procedures other than the two techniques investigated were also excluded.

Demographic and clinical variables

Demographic and clinical variables were retrospectively retrieved from the patients' records. The recorded variables included age, sex, smoking status, American Society of Anesthesiologists (ASA) physical status classification, anatomical location of the augmentation site by jaw (maxilla or mandible) and region (anterior or posterior), Seibert classification, and defect type.

Alveolar ridge defects were characterized according to their dimensional pattern and the Seibert classification. Defects presenting predominantly with loss of buccolingual ridge width were categorized as horizontal defects, whereas defects exhibiting both horizontal and vertical deficiencies were categorized as combined defects. According to the Seibert classification, Class I defects were defined as loss of ridge width with relatively preserved ridge height, while Class III defects were characterized by combined loss of ridge width and height. Horizontal dimensional changes were assessed in all included augmentation sites, whereas vertical dimensional changes were evaluated only in sites presenting a vertical defect component.

Surgical procedures

All augmentation procedures were performed at the Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Hatay Mustafa Kemal University. The surgical technique was selected according to the clinical and radiographic characteristics of the alveolar ridge defect and was categorized as either PTFE membrane-assisted GBR or autogenous mandibular ramus block grafting. The surgical procedures were identified retrospectively from the patients' operative records.

All augmentation procedures were performed under local anesthesia using standard aseptic conditions. Following incision and full-thickness mucoperiosteal flap elevation, the recipient alveolar ridge was exposed and residual soft tissue was carefully removed from the underlying bone surface. The augmentation procedure was then performed according to the selected surgical technique, as described below.

PTFE membrane-assisted guided bone regeneration technique

A titanium-reinforced PTFE membrane was trimmed and adapted according to the morphology and extent of the alveolar ridge defect and stabilized to the recipient site using fixation pins. The grafting material consisted of a 1:1 mixture of particulate allograft and xenograft, which was placed within the defect and contained beneath the stabilized membrane to reconstruct the deficient alveolar ridge. Following stabilization of the graft and membrane, leukocyte- and platelet-rich fibrin (L-PRF) membranes were placed over the augmented area. Periosteal releasing incisions were performed to provide adequate flap advancement and achieve tension-free primary closure of the surgical site (Fig. 1).

After an average healing period of approximately 6 months, the augmented site was surgically re-entered, and the PTFE membrane and fixation components were removed. Dental implants were subsequently placed in the regenerated alveolar ridge (Fig. 2).

Autogenous mandibular ramus block grafting technique

An autogenous cortical bone block of appropriate dimensions was harvested from the mandibular ramus using a piezosurgical device according to the size and morphology of the recipient-site defect

(Fig. 3).

The harvested bone block was shaped and adapted to the recipient alveolar ridge and rigidly stabilized using fixation screws. The remaining contours around the block graft were augmented with particulate allograft, and the grafted area was covered with a resorbable collagen membrane (Fig. 4).

Following placement of the collagen membrane, leukocyte- and platelet-rich fibrin (L-PRF) membranes were applied over the augmented area. Periosteal releasing incisions were performed to provide adequate flap advancement and achieve tension-free primary closure of the surgical site.

After an average healing period of approximately 6 months, the augmented site was surgically re-entered and the fixation screws were removed. Dental implants were subsequently placed in the reconstructed alveolar ridge (Fig. 5).

For both treatment groups, systemic antibiotic therapy with amoxicillin (750 mg every 8 h for 7 days) was prescribed postoperatively. Ibuprofen (600 mg every 8 h as needed) was administered for postoperative pain control. Following implant placement, an osseointegration period of approximately 3–4 months was allowed before completion of prosthetic rehabilitation.

The duration of follow-up was defined as the interval between the augmentation surgery and the last documented clinical examination and ranged from 9 to 12 months.

Radiographic assessment and CBCT measurements

Preoperative CBCT examinations and postoperative CBCT examinations obtained approximately 6 months after augmentation were used for radiographic assessment. All measurements were performed by a single examiner on cross-sectional CBCT images. Horizontal ridge width was measured 1 mm apical to the most coronal point of the alveolar crest, using a linear CBCT-based measurement protocol adapted from Barbu et al.(16). Corresponding anatomical landmarks were used to reproduce the measurement location on the preoperative and postoperative CBCT examinations. Horizontal bone gain was calculated as the difference between postoperative and preoperative ridge width (postoperative width – preoperative width).

In sites presenting a vertical defect component, vertical ridge dimensions were assessed using stable anatomical boundaries as reference points to ensure reproducibility between the preoperative and postoperative CBCT examinations. Vertical bone gain was calculated as the difference between postoperative and preoperative vertical measurements (postoperative height – preoperative height).

For assessment of intra-examiner reliability, CBCT examinations from 20 anonymized patients, comprising 10 patients from the PTFE group and 10 patients from the ramus group, were re-evaluated by the same examiner after a 2-week interval. During the second assessment, the examiner was blinded to

the initial measurements. Intra-examiner reliability was assessed using the intraclass correlation coefficient (ICC)(17).

Clinical outcomes and complications

Clinical outcomes and postoperative complications were retrospectively assessed from the patients' clinical records throughout the follow-up period. Complications were categorized as early or late according to their occurrence during the postoperative course. Early complications included bleeding, hematoma, wound dehiscence, infection, membrane exposure, graft exposure, paresthesia, and trismus. Late complications included graft resorption, graft separation, partial or complete graft loss, fixation screw fracture, persistent paresthesia, esthetic complications, and the need for additional augmentation procedures.

In addition to augmentation-related complications, subsequent implant rehabilitation was evaluated by recording whether implant placement was performed, the occurrence of implant failure, and completion of prosthetic rehabilitation.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics version 23.0 (IBM Corp., Armonk, NY, USA) and R software version 4.5.0 (R Foundation for Statistical Computing, Vienna, Austria).

Sample size calculation was based on horizontal bone gain as the primary radiographic outcome. Based on the assumptions reported by Barbu et al. (16), an expected intergroup difference of 1.0 mm with a standard deviation of 1.3 mm was considered. With a two-sided alpha level of 0.05 and a statistical power of 80%, a minimum of 28 evaluable patients per group was required.

The normality of continuous variables was assessed using the Shapiro–Wilk test. Normally distributed continuous variables were expressed as mean $\pm$ standard deviation (SD) and compared between groups using the independent-samples *t*-test. Non-normally distributed continuous variables were expressed as median (minimum–maximum) together with mean ranks and compared using the Mann–Whitney *U* test. Effect sizes for continuous variables were calculated using the Z/η^2 -based equivalent Cohen's *d* and reported with corresponding 95% confidence intervals (CIs).

Categorical variables were summarized as frequencies and percentages and compared between groups using the Yates-corrected Pearson chi-square test, Fisher's exact test, or Fisher's exact test with Monte Carlo simulation, as appropriate. Statistical significance was reported using *p* values, and effect sizes for categorical comparisons were expressed using the phi coefficient (ϕ) with corresponding 95% CIs.

Binary logistic regression analyses were performed to evaluate the effects of independent variables on the occurrence of early and late postoperative complications. Both univariable and multivariable logistic

regression models were evaluated, and the results were reported as odds ratios (ORs) with corresponding 95% CIs.

Intra-examiner reliability and repeatability of the radiographic measurements were assessed using the intraclass correlation coefficient (ICC). A two-way mixed-effects model with absolute agreement and single-measure assessment was applied, and ICC estimates were reported with corresponding 95% CIs. A two-sided *p* value < 0.05 was considered statistically significant.

Results

A total of 60 patients were included in the final analysis, with 30 patients allocated to each treatment group. The mean age was 46.80 ± 11.30 years in the PTFE group and 45.33 ± 12.58 years in the ramus group, with no statistically significant difference between the groups (*p* = 0.637). The PTFE group comprised 16 men (53.3%) and 14 women (46.7%), whereas the ramus group comprised 10 men (33.3%) and 20 women (66.7%); the difference in sex distribution was not statistically significant (*p* = 0.193). Regarding smoking status, 12 patients (40.0%) in the PTFE group and 9 patients (30.0%) in the ramus group were smokers, with no significant between-group difference (*p* = 0.588). These findings indicated that the groups were comparable with respect to the evaluated demographic characteristics (Table 1).

Table 1
Demographic characteristics of the study population according to treatment group

Age	PTFE	Ramus	Total	Test statistic	<i>p</i> value	Effect size (95% CI)
	46.80 ± 11.30	45.33 ± 12.58	46.07 ± 11.88	0.475	0.637 _x	0.123 [-0.384: 0.629]
Sex				1.697	0.193 _y	0.202 [0.009: 0.434]
Male	16 (53.3)	10 (33.3)	26 (43.3)			
Female	14 (46.7)	20 (66.7)	34 (56.7)			
Smoking status				0.293	0.588 _y	0.105 [0.000: 0.301]
No	18 (60)	21 (70)	39 (65)			
Yes	12 (40)	9 (30)	21 (35)			

Data are presented as mean ± standard deviation or n (%), as appropriate. ^xIndependent-samples t-test; ^yYates-corrected Pearson chi-square test. Effect sizes are reported as Cohen’s d for continuous variables and the phi coefficient (φ) for categorical variables, with 95% confidence intervals (CIs). The 95% CIs were calculated using the bootstrap method.

Regarding clinical characteristics, no statistically significant differences were observed between the PTFE and ramus groups in ASA classification ($p = 1.000$), jaw distribution ($p = 1.000$), anatomical localization ($p = 1.000$), or defect type ($p = 0.792$). In both groups, mandibular and posterior sites predominated. Combined defects were observed in 19 patients (63.3%) in the PTFE group and 17 patients (56.7%) in the ramus group, whereas horizontal defects were present in 11 (36.7%) and 13 (43.3%) patients, respectively. Overall, the

distribution of clinical characteristics was comparable between the two treatment groups (Table 2).

Table 2
Clinical characteristics of the study population according to treatment group

ASA classification	PTFE	Ramus	Total	Test statistic	p ^x	Effect size (95% CI)
				0.000	1.000	0.041 [0.000: 0.137]
ASA I	24 (80)	23 (76.7)	47 (78.3)			
ASA II	6 (20)	7 (23.3)	13 (21.7)			
Jaw Area				0.000	1.000	0.000 (-)
Maxilla	11 (36.7)	11 (36.7)	22 (36.7)			
Mandible	19 (63.3)	19 (63.3)	38 (63.3)			
Localization				0.000	1.000	0.036 [0.000: 0.118]
Anterior	9 (30)	10 (33.3)	19 (31.7)			
Posterior	21 (70)	20 (66.7)	41 (68.3)			
Defect type				0.069	0.792	0.068 [0.000: 0.224]
Horizontal	11 (36.7)	13 (43.3)	24 (40)			
Combined	19 (63.3)	17 (56.7)	36 (60)			

Data are presented as n (%). Group comparisons were performed using the Yates-corrected Pearson chi-square test. Effect sizes are reported as phi coefficients (ϕ) with 95% confidence intervals (CIs), calculated using the bootstrap method.

Preoperative horizontal measurements were comparable between the PTFE and ramus groups (3.88 ± 0.90 mm and 3.97 ± 0.57 mm, respectively; $p = 0.645$). Similarly, no significant between-group difference was observed in postoperative horizontal measurements (6.71 ± 1.52 mm vs. 6.83 ± 1.17 mm; $p = 0.725$). Horizontal bone gain was 2.83 ± 1.19 mm in the PTFE group and 2.86 ± 1.00 mm in the ramus group, with no statistically significant difference between the groups ($p = 0.907$). Preoperative vertical measurements also did not differ significantly between the groups ($p = 0.506$). In contrast, postoperative vertical measurements were significantly greater in the PTFE group than in the ramus group (11.04 ± 1.88 mm vs. 9.81 ± 0.50 mm; $p = 0.013$). Furthermore, median vertical bone gain was significantly greater in the PTFE group than in the ramus group [3.3 (1.5–5.5) mm vs. 2.0 (0.9–3.0) mm; $p < 0.001$] (Table 3).

Table 3
Comparison of horizontal and vertical bone measurements and gains between groups

Preoperative Horizontal	PTFE	Ramus	Total	Test statistic	p	Effect size (95% CI)
	3.88 ± 0.90	3.97 ± 0.57	3.93 ± 0.75	-0.463	0.645^x	-0.120 [-0.626: 0.388]
Postoperative Horizontal	6.71 ± 1.52	6.83 ± 1.17	6.77 ± 1.34	-0.353	0.725 ^x	-0.091 [-0.597: 0.416]
Horizontal Gain	2.83 ± 1.19	2.86 ± 1.00	2.84 ± 1.09	-0.117	0.907 ^x	-0.030 [-0.536: 0.476]
Preoperative Vertical	7.5 (4.5: 12) / 17.39	7.8 (6: 9.6) / 19.74	7.65 (4.5: 12)	-0.665	0.506 ^y	0.223 [-0.435: 0.878]
Postoperative Vertical	11.04 ± 1.88	9.81 ± 0.50	10.46 ± 1.52	2.735	0.013^x	0.869 [0.177: 1.549]
Vertical Gain	3.3 (1.5: 5.5) / 24.39	2 (0.9: 3) / 11.91	2.2 (0.9: 5.5)	-3.549	< 0.001^y	1.467 [0.718: 2.200]

Data are presented as mean $\pm$ standard deviation and median (minimum–maximum) / mean rank.

^xIndependent-samples t-test; ^yMann–Whitney U test. Effect size (95% CI): Z/η^2 -based equivalent Cohen's d with 95% confidence interval.

Early postoperative complications were evaluated in both treatment groups. Early paresthesia occurred in 3 patients (10.0%) in the PTFE group and 10 patients (33.3%) in the ramus group. Although paresthesia was more frequent in the ramus group, the between-group difference did

not reach statistical significance ($p = 0.060$). No statistically significant differences were observed between the groups with respect to early bleeding, hematoma, dehiscence, infection, graft exposure, or

trismus (all $p > 0.05$). PTFE membrane exposure was observed in 9 patients (30.0%) in the PTFE group (Table 4).

Table 4
Comparison of early postoperative complications between groups

Early bleeding	PTFE	Ramus	Total	Test statistic	p	Effect size (95% CI)
				---	0.612_y	0.134 [0.000: 0.296]
No	27 (90)	29 (96.7)	56 (93.3)			
Yes	3 (10)	1 (3.3)	4 (6.7)			
Early hematoma				---	1.000_y	0.077 [0.000: 0.199]
No	28 (93.3)	29 (96.7)	57 (95)			
Yes	2 (6.7)	1 (3.3)	3 (5)			
Early dehiscence				0.000	1.000_x	0.035 [0.000: 0.105]
No	19 (63.3)	20 (66.7)	39 (65)			
Yes	11 (36.7)	10 (33.3)	21 (35)			
Early infection				---	0.146_y	0.233 [0.017: 0.419]
No	23 (76.7)	28 (93.3)	51 (85)			
Yes	7 (23.3)	2 (6.7)	9 (15)			
Early graft exposure				0.000	1.000_x	0.000 [:]*
No	23 (76.7)	23 (76.7)	46 (76.7)			
Yes	7 (23.3)	7 (23.3)	14 (23.3)			
Early paresthesia				3.535	0.060_x	0.283 [0.047: 0.500]
No	27 (90)	20 (66.7)	47 (78.3)			
Yes	3 (10.0)	10 (33.3)	13 (21.7)			

Early bleeding	PTFE	Ramus	Total	Test statistic	p	Effect size (95% CI)
				---	0.612_y	0.134 [0.000: 0.296]
Early trismus				1.422	0.233 _x	0.193 [0.005: 0.424]
No	25 (83.3)	20 (66.7)	45 (75)			
Yes	5 (16.7)	10 (33.3)	15 (25)			

Data are presented as n (%). ^xYates-corrected Pearson chi-square test; ^yFisher's exact test. Effect sizes are reported as phi coefficients (ϕ) with 95% confidence intervals (CIs), calculated using the bootstrap method.

Late graft resorption was observed in 15 patients (50.0%) in each group, with no statistically significant between-group difference ($p = 1.000$). Partial graft loss occurred in 14 patients (46.7%) in the PTFE group and 10 patients (33.3%) in the ramus group; however, the difference between the groups was not statistically significant ($p = 0.429$). Additional augmentation was required in 4 patients (13.3%) in the PTFE group and 2 patients (6.7%) in the ramus group, with no statistically significant difference between the groups ($p = 0.671$). No cases of screw fracture, permanent paresthesia, or esthetic problems were observed in either group (Table 5).

Table 5
Comparison of late postoperative complications between groups

Late graft resorption	PTFE	Ramus	Total	Test statistic	p	Effect size (95% CI)
				0.000	1.000 _x	0.000 [:]*
No	15 (50)	15 (50)	30 (50)			
Yes	15 (50)	15 (50)	30 (50)			
Late partial graft loss				0.625	0.429 _x	0.136 [0.003: 0.369]
No	16 (53.3)	20 (66.7)	36 (60)			
Yes	14 (46.7)	10 (33.3)	24 (40)			
Late screw fracture				---	---	---
No	30 (100)	30 (100)	60 (100)			
Yes	0 (0)	0 (0)	0 (0)			
Late permanent paresthesia				---	---	---
No	30 (100)	30 (100)	60 (100)			
Yes	0 (0)	0 (0)	0 (0)			
Late esthetic problem				---	---	---
No	30 (100)	30 (100)	60 (100)			
Yes	0 (0)	0 (0)	0 (0)			
Late Additional augmentation				---	0.671 _y	0.111 [0.000: 0.296]
No	26 (86.7)	28 (93.3)	54 (90)			
Yes	4 (13.3)	2 (6.7)	6 (10)			

*Yates-corrected Pearson chi-square test; ^yFisher's exact test. ES = effect size; phi coefficient (ϕ). The 95% confidence intervals were calculated using the bootstrap method. *The point estimate was zero;*

however, a small effect cannot be excluded considering sampling uncertainty. Data are presented as frequency (percentage).

Note

Statistical comparisons could not be performed for late screw fracture, late permanent paresthesia, and late esthetic problems because all observations were coded as 0.

Implant placement was successfully performed in all patients in both groups. Implant failure occurred in 3 patients (10.0%) in the PTFE group and 2 patients (6.7%) in the ramus group, with no statistically significant difference between the groups ($p = 1.000$). Prosthetic rehabilitation was completed in 27 patients (90.0%) in the PTFE group and 28 patients (93.3%) in the ramus group, with no significant between-group difference ($p = 1.000$). Follow-up duration ranged from 9 to 12 months, and its distribution did not differ significantly between the groups ($p = 0.817$) (Table 6).

Table 6

Comparison of implant-related and prosthetic outcomes and follow-up duration between groups

Implant placement	PTFE	Ramus	Total	Test statistic	p	Effect size (95% CI)
				---	---	---
No	0 (0)	0 (0)	0 (0)			
Yes	30 (100)	30 (100)	60 (100)			
Implant failure				---	1,000 ^x	0,060[0.000–0.302]
No	27 (90)	28 (93,3)	55 (91,7)			
Yes	3 (10)	2 (6, 7)	5 (8, 3)			
Prosthetic completion				---	1,000 ^x	0,060[0.000–0.302]
No	3 (10)	2 (6, 7)	5 (8, 3)			
Yes	27 (90)	28 (93,3)	55 (91,7)			
Follow-up duration (months)				1,159	0,817 ^y	0,136 [0,000: 0,378]
9 Months	8 (26, 7)	10 (33,3)	18 (30)			
10 Months	8 (26, 7)	8 (26, 7)	16 (26, 7)			
11 Months	7 (23, 3)	8 (26, 7)	15 (25)			
12 Months	7 (23, 3)	4 (13, 3)	11 (18, 3)			

^xFisher's exact test; ^yFisher's exact test with Monte Carlo simulation. ES = effect size; phi coefficient (ϕ) and Cramer's V (V). The 95% confidence intervals were calculated using the bootstrap method. Data are presented as frequency (percentage).

Binary logistic regression analysis was performed to evaluate factors associated with the occurrence of early postoperative complications. In the univariate analysis, posterior localization was significantly associated with an increased likelihood of early complications compared with anterior localization (OR = 4.889, 95% CI: 1.513–15.802; $p = 0.008$). In the multiple logistic regression model, posterior localization remained significantly associated with early complications (OR = 10.059, 95% CI: 1.669–60.625; $p =$

0.012). Age, sex, smoking status, region, defect type, and treatment group were not significantly associated with the occurrence of early complications in either the univariate or multiple models (all $p > 0.05$) (Table 7).

Table 7
Effects of independent variables on the likelihood of early postoperative complications

	Early Complication		Univariate		Multiple	
	No	Yes	OR (%95 CI)	p	OR (%95 CI)	p
Age	44.600 ± 13.500	46.800 ± 11.090	1.016 (0.971: 1.063)	0.497	1.011 (0.952: 1.075)	0.716
Sex						
Male	11 (42.3)	15 (57.7)	Reference			
Female	9 (26.5)	25 (73.5)	2.037 (0.686: 6.052)	0.200	2.095 (0.529: 8.288)	0.292
Smoking						
No	16 (41)	23 (59)	Reference			
Yes	4 (19)	17 (81)	2.957 (0.837: 10.447)	0.092	3.825 (0.825: 17.741)	0.087
Region						
Maxilla	8 (36.4)	14 (63.6)	Reference			
Mandible	12 (31.6)	26 (68.4)	1.238 (0.410: 3.740)	0.705	0.339 (0.055: 2.099)	0.245
Localization						
Anterior	11 (57.9)	8 (42.1)	Reference			
Posterior	9 (22)	32 (78)	4.889 (1.513: 15.802)	0.008	10.059 (1.669: 60.625)	0.012
Defect type						
Horizontal	8 (33.3)	16 (66.7)	Reference			
Combined	12 (33.3)	24 (66.7)	1.000 (0.334: 2.991)	1.000	1.116 (0.269: 4.633)	0.880
Group						
PTFE	12 (40)	18 (60)	Reference			
Ramus	8 (26.7)	22 (73.3)	1.833 (0.616: 5.453)	0.276	2.406 (0.643: 9.004)	0.192

OR = odds ratio; CI = confidence interval. Data are presented as mean $\pm$ standard deviation or frequency (percentage), as appropriate.

Binary logistic regression analysis was performed to evaluate factors associated with the occurrence of late postoperative complications. In the univariate analysis, smoking was significantly associated with an increased likelihood of late complications, with smokers having approximately four times higher odds of developing late complications than non-smokers (OR = 4.141, 95% CI: 1.264–13.572; $p = 0.019$). This association remained statistically significant in the multiple logistic regression model (OR = 4.180, 95% CI: 1.172–14.913; $p = 0.028$). Age, sex, region, localization, defect type, and treatment group were not significantly associated with the occurrence of late complications in either the univariate or multiple models (all $p > 0.05$) (Table 8).

Table 8
Effects of independent variables on the likelihood of late postoperative complications

	Late Complication		Univariate		Multiple	
	No	Yes	OR (%95 GA)	p	OR (%95 CI)	p
Age	43.07 ± 13.304	48.52 ± 10.128	1.042 (0.995: 1.091)	0.083	1.033 (0.979: 1.091)	0.236
Sex						
Male	10 (38.5)	16 (61.5)	Reference			
Female	17 (50)	17 (50)	0.625 (0.221: 1.764)	0.375	0.689 (0.208: 2.279)	0.542
Smoking						
No	22 (56.4)	17 (43.6)	Reference			
Yes	5 (23.8)	16 (76.2)	4.141 (1.264: 13.572)	0.019	4.18 (1.172: 14.913)	0.028
Region						
Maxilla	11 (50)	11 (50)	Reference			
Mandible	16 (42.1)	22 (57.9)	1.375 (0.479: 3.949)	0.554	1.142 (0.281: 4.643)	0.853
Localization						
Anterior	10 (52.6)	9 (47.4)	Reference			
Posterior	17 (41.5)	24 (58.5)	1.569 (0.525: 4.685)	0.420	1.166 (0.285: 4.768)	0.830
Defect type						
Horizontal	10 (41.7)	14 (58.3)	Reference			
Combined	17 (47.2)	19 (52.8)	0.798 (0.281: 2.264)	0.672	1.303 (0.378: 4.495)	0.675
Group						
PTFE	13 (43.3)	17 (56.7)	Reference			
Ramus	14 (46.7)	16 (53.3)	0.874 (0.316: 2.418)	0.795	1.165 (0.372: 3.645)	0.793

OR = odds ratio; CI = confidence interval. Data are presented as mean ± standard deviation or frequency (percentage), as appropriate.

Intra-examiner reliability was excellent for all radiographic measurements. In the ramus group, ICC values ranged from 0.972 to 0.996 for preoperative and postoperative horizontal and vertical measurements, whereas in the PTFE group, ICC values ranged from 0.996 to 0.999. In the overall analysis, ICC values were 0.993 (95% CI: 0.983–0.997) for preoperative horizontal measurements, 0.998 (95% CI: 0.995–0.999) for postoperative horizontal measurements, and 0.999 for both preoperative and postoperative vertical measurements. All ICC values were statistically significant ($p < 0.001$), indicating excellent intra-examiner reliability (Table 9).

Table 9
Intraclass correlation coefficient (ICC) and agreement analysis of
preoperative and postoperative measurements by group

Ramus	N	ICC (%95 CI)	p
Preoperative Horizontal	10	0.972 (0.892: 0.993)	< 0.001
Postoperative Horizontal	10	0.996 (0.983: 0.999)	< 0.001
Preoperative Vertical	7	0.994 (0.964: 0.999)	< 0.001
Postoperative Vertical	7	0.974 (0.859: 0.996)	< 0.001
PTFE			
Preoperative Horizontal	10	0.996 (0.983: 0.999)	< 0.001
Postoperative Horizontal	10	0.999 (0.995: 1.000)	< 0.001
Preoperative Vertical	7	0.999 (0.996: 1.000)	< 0.001
Postoperative Vertical	7	0.999 (0.996: 1.000)	< 0.001
Overall			
Preoperative Horizontal	20	0.993 (0.983: 0.997)	< 0.001
Postoperative Horizontal	20	0.998 (0.995: 0.999)	< 0.001
Preoperative Vertical	14	0.999 (0.997: 1.000)	< 0.001
Postoperative Vertical	14	0.999 (0.997: 1.000)	< 0.001

ICC (95% CI): intraclass correlation coefficient (95% confidence interval).

Discussion

The present retrospective cohort study compared titanium-reinforced PTFE membrane-assisted guided bone regeneration with autogenous mandibular ramus block grafting for the reconstruction of deficient alveolar ridges. The main findings were that both techniques resulted in comparable horizontal bone

gain, whereas significantly greater vertical bone gain was observed in the PTFE group. Although the two techniques exhibited different postoperative morbidity profiles, treatment modality itself was not independently associated with either early or late complications. Posterior localization was associated with a higher likelihood of early complications, while smoking was independently associated with late complications. These findings indicate that both approaches can provide effective ridge reconstruction, but their relative clinical advantages may differ according to defect morphology and patient-related risk factors.

Horizontal bone gain was nearly identical between the groups, reaching 2.83 ± 1.19 mm with PTFE-assisted GBR and 2.86 ± 1.00 mm with ramus block grafting. This finding is consistent with clinical evidence indicating that both barrier-based GBR and autogenous block grafting can provide sufficient horizontal reconstruction for subsequent implant placement. Mendoza-Azpur et al. compared GBR with an autogenous block-based approach in a randomized clinical trial and reported adequate ridge-width augmentation with both techniques, without a significant between-group difference in horizontal gain at either 6 or 18 months (11). In a retrospective CBCT-based comparison, Gultekin et al. likewise demonstrated that both GBR and ramus block grafting provided sufficient reconstructed bone volume for implant placement, although greater horizontal gain was observed in the GBR group in that cohort (18). The numerical differences between these studies and the present findings should be interpreted in the context of differences in baseline ridge morphology, graft composition, membrane type, healing interval and radiographic measurement methods. Nevertheless, the consistent observation that both approaches can provide clinically useful horizontal augmentation supports their use as alternative reconstructive strategies rather than suggesting clear superiority of one technique for horizontal defects.

The most distinctive radiographic finding of the present study was the greater vertical gain obtained with PTFE-assisted GBR. Median vertical bone gain was 3.3 mm in the PTFE group compared with 2.0 mm in the ramus group. This difference may be related to the ability of titanium-reinforced PTFE barriers to maintain a stable regenerative space beyond the native bony envelope. Vertical reconstruction is particularly dependent on mechanical stability and resistance to soft-tissue pressure, and rigid non-resorbable barriers have been developed specifically to preserve this three-dimensional space throughout healing. Urban et al., in a clinical series of 65 vertically deficient sites, reported a mean vertical gain of 5.2 ± 2.4 mm with titanium-reinforced PTFE mesh and achieved complete regeneration in the majority of cases (19). Windisch et al. similarly reported substantial vertical and horizontal hard-tissue gain following titanium-reinforced d-PTFE GBR in a prospective case series (20). Randomized clinical evidence has also shown stable hard- and soft-tissue outcomes following vertical augmentation with reinforced PTFE membranes and titanium mesh-based approaches (21). These data support the high regenerative capacity of rigid space-maintaining GBR techniques, although absolute gain values vary considerably according to initial defect dimensions and surgical protocol.

The lower vertical gain observed in the ramus group does not necessarily imply inferior efficacy of autogenous block grafts. Ramus blocks remain a well-established source of dense intraoral autogenous bone and provide immediate structural stability. Proussaefs et al. demonstrated a mean radiographic

vertical augmentation of approximately 5 mm at 4–6 months following ramus block grafting, while also documenting physiological graft remodeling and a radiographic resorption rate of approximately 16% (22). Therefore, the final vertical dimension obtained with block grafting is influenced not only by the initial graft geometry, but also by adaptation to the recipient site, revascularization and subsequent remodeling. The present findings may therefore reflect different mechanisms of space preservation rather than an inability of ramus grafts to achieve vertical augmentation.

Postoperative events also highlighted differences in the clinical behavior of the two techniques. PTFE membrane exposure occurred in 30% of patients treated with PTFE-assisted GBR. Membrane exposure is a recognized complication of non-resorbable barrier techniques and does not inevitably herald treatment failure. In a prospective clinical and histomorphometric study using titanium-reinforced microporous PTFE membranes, exposure did not significantly reduce the amount of new bone formation, although less residual graft material was observed in exposed sites (23). Lindfors et al. likewise reported membrane exposure in approximately 15% of titanium-reinforced ePTFE augmentations and found that exposure itself did not inevitably compromise the final regenerative outcome (24). These observations are clinically relevant because they suggest that exposure should be regarded as an important healing event requiring appropriate management, but not automatically as evidence of unsuccessful augmentation.

Neurosensory morbidity, on the other hand, is particularly relevant to ramus harvesting because of the additional donor-site procedure and the anatomical proximity of the inferior alveolar and lingual neurovascular structures. Mendoza-Azpur et al. reported a significantly greater prevalence of sensory disturbances in the autogenous block group compared with GBR (11). A systematic review focusing on intraoral donor-site morbidity also confirmed that neurosensory disturbance is among the recognized complications of mandibular bone harvesting, although the ramus generally demonstrates a favorable morbidity profile compared with the chin (10). In the present cohort, early paresthesia was more frequent in the ramus group, although the corrected between-group comparison did not reach statistical significance, and no permanent paresthesia was observed in either group. Accordingly, the findings are compatible with transient donor-site-related sensory morbidity rather than persistent neurological injury.

Neither augmentation technique was independently associated with the overall occurrence of early or late complications in the regression models. Instead, posterior localization was significantly associated with early complications. Although the magnitude of this association was substantial, the wide confidence interval indicates that it should be interpreted cautiously. Posterior regions may represent technically more demanding surgical sites because of restricted access, limited visibility and greater difficulty in flap advancement and tension-free closure. However, the available literature does not consistently identify site localization as an independent predictor of complications, and this finding should therefore be regarded as a potentially relevant site-related indicator that requires confirmation in larger cohorts.

Smoking showed a more consistent association with adverse healing. Smokers had approximately four-fold higher odds of late complications in both the univariate and multiple models. This observation is supported by previous augmentation studies. Lindfors et al. reported markedly lower success rates and more frequent soft-tissue inflammation among smokers undergoing titanium-reinforced ePTFE GBR (24). In a large retrospective analysis of staged ridge augmentation, Kloss et al. also identified smoking as an important factor associated with postoperative complications (25). These findings reinforce the clinical importance of smoking status during treatment planning and patient counseling and suggest that patient-related biological factors may influence complication risk independently of the selected augmentation technique.

Despite the occurrence of early and late complications, implant-related outcomes were favorable in both groups. Implant placement was achieved in all patients, while implant failure occurred in 10.0% of the PTFE group and 6.7% of the ramus group, without a significant difference. Prosthetic rehabilitation was completed in 90.0% and 93.3% of patients, respectively. Comparable implant rehabilitation following different augmentation strategies has also been reported elsewhere. Mendoza-Azpur et al. observed 100% implant survival following both treatment approaches during their follow-up period (11), while Gultekin et al. found comparable implant insertion torque following GBR and ramus block grafting (18). Although follow-up periods and definitions of success differ among studies, the available clinical evidence generally supports predictable implant placement after successful staged ridge augmentation.

From a clinical perspective, the present findings do not support a universally superior augmentation method. In predominantly horizontal deficiencies, the nearly identical bone gain observed with both techniques suggests that either approach may be selected according to surgeon experience, donor-site considerations and defect configuration. In defects with a relevant vertical component, the greater vertical gain achieved with PTFE-assisted GBR may favor a rigid barrier-based approach when maintenance of a three-dimensional regenerative space is critical. Conversely, ramus block grafting offers the biological advantages and structural rigidity of autogenous bone but requires a second surgical site. Contemporary systematic evidence similarly indicates that several vertical augmentation strategies are clinically effective, while each is accompanied by a distinct balance between regenerative potential and morbidity (26).

The present study should be interpreted in light of its retrospective design and the smaller number of patients available for vertical measurements. In addition, the 9–12-month observation period limits assessment of long-term dimensional stability and implant survival. Nevertheless, the use of standardized CBCT measurements with excellent intra-examiner reliability, comparable baseline characteristics between the groups and the simultaneous evaluation of radiographic outcomes, complications and subsequent implant rehabilitation strengthen the clinical relevance of the findings.

Conclusions

The present study provides a comprehensive clinical and radiographic comparison of PTFE membrane-assisted GBR and autogenous ramus block grafting for alveolar ridge augmentation. Evaluation of bone gain, postoperative complications, and subsequent implant rehabilitation demonstrated that both approaches can provide clinically effective reconstruction, although their outcomes may vary according to defect characteristics and patient-related factors. These findings may assist clinicians in selecting an appropriate augmentation strategy and in counseling patients regarding the expected benefits and potential risks of each approach.

Abbreviations

ASA

American Society of Anesthesiologists

CBCT

cone-beam computed tomography

CI

confidence interval

GBR

guided bone regeneration

ICC

intraclass correlation coefficient

L-PRF

leukocyte- and platelet-rich fibrin

OR

odds ratio

PTFE

polytetrafluoroethylene.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the Hatay Mustafa Kemal University Non-Interventional Clinical Research Ethics Committee (meeting no. 09, decision no. 69; July 1, 2026). The study was conducted in accordance with the principles of the Declaration of Helsinki and applicable institutional and ethical guidelines. Patient data were anonymized before analysis.

Consent for publication

Not applicable

Competing interests

The authors declare no competing interests.

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Author Contribution

AD contributed to the conception and design of the study, data acquisition, radiographic measurements, data interpretation, and drafting of the manuscript. MSA contributed to data acquisition, clinical data collection, and critical revision of the manuscript. AH contributed to data acquisition, interpretation of the findings, and critical revision of the manuscript. FS contributed to the conception and design of the study, supervision, interpretation of the findings, and critical revision of the manuscript. All authors read and approved the final manuscript.

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Data Availability

The datasets generated and/or analyzed during the current study are not publicly available due to patient confidentiality and ethical considerations but are available from the corresponding author on reasonable request, subject to applicable institutional and ethical requirements.

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Figures

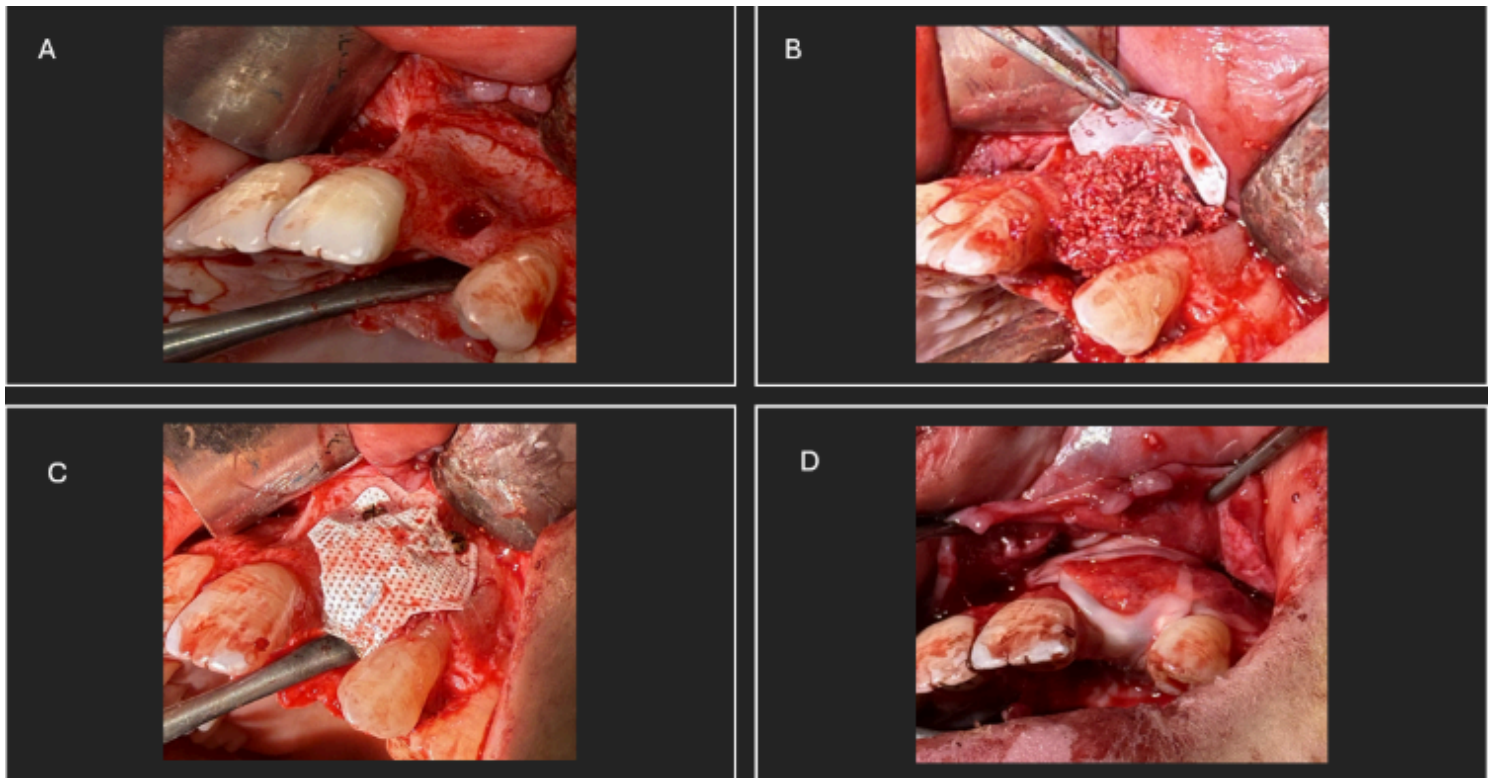


Figure 1

Surgical steps of PTFE membrane-assisted guided bone regeneration. (A) Initial alveolar ridge defect following flap elevation and recipient-site preparation. (B) Placement of a 1:1 mixture of particulate allograft and xenograft. (C) Adaptation and fixation of the titanium-reinforced PTFE membrane over the grafted area. (D) Placement of leukocyte- and platelet-rich fibrin (L-PRF) membranes before tension-free primary wound closure.

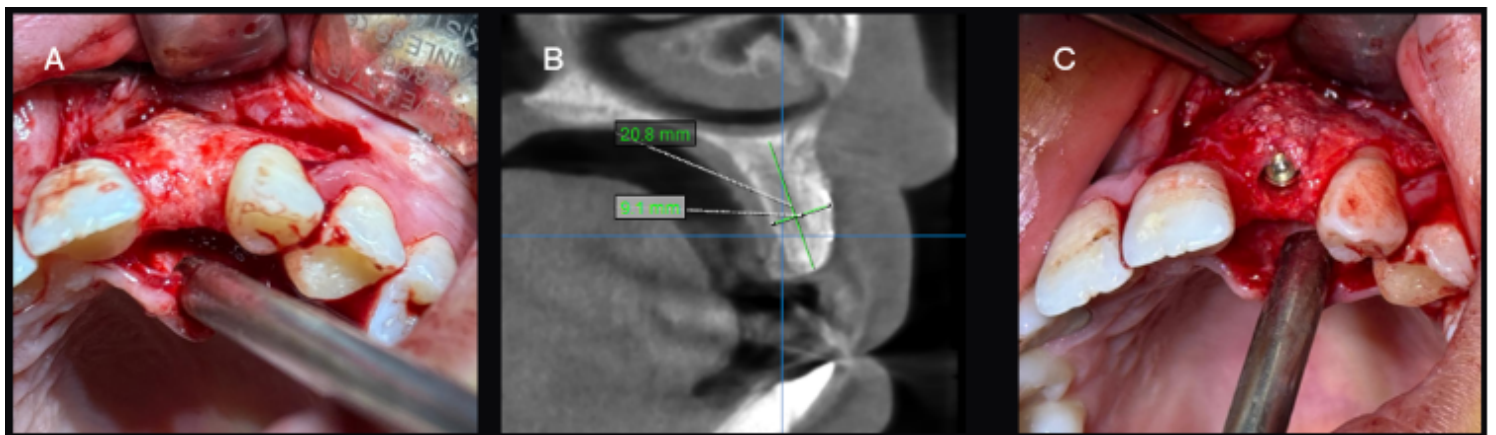


Figure 2

Clinical and radiographic assessment of the augmented site approximately 6 months after PTFE membrane-assisted guided bone regeneration. (A) Clinical appearance of the augmented alveolar ridge following removal of the PTFE membrane. (B) Postoperative CBCT image obtained approximately 6 months after surgery. (C) Clinical appearance of the augmented alveolar ridge following removal of the PTFE membrane.

months after augmentation, demonstrating the radiographic assessment of the augmented ridge. (C) Implant placement in the augmented alveolar ridge.

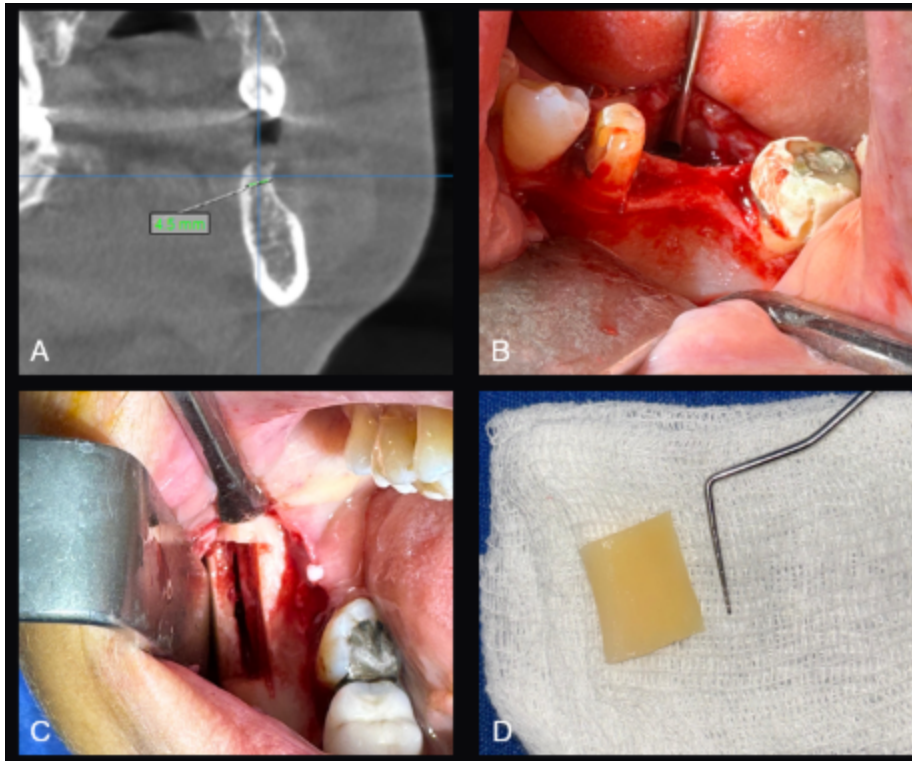


Figure 3

Preoperative assessment and surgical steps of autogenous mandibular ramus block grafting. (A) Preoperative CBCT image demonstrating the horizontal alveolar ridge deficiency. (B) Clinical appearance of the recipient site following flap elevation. (C) Clinical appearance of the mandibular ramus donor site following harvesting of the autogenous bone block. (D) Harvested autogenous cortical bone block prior to adaptation to the recipient site.

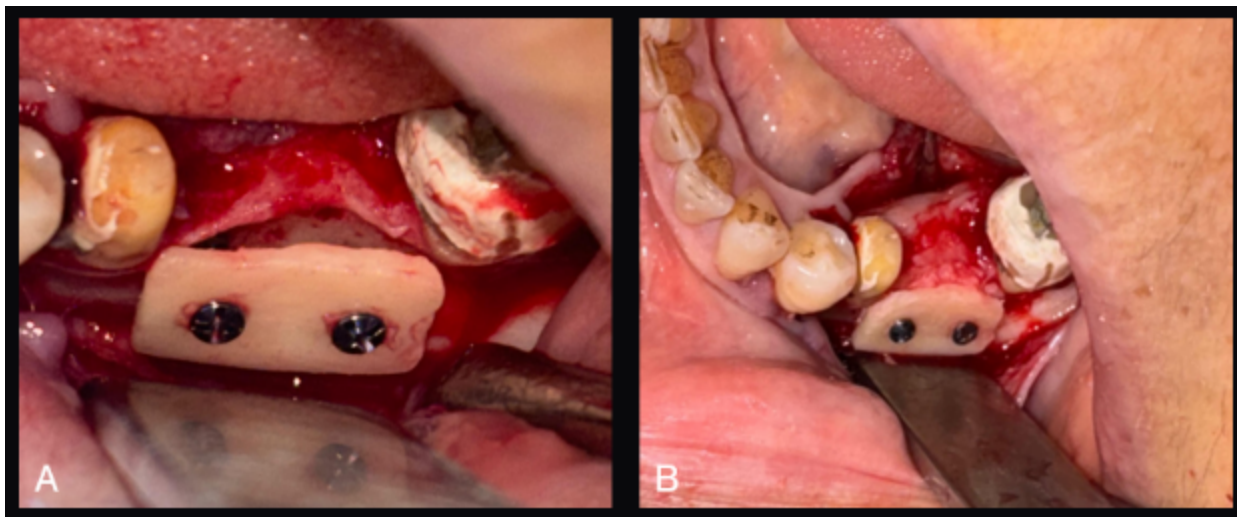


Figure 4

Adaptation and fixation of the autogenous ramus block graft at the recipient site. (A) Adaptation of the harvested autogenous ramus block to the recipient alveolar ridge and rigid fixation with screws. (B) Placement of particulate allograft around the stabilized block graft.

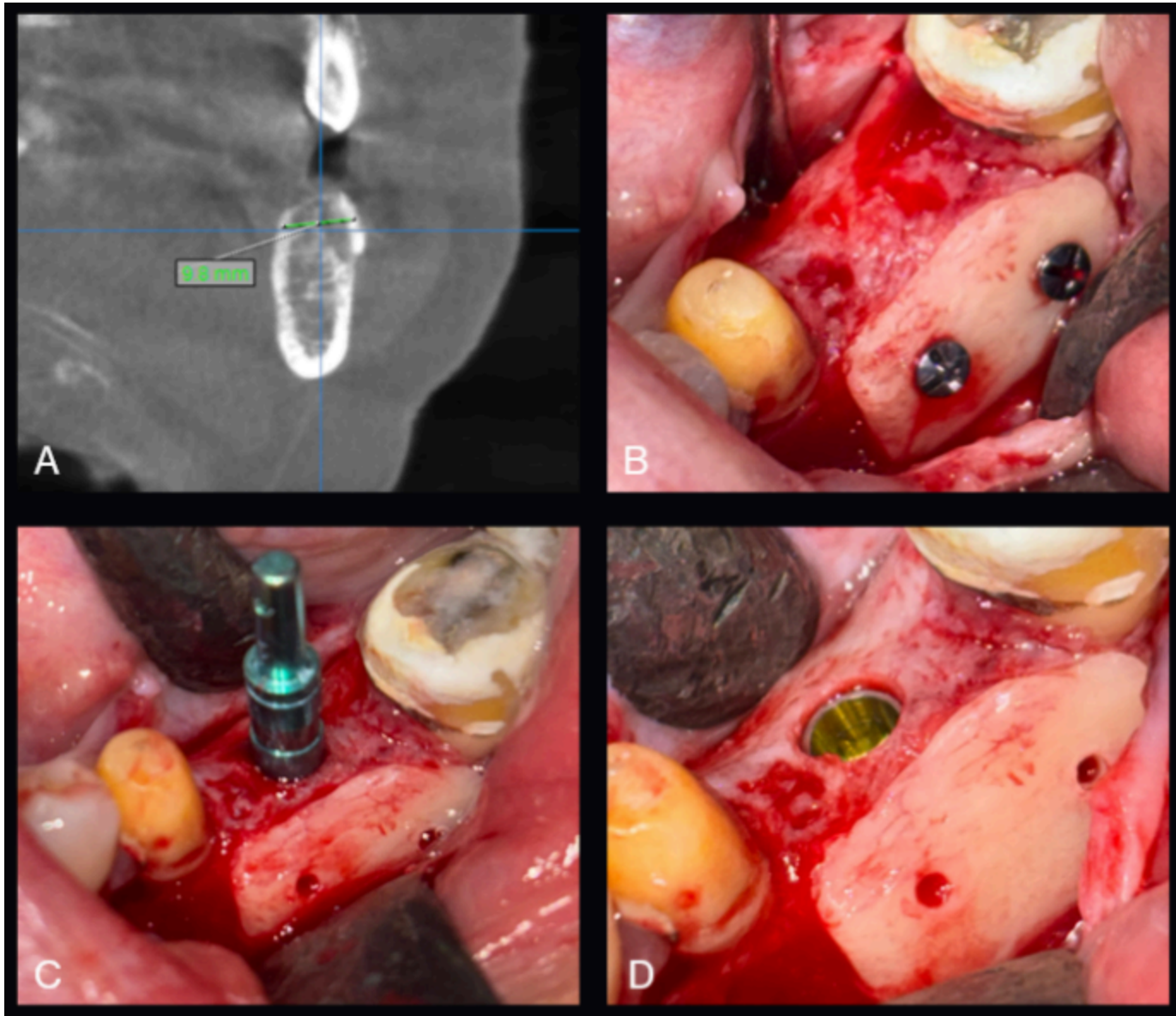


Figure 5

Radiographic and clinical assessment approximately 6 months after autogenous mandibular ramus block grafting and subsequent implant placement. (A) CBCT image obtained approximately 6 months after augmentation, demonstrating the augmented alveolar ridge. (B) Clinical appearance of the augmented site following surgical re-entry. (C) Removal of the fixation screws and preparation of the implant osteotomy. (D) Implant placement in the augmented alveolar ridge.