E-ISSN 2250-0944
ISSN 2250-1150
doi: 10.48047/ijprt/15.02.276

Research Article

Impact of Graft Material Type on Bone Regeneration Around Implants: A Case-Control Study

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Abstract

Bone regeneration around dental implants is a decisive factor for long-term osseointegration and functional stability. The choice of graft material has been debated, with autografts, allografts, xenografts, and synthetic substitutes offering distinct biological and mechanical advantages. This case–control study investigated the impact of graft material type on peri-implant bone regeneration in patients undergoing implant placement with concurrent grafting. Consecutive participants were stratified into groups based on graft material and assessed using standardized radiographic bone-level measurements and resonance frequency analysis for implant stability. The primary objective was to compare the quantitative gain in bone height and density at six months, while secondary endpoints included implant stability quotient scores and complication rates. Statistical analyses included ANOVA, post hoc comparisons, and multivariable regression controlling for confounders. Results demonstrated that autogenous grafts provided the highest mean bone gain, but xenografts and alloplasts achieved comparable outcomes in terms of stability with fewer donor-site morbidities. Discussion highlights that graft material type exerts a statistically significant influence on peri-implant bone regeneration, with implications for material selection in routine practice. The study underscores the potential of certain biomaterials to approximate autograft outcomes while reducing patient morbidity, suggesting a paradigm shift in contemporary implantology.

Keywords: bone regeneration; dental implants; graft materials

Introduction: Dental implantology has evolved into a predictable and widely accepted modality for replacing missing teeth, supported by decades of evidence demonstrating high survival and success rates. However, optimal outcomes remain heavily dependent on adequate bone volume and quality at the recipient site. Alveolar bone resorption following tooth loss is a biologically inevitable process, exacerbated by periodontal disease, trauma, or infection. In many patients, residual ridge dimensions are insufficient to support implant placement without augmentation. Guided bone regeneration (GBR) techniques have thus become integral to implant practice, relying on barrier membranes and grafting materials to re-establish a stable osseous foundation.1-4

The choice of graft material represents one of the most critical decisions in GBR. Autogenous bone has traditionally been considered the gold standard, owing to its osteogenic, osteoinductive, and osteoconductive properties. However, harvesting autograft requires additional surgical intervention, introducing donor-site morbidity, increased operative time, and patient discomfort. Allografts offer osteoconductive scaffolding with partial osteoinductive potential but carry concerns regarding disease transmission and immunogenicity despite rigorous processing. Xenografts, derived predominantly from bovine or porcine sources, provide biocompatible scaffolds with slow resorption rates that maintain volume stability, yet integration dynamics differ from native bone. Synthetic alloplasts, including calcium phosphates and bioactive glasses, have emerged as promising alternatives with controllable resorption and abundant availability.5-9

Recent research has emphasized the comparative performance of these materials in clinical settings. Advances in material science, sterilization, and nanotechnology have enhanced the predictability of xenografts and synthetics, challenging the long-standing dominance of autogenous grafts. Moreover, the biological principle of using grafts as osteoconductive scaffolds that facilitate host bone in-growth has gained traction, particularly as biologically active agents such as platelet concentrates and growth factors are increasingly combined with graft matrices. Despite these innovations, comparative evidence across material types remains heterogeneous, often limited by small sample sizes, varying measurement endpoints, and inconsistent follow-up durations.10 The biological processes underpinning graft incorporation differ among materials, influencing outcomes in both early and late healing phases. Autografts undergo rapid remodeling but are susceptible to unpredictable resorption. Xenografts maintain space effectively but may persist partially unresorbed. Synthetic alloplasts, depending on composition, can integrate via surface dissolution, ion release, and osteoconduction. These differences raise important clinical questions regarding which graft materials best support early implant stability and long-term peri-implant bone maintenance. Understanding these distinctions is critical for evidence-based selection of grafts in implant dentistry. From a patient-centered perspective, reducing surgical morbidity while achieving reliable regeneration is paramount. Eliminating the need for secondary donor sites enhances patient comfort and reduces recovery time. Equally, clinicians seek graft materials that balance biological efficacy, predictability, cost, and availability. The growing range of biomaterials necessitates robust comparative studies that quantify their impact on measurable clinical endpoints such as bone gain, density, and implant stability. The present case–control study was designed to directly compare peri-implant bone regeneration outcomes across different graft materials. By employing standardized radiographic and stability assessments and controlling for confounders, this study sought to identify whether clinically significant differences exist among autografts, allografts, xenografts, and alloplasts. It was hypothesized that while autogenous grafts might remain superior in absolute terms, certain xenografts and synthetic substitutes could approximate these results, offering comparable regeneration with reduced morbidity.

Methodology

A prospective case–control study was undertaken in Baqai Dental College enrolling consecutive patients indicated for implant placement with simultaneous bone grafting. Inclusion criteria comprised adults aged 18–65 with single or multiple edentulous sites requiring horizontal or vertical augmentation to achieve implant placement, adequate systemic health (ASA I–II), and willingness to comply with follow-up. Exclusion criteria included uncontrolled systemic disease, bisphosphonate or corticosteroid therapy, history of head and neck irradiation, pregnancy, smoking >10 cigarettes/day, and active periodontal disease. Eligible patients were assigned to groups based on graft material utilized: Group A (autogenous intraoral bone block/particulate), Group B (processed allograft), Group C (bovine-derived xenograft), and Group D (synthetic alloplast such as β-tricalcium phosphate or hydroxyapatite). Allocation reflected surgeon–patient shared decision-making rather than randomization, and controls were matched for age, sex, and defect type. All surgeries followed standardized GBR protocols using titanium-reinforced collagen membranes where indicated. Implants were placed simultaneously with grafting when primary stability was achievable, or staged after four months otherwise. Sample size was calculated using

Epi Info software (CDC, StatCalc module for two-sample mean comparison) targeting a mean difference in bone gain of 1.0 mm between groups, SD of 1.5 mm, alpha 0.05, and power 0.8, yielding 40 patients per group, inflated to 45 to account for attrition. Postoperative care included antibiotics, analgesics, and standardized oral hygiene instruction. Outcomes were assessed at six months by cone-beam CT for bone height and density (Hounsfield units) and by resonance frequency analysis for implant stability quotient (ISQ). Statistical analyses included ANOVA with Tukey post hoc tests for continuous outcomes, chi-square for categorical variables, and multivariate regression adjusting for confounders. Significance threshold was set at $p<0.05$. All participants provided verbal informed consent after explanation of procedures and risks, and ethical approval was obtained from the institutional review board.

Results

Table 1. Demographic and baseline characteristics

Variable	**Autograft (n=45)**	**Allograft (n=45)**	**Xenograft (n=45)**	**Alloplast (n=45)**	**p value**
Age (years, mean±SD)	42.6±9.3	43.1±8.8	41.7±10.1	42.4±9.5	0.88
Male (%)	51.1	48.9	53.3	46.7	0.74
Defect type (horizontal/vertical, %)	66.7/33.3	64.4/35.6	68.9/31.1	62.2/37.8	0.92
Note: No significant baseline differences across groups.					

Table 2. Radiographic bone regeneration outcomes at 6 months

Outcome	**Autograft**	**Allograft**	**Xenograft**	**Alloplast**	**p value (ANOVA)**
Bone height gain (mm, mean±SD)	4.2±1.1	3.6±1.2	3.9±1.0	3.4±1.3	0.02
Bone density (HU, mean±SD)	980±120	910±135	940±128	905±140	0.04
Note: Autografts achieved significantly greater bone height gain					

Outcome	Autograft	Allograft	Xenograft	Alloplast	p value (ANOVA)
and density; xenografts approached autografts.					

Table 3. Implant stability and complications

Variable	Autograft	Allograft	Xenograft	Alloplast	p value
ISQ at 6 months (mean±SD)	74.5±5.1	72.2±5.6	73.7±5.3	71.8±6.0	0.03
Complication rate (%)	6.7	8.9	4.4	11.1	0.41
Note: All groups achieved high stability; xenografts closely matched autografts with fewer complications than alloplasts.					

Discussion

This study provides comparative evidence that graft material type significantly influences peri-implant bone regeneration, corroborating and extending prior observations. Autografts demonstrated superior performance in terms of bone height and density gains, consistent with their intrinsic osteogenic potential. However, xenografts closely approximated these outcomes, highlighting their reliability as substitutes in cases where autograft harvesting is not feasible.11-14. The statistical significance of bone regeneration outcomes affirms that material selection is not merely a technical consideration but a determinant of biological success. While allografts and alloplasts achieved acceptable results, their comparatively lower density and gain suggest they may be less favorable in scenarios demanding maximal regeneration, such as vertical augmentation or compromised ridges.15-17

A notable finding is that xenografts provided outcomes comparable to autografts in implant stability measures. This reflects their capacity for slow resorption, space maintenance, and effective osteoconduction. The low complication rates observed further strengthen the case for xenografts as a practical alternative. 18-20 Autografts, while biologically ideal, impose donor-site morbidity, surgical complexity, and limited availability. These limitations underscore the clinical value of high-performing alternatives. The present results suggest that xenografts, and to a lesser extent alloplasts, can meet clinical demands while minimizing patient burden.

The implications extend to patient-centered care. Reducing morbidity, procedure time, and cost enhances acceptance and accessibility of implant therapy. The comparable performance of xenografts allows clinicians to avoid secondary harvest procedures without substantially compromising outcomes.

From a translational perspective, these findings align with the trajectory of biomaterial research, where synthetic modifications and bioactive enhancements are closing the gap with autografts. Future research integrating growth factors, stem cells, and nanostructured scaffolds may further elevate alloplast performance, potentially surpassing biological grafts.

Limitations include non-randomized group allocation and reliance on radiographic proxies rather than histological confirmation of bone remodeling. Nevertheless, the use of objective, blinded radiographic and stability measures enhances validity. Multicenter randomized trials with long-term follow-up remain necessary to confirm these findings and establish definitive guidelines.

Conclusion

Graft material type significantly impacts peri-implant bone regeneration, with autografts maintaining superiority but xenografts demonstrating near-equivalent outcomes with fewer complications. These results support the selective use of xenografts as a reliable alternative to autogenous bone. Future research should focus on enhancing synthetic graft performance to achieve biologically equivalent regeneration.

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