

Evidence-Based Selection of Hard Tissue Grafts in Implantology: An Umbrella Review.

Dr. Bhargavi Lakshmi Gariganti¹, Dr. Ch Sai Phanindra², Dr. V V S N Raju Jampana^{3*}, Dr. Sumeet Sharma⁴, Dr. Karthik Padavala⁵, Dr. K M S Sagar Reddy⁶

¹Post graduate, Department of Prosthodontics, KIMS Dental college & Hospital, Amalapuram.

Email: bhargavigariganti88@gmail.com, ORCID id: 0009-0000-8763-9605

²Post graduate, Department of Prosthodontics, KIMS Dental college & Hospital, Amalapuram

Email: saiphanindra0075@gmail.com

^{3*} Associate Professor, Department of Prosthodontics, KIMS Dental college & Hospital, Amalapuram.

Email id: dr.rajujampana@gmail.com

⁴Professor & Head of the Department, Department of Prosthodontics, KIMS Dental college & Hospital, Amalapuram.

Email id: sumeetsharma14@gmail.com

⁵Post graduate, Department of Prosthodontics, KIMS Dental college & Hospital, Amalapuram.

Email id: padavalak143@gmail.com

⁶Post graduate, Department of Prosthodontics, KIMS Dental college & Hospital, Amalapuram.

Email id: kmssagar.reddy44@gmail.com

DOI: [https://doi.org/10.63001/tbs.2026.v21.i04.S.I\(4\).pp527-536](https://doi.org/10.63001/tbs.2026.v21.i04.S.I(4).pp527-536)

KEYWORDS: Implant dentistry; bone grafts; xenografts; autografts; dentin-derived grafts; guided bone regeneration; socket preservation; sinus augmentation.

Received: 20/09 /2026

Accepted :07/10/2026

Published: 17/10/2026

ABSTRACT

This umbrella review, conducted in accordance with PRISMA 2020 guidelines and registered in PROSPERO (CRD420261325454), synthesized high-level evidence to evaluate the clinical effectiveness of hard tissue graft materials in implant dentistry. To gather relevant data, the authors executed a targeted electronic search strategy across the PubMed and Scopus databases, specifically filtering for systematic reviews and meta-analyses published between January 2015 and December 2025. Out of all the literature screened, 18 specific studies were ultimately included.

The findings revealed that no single graft material holds universal superiority across all clinical indications. Instead, effectiveness is highly procedure-dependent: xenografts and alloplastic substitutes demonstrated favorable long-term volumetric stability, particularly in socket preservation and maxillary sinus augmentation procedures. Furthermore, composite grafts that combine autogenous bone with xenogeneic or synthetic substitutes consistently yielded superior regenerative outcomes compared to single-material grafts. Autogenous dentin-derived grafts emerged as a promising alternative, demonstrating favorable dimensional stability alongside strong osteogenic and osteoconductive potential. Additionally, the use of membrane-assisted guided bone regeneration significantly enhanced clinical outcomes in both buccal dehiscence defects and peri-implant regenerative procedures.

Ultimately, the review concludes that current evidence strongly supports an individualized, procedure-oriented approach to graft selection. Utilizing composite grafting strategies and biologically enhanced regenerative approaches appears to optimize clinical predictability and structural stability. While dentin-derived autografts represent a highly promising and innovative alternative for alveolar reconstruction, further long-term clinical evidence is still required to fully validate their regular use.

INTRODUCTION

Dental implant therapy has become a cornerstone of modern prosthodontic rehabilitation, offering predictable and long-term replacement of missing teeth. Successful implant outcomes depend on stable osseointegration, which in turn requires sufficient alveolar bone volume and quality to support implant positioning and long-term functional loading (1,2). Despite advances in implant design and surgical protocols, inadequate alveolar bone remains a common clinical challenge (1,3).

Alveolar bone deficiency frequently occurs as a result of post-extraction resorption, periodontal disease, periapical pathology, trauma, congenital conditions, or prolonged edentulism (4,3). These deficiencies may present as horizontal, vertical, or combined ridge defects, compromising implant stability, aesthetic outcomes, and peri-implant tissue health. Consequently, bone augmentation procedures have become an integral component of implant dentistry to facilitate implant placement in anatomically and prosthetically ideal positions (2,3).

Bone grafting aims to reconstruct deficient alveolar ridges, restore lost bone contours, and provide a biologically favorable environment for

osseointegration (1,5). Over the years, a wide range of bone graft materials has been developed, each differing in origin, biological properties, and clinical behaviour. Autogenous bone grafts, harvested from intraoral or extraoral donor sites, possess osteogenic, osteo-inductive, and osteoconductive properties and have traditionally been regarded as the reference standard for bone regeneration (3). However, their use is limited by donor-site morbidity, increased surgical complexity, limited availability, and unpredictable resorption (3,6).

To overcome these limitations, alternative graft materials have been widely adopted. Allogeneic bone grafts, obtained from human donors and processed to minimize immunogenicity, provide an osteoconductive scaffold and, in some forms, potential osteo-inductive properties (5,7). Xenogeneic grafts, commonly derived from bovine or porcine sources, consist of a mineral matrix that closely resembles human bone and are primarily osteoconductive, with the advantage of slow resorption and long-term volume stability (5,8). Synthetic or alloplastic grafts, composed of materials such as hydroxyapatite, β -tricalcium phosphate, calcium sulphate, and bioactive glass, offer biocompatible osteoconductive scaffolds without the risk of disease transmission,

although their regenerative potential may be limited when used alone in extensive defects (6,9).

In clinical practice, graft materials are often combined to optimize biological activity and structural stability. Composite grafts, typically consisting of autogenous bone mixed with allogeneic, xenogeneic, or synthetic substitutes, aim to reduce donor-site morbidity while maintaining regenerative capacity (6,7). Furthermore, biologically enhanced grafting approaches incorporating platelet concentrates, growth factors, or osteo inductive proteins have been introduced to promote angiogenesis, cellular differentiation, and accelerated bone formation, although variability in protocols and outcomes remains a concern (10,11). Alongside material development, multiple surgical techniques such as socket preservation, guided bone regeneration, ridge augmentation, ridge splitting, sinus floor elevation, and immediate implant placement with simultaneous grafting have been described to manage bone deficiencies (2,12,13). While these approaches have demonstrated favorable clinical outcomes, the diversity of graft materials and techniques has resulted in a rapidly expanding and heterogeneous body of literature.

In the context of evidence-based dentistry, systematic reviews and meta-analyses play a critical role in synthesizing clinical data related to bone graft materials and augmentation procedures in implant therapy (5,14,15). Numerous systematic reviews have evaluated outcomes such as implant survival, marginal bone loss, volumetric bone gain, and complication rates associated with different grafting strategies. However, overlap among reviews, variations in methodological quality, and inconsistent conclusions have made clinical interpretation challenging (14,15).

Umbrella reviews, which compile and critically appraise findings from multiple systematic reviews and meta-analyses, provide a higher-level synthesis of evidence. This approach allows for assessment of evidence consistency, identification of knowledge gaps, and clarification of the overall strength of available data (5,7). Given the complexity of bone augmentation procedures and the wide range of graft materials used in implant dentistry, an umbrella review offers a comprehensive framework to guide clinical decision-making and future research.

Therefore, the present umbrella review aims to synthesize and critically evaluate existing systematic reviews and meta-analyses on hard tissue graft materials and augmentation techniques used in implant dentistry, with particular emphasis on their clinical effectiveness, limitations, and evidence quality in the management of alveolar bone deficiencies. The review protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD420261325454.

Although numerous systematic reviews and meta-analyses have evaluated individual graft materials or specific augmentation procedures, they have generally focused on isolated clinical indications such as socket preservation, sinus floor augmentation, lateral ridge augmentation, or peri-implantitis. Consequently, clinicians are required to interpret multiple reviews that frequently report inconsistent conclusions and vary considerably in methodological quality. Furthermore, no previous umbrella review has comprehensively synthesized procedure-specific evidence across all major hard tissue graft materials while simultaneously evaluating the methodological quality of the available systematic reviews and identifying areas where evidence remains insufficient. Therefore, this umbrella review was undertaken to provide an integrated, high-level synthesis that bridges this knowledge gap and facilitates evidence-based clinical decision-making in implant dentistry.

AIM AND OBJECTIVES

Aim

To synthesize evidence from systematic reviews and meta-analyses on hard tissue graft selection in implant dentistry.

Objectives

- (i) To compare the effectiveness of autografts, allografts, xenografts, alloplast, and composite grafts.
- (ii) To assess outcomes across socket preservation, sinus augmentation, ridge splitting, immediate implant placement, buccal defects, and peri-implantitis.

- (iii) To evaluate bone dimensional stability and implant survival.
- (iv) To identify emerging trends including dentin-derived grafts.
- (v) To identify current research gaps.

MATERIALS AND METHODS

Study Design and Protocol

This study was designed as an umbrella review of systematic reviews and meta-analyses to synthesize high-level evidence on hard tissue graft materials used in implant dentistry (1,7). The methodology was developed in accordance with the PRISMA guidelines to ensure transparency and methodological rigor (16). The review protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD420261325454.

Search Strategy

A comprehensive electronic search was conducted independently by two reviewers in PubMed (MEDLINE) and Scopus from January 2015 to December 2025. Controlled vocabulary (Medical Subject Headings; MeSH) and free-text terms were combined using Boolean operators (AND, OR). The PubMed search strategy included:

("Dental Implants"[MeSH] OR implant dentistry OR implantology) AND

("Bone Transplantation"[MeSH] OR bone graft* OR autograft* OR allograft* OR xenograft* OR alloplast* OR dentin graft*) AND

("Systematic Review" OR "Meta-analysis")

The Scopus search strategy was adapted using TITLE-ABS-KEY fields with equivalent keywords and Boolean operators.

The search strategy combined Medical Subject Headings (MeSH) and free-text terms related to hard tissue grafting and implantology, including "autografts," "allografts," "xenografts," "alloplast," "hard tissue grafts," "dental implants," "sinus augmentation," "socket preservation," "immediate implant placement," "buccal defects," and "peri-implantitis" (6,8). Boolean operators (AND, OR) were applied to refine the search. Additionally, manual screening of reference lists of included articles was performed to identify further relevant studies (1,7).

Inclusion Criteria

Systematic reviews and meta-analyses evaluating hard tissue graft materials in implant-related procedures, including human clinical studies, and reporting clinically relevant outcomes such as bone gain, implant survival, or peri-implant tissue health.

Exclusion Criteria

Individual randomized controlled trials, case reports, case series, animal studies, in vitro studies, and narrative reviews were excluded. Studies lacking clear methodology or outcome reporting were also excluded.

Study Selection

The study selection process was conducted in two stages. Initially, titles and abstracts were screened for relevance, followed by full-text assessment of potentially eligible studies.

A total of 200 records were identified through database searching. After removal of duplicates and screening, 182 studies were excluded because of irrelevance or failure to meet the eligibility criteria. Finally, 18 systematic reviews and meta-analyses were included in the qualitative synthesis. Two independent reviewers screened titles and abstracts, followed by full-text assessment. Any disagreement was resolved through discussion, and when consensus could not be reached, a third reviewer adjudicated the decision. Duplicate removal was performed before screening.

Data Extraction

Data were extracted independently using a standardized form. The following variables were recorded: author and year of publication, number of included studies, graft materials evaluated, clinical indications, outcome measures, and main conclusions. Extracted outcomes included bone regeneration, volumetric stability, implant survival, and peri-implant tissue health.

Quality Assessment:

The methodological quality of included studies was assessed using the AMSTAR-2 tool. Reviews were categorized as high, moderate, low, or critically low quality based on compliance with critical appraisal domains (16).

Data Synthesis:

A qualitative synthesis of the included studies was performed because of heterogeneity in study designs, graft materials, and outcome measures. Findings were categorized based on graft type and clinical indication. Comparative evaluation was conducted to identify trends in effectiveness, and evidence tables were constructed to summarize outcomes and strength of evidence across studies.

Overlap Assessment

Because umbrella reviews may include systematic reviews containing overlapping primary studies, overlap was assessed qualitatively by comparing the primary studies included in each review. Considerable overlap was observed among reviews evaluating socket preservation and sinus augmentation. However, because the objectives, interventions, and outcome measures differed substantially across reviews, duplicate evidence was interpreted cautiously during qualitative synthesis.

PRISMA Flowchart:

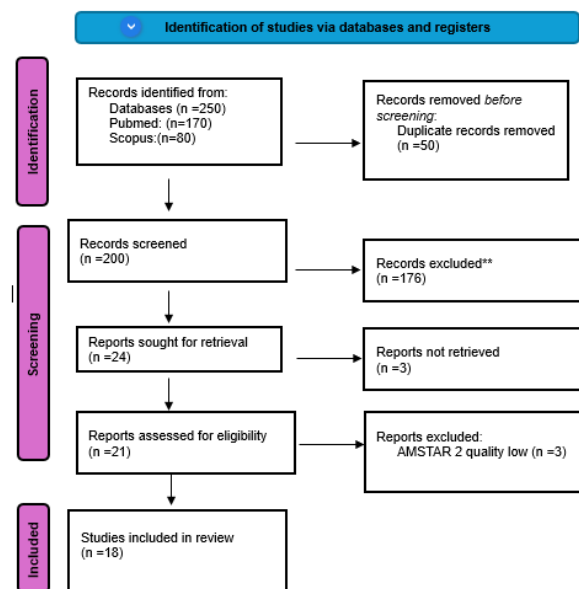


Table 1: List Of Systematic Reviews Included in the Study

Author (Year)	Study Type	Graft Types Evaluated	Clinical Indications	Key Outcomes Assessed	Main Findings / Conclusions	AMSTAR-2 Quality
Esposito et al. (2014) ⁽¹⁶⁾	Systematic Review	Various graft substitutes vs autografts	Maxillary sinus augmentation	Implant survival, marginal bone loss	No conclusive superiority of any single graft material	High
Avila-Ortiz et al. (2014) ⁽²⁾	Systematic Review & Meta-analysis	Xenografts, alloplasts	Socket preservation / immediate implant placement	Ridge dimensional changes	Ridge preservation significantly reduced horizontal and vertical bone loss	High
Troeltzsch et al. (2016) ⁽¹⁷⁾	Systematic Review	Autografts, xenografts, bone substitutes	Alveolar ridge augmentation	Histomorphometry, implant survival	Implant survival remained high regardless of graft type; autografts remodeled faster	Moderate
Elnayef et al. (2018) ⁽¹⁸⁾	Systematic Review & Meta-analysis	Autogenous block grafts, GBR, xenografts, allografts, alloplasts	Lateral ridge augmentation	Horizontal bone gain, graft resorption, implant survival	GBR showed lower morbidity; autografts demonstrated greater initial bone gain with higher resorption	High
Gual-Vaqués et al. (2018) ⁽¹⁹⁾	Systematic Review	Tooth-derived autogenous grafts	Ridge augmentation and bone grafting	Bone regeneration, graft integration	Tooth-derived grafts demonstrated favorable osteoconductive properties and satisfactory outcomes	High

Titsinides et al. (2019) ⁽²⁰⁾	Systematic Review	Autografts, allografts, xenografts, alloplasts	Dentoalveolar reconstruction	Bone regeneration, complications	Outcomes depended more on defect morphology and host biology than graft type	Moderate
Starch-Jensen et al. (2021) ⁽⁶⁾	Systematic Review & Meta-analysis	Autogenous bone, composite grafts, substitutes	Maxillary sinus augmentation	Volumetric stability, graft resorption	Composite grafts improved volumetric stability and reduced graft resorption	High
Trimmel et al. (2021) ⁽²¹⁾	Bayesian Network Meta-analysis	Autografts, xenografts, allografts, alloplasts, composite grafts	Maxillary sinus augmentation	New bone formation, implant survival, graft stability	Xenografts showed superior volume maintenance; autografts produced greater new bone formation	High
Di Stefano et al. (2022) ⁽²²⁾	Systematic Review	An organic bone xenografts vs collagen-preserving xenografts	Alveolar ridge preservation	Ridge dimensional changes, new bone formation	Collagen-preserving xenografts enhanced new bone formation; an-organic xenografts improved dimensional stability	High
Ferraz (2023) ⁽⁸⁾	Systematic Review	Autogenous, allogeneic, xenogeneic, alloplastic grafts	Ridge augmentation, sinus lift, socket preservation	Biological properties, bone regeneration	Autogenous bone remains the gold standard; substitutes provide predictable osteo-conduction with reduced morbidity	Moderate
Peceliunaite et al. (2023) ⁽²³⁾	Systematic Review	Autogenous tooth-derived grafts	Alveolar bone reconstruction	Bone regeneration, graft integration	Dentin-derived grafts demonstrated promising regenerative potential and biocompatibility	Moderate
Castro et al. (2023) ⁽²⁴⁾	Systematic Review	GBR materials and bone substitutes	Peri-implantitis regeneration	Bone regeneration, radiographic defect fill	Regenerative approaches improved peri-implant defect fill compared with debridement alone	Moderate
Alavi et al. (2024) ⁽¹⁵⁾	Systematic Review & Meta-analysis	Regenerative graft materials	Socket preservation	Ridge dimensional preservation	Regenerative graft materials significantly reduced post-extraction ridge collapse	High
Nunn et al. (2024) ⁽⁹⁾	Systematic Review	Carbonate apatite alloplasts	Bone regeneration procedures	Bone formation, graft integration	Carbonate apatite showed favorable osteoconductive and regenerative properties	Moderate
Rondone et al. (2024) ⁽²⁵⁾	Systematic Review & Meta-analysis	Hard and soft tissue grafts	Immediate implant placement	Peri-implant stability, esthetic outcomes	Tissue grafts improved peri-implant stability and esthetic integration	High
Azadi et al. (2025) ⁽²⁶⁾	Systematic Review & Bayesian Network Meta-analysis	Soft tissue grafting materials	Immediate implant placement	Soft tissue thickness, dimensional stability	Connective tissue grafts improved peri-implant soft tissue stability and reduced dimensional alterations	High
Del Fabbro et al. (2025) ⁽²⁷⁾	Systematic Review	Autogenous grafts, xenografts, hydroxyapatite, β -TCP	Maxillary sinus augmentation	Bone gain, graft stability	Autogenous grafts produced greater new bone formation, while xenografts showed superior long-term stability	High

Pushpanathan et al. (2025) ⁽²⁸⁾	Systematic Review & Meta-analysis	Socket preservation graft materials	Socket preservation	Ridge dimensional preservation	Socket preservation techniques significantly minimized alveolar ridge collapse	Moderate
--	-----------------------------------	-------------------------------------	---------------------	--------------------------------	--	----------

Table 2. Graft Material Performance Across Implant Indications:

Graft Material	Socket Preservation	Sinus Augmentation	Immediate Placement	Implant	Buccal Dehiscence (GBR)	Peri-implantitis	Strength of Evidence
Autograft	Moderate ^[8,17]	Moderate ^[6,21,27]	Limited ^[17]		Moderate ^[18]	Moderate ^[8]	Moderate
Allograft	Variable ^[8,13]	Variable ^[5,8,21]	Limited ^[8]		Limited ^[18]	Limited ^[5]	Low–Moderate
Xenograft	High ^[2,22]	High ^[6,21,27]	High ^[25,26]		High ^[18]	Moderate ^[24]	High
Alloplast	Moderate ^[2,15]	Moderate ^[27]	Moderate ^[9]		Moderate ^[20]	Limited ^[9]	Moderate
Composite Grafts	High ^[14]	High ^[6,21]	High ^[25]		High ^[18]	High ^[24]	High
Dentin-derived Grafts	High ^[19,23,28]	Moderate ^[23]	High ^[19]		High ^[23]	Emerging ^[19]	Low

RESULTS

Data extracted from the included systematic reviews and meta-analyses comprised graft type, clinical indication, membrane use, dimensional changes, implant survival or success, and comparative effectiveness (Table 1).

Methodological quality and risk of bias were assessed as reported within the included reviews and summarized using AMSTAR-2 baseline metrics (Table 1).

Overall Findings

Across all indications, no bone graft material demonstrated universal superiority (Table 1). Clinical outcomes were largely indication-specific and influenced by graft resorption characteristics, membrane use, and surgical protocol. Implant survival rates were generally comparable across graft materials when appropriate regenerative principles were followed (Table 4).

Emerging Materials

Autogenous dentin-derived grafts ^(19,23,29,30) demonstrated promising osteoconductive and osteo inductive properties, with regenerative outcomes comparable to xenografts while reducing donor-site morbidity (Table 2). Nevertheless, current evidence remains limited because of short follow-up periods and small sample sizes ^(23,28).

Strength of evidence: Low (Table 2).

Peri-Implantitis Regeneration

Regenerative management of peri-implantitis demonstrated heterogeneous outcomes across studies. Composite grafts combined with biologic modifiers and membrane-assisted regeneration showed improved defect fill and peri-implant bone regeneration; however, variability in defect morphology and treatment protocols limited definitive conclusions ^(12,13,24) (summarized in Table 2 and Table 3).

Strength of evidence: Low to moderate (Table 2).

Immediate Implant Placement

Adjunctive grafting during immediate implant placement improved facial bone thickness, ridge contour preservation, and peri-implant tissue stability ^(2,25,26) (Table 3). Xenograft-based guided bone regeneration combined with barrier membranes demonstrated improved aesthetic and dimensional outcomes compared with implant placement alone ^(17,25) (Table 4).

Strength of evidence: Moderate to high (Table 2).

Buccal Dehiscence and Fenestration Defects

Guided bone regeneration using xenografts in combination with resorbable membranes achieved superior defect resolution and improved graft stabilization ^(18,31) (Table 2). Membrane use was found to be critical for maintaining regenerative space, achieving strict graft particle containment, and minimizing soft tissue collapse ^(26,27,31) (Table 3).

Strength of evidence: High (Table 2).

Socket Preservation

Xenogeneic grafts and alloplastic substitutes consistently demonstrated superior horizontal and vertical dimensional stability when compared with autogenous grafts ^(2,15,22) (Table 4). Membrane-assisted socket preservation procedures significantly reduced post-extraction ridge resorption and improved clinical contour preservation ^(4,13,32) (Table 3).

Strength of evidence: High (Table 2).

Sinus Augmentation

In maxillary sinus floor augmentation procedures, xenografts ⁽²¹⁾ and composite grafts ⁽⁶⁾ demonstrated favorable histo-morphometric outcomes and superior long-term volumetric stability (Table 2). Autogenous grafts ⁽⁸⁾ exhibited greater early bone formation but also showed increased resorption over time (Table 4). Composite grafts effectively balanced osteogenic potential with space maintenance and graft stability (Table 2 and Table 3).

Strength of evidence: High (Table 2).

EVIDENCE SYNTHESIS

Overall, AMSTAR-2 assessment revealed heterogeneous methodological quality among the included reviews (summarized in Table 1). Most socket preservation and sinus augmentation reviews demonstrated moderate-to-high methodological quality, whereas evidence related to emerging biomaterials and peri-implantitis regeneration remained limited because of inadequate bias assessment and a lack of protocol standardization in the secondary literature (Table 1). Current evidence consistently supports procedure-oriented graft selection rather than reliance on a single universally superior graft material ^(21,22,23,24) (Table 2).

Table 3. Effect of Membrane Use and Adjuncts on Regenerative Outcomes:

Clinical Scenario	Graft + Membrane vs Graft Alone / Technique Used	Observed Benefit	Evidence Consistency
Socket Preservation	Yes (Membrane-assisted GBR)	Significant reduction in horizontal and vertical ridge resorption; improved contour preservation ^[2,15,32]	High
Immediate Implant Placement	Yes (Membrane with/without particulate graft)	Increased facial bone thickness; improved marginal bone stability and aesthetic outcomes ^[25,26]	Moderate–High
Buccal Dehiscence (GBR)	Yes (Barrier membrane critical)	Superior defect resolution; improved graft containment and space maintenance ^[18,31]	High
Sinus Augmentation	Adjunctive membrane use	Improved graft stability and reduced volumetric shrinkage; implant survival unaffected ^[6,27]	Moderate
Peri-implantitis Regeneration	Adjunctive membrane with biologics	Improved bone fill; technique-sensitive; heterogeneous outcomes ^[12,13,24]	Low–Moderate
Horizontal Ridge Deficiency	Ridge Splitting Alone (minimal grafting)	Adequate width gain in selected ridges; allows simultaneous implant placement ^[17,20]	Moderate
Ridge Splitting Gap	Ridge Splitting with Particulate Graft	Composite graft fills expansion gap; improved bone fill and reduced cortical collapse ^[8,18]	Moderate–High
GBR-Assisted Expansion	Ridge Splitting +with Membrane	Barrier membrane maintains expanded ridge space; enhanced dimensional stability ^[18,31]	High

DISCUSSION

This umbrella review synthesized and critically appraised evidence from systematic reviews and meta-analyses evaluating hard tissue graft materials used in implant-related regenerative procedures (Table 1). Unlike conventional systematic reviews that focus on individual graft materials or specific clinical procedures, this umbrella review provides a higher-level synthesis of evidence across multiple clinical indications, enabling comparison of graft performance while simultaneously evaluating the methodological quality and consistency of the available literature ^(5,7,16). Overall, the findings demonstrate that no single graft material can be considered universally superior for all clinical situations. Instead, successful regenerative outcomes are influenced by defect morphology, anatomical location, biological characteristics of the graft material, membrane utilization, surgical technique, patient-related factors, and clinician expertise ^(1,5,6,7). Consequently, the available evidence strongly supports a procedure-oriented rather

than a material-oriented approach to graft selection in implant dentistry ^(6,21,27).

Although several graft materials demonstrated favorable regenerative outcomes, direct comparison among studies remains challenging because of considerable heterogeneity in patient populations, defect characteristics, surgical protocols, outcome measures, healing intervals, and follow-up durations ^(6,17,18,21). Therefore, the interpretation of the findings should consider not only the reported clinical outcomes but also

the methodological quality and limitations of the included systematic reviews ⁽¹⁶⁾.

Regenerative Treatment of Peri-Implantitis

The regenerative management of peri-implantitis remains one of the most challenging areas in implant dentistry because successful treatment depends on multiple biological and technical factors. This umbrella review demonstrated that regenerative approaches combining composite graft materials, biologic modifiers, and membrane-assisted guided bone regeneration generally resulted in improved radiographic defect fill and peri-implant bone regeneration compared with debridement alone ^(11,24). However, despite these encouraging findings, no single regenerative protocol consistently demonstrated superior clinical outcomes across all studies.

The considerable heterogeneity among the included reviews largely explains these inconsistent findings. Differences in peri-implant defect morphology, implant surface characteristics, methods of implant surface decontamination, graft materials, membrane types, biologic adjuncts, and follow-up duration substantially influenced treatment outcomes ^(11,24). Furthermore, several systematic reviews included relatively small numbers of randomized clinical trials with varying risks of bias and inconsistent outcome reporting, thereby reducing the overall certainty of evidence. Consequently, although regenerative therapy appears promising, current evidence remains insufficient to recommend a single graft material as the preferred treatment modality for peri-implantitis ^(11,24).

Table 4: Outcome Measures Reported in Included Reviews:

Outcome measure	Overall trend across reviews
-----------------	------------------------------

Horizontal ridge stability	Improved with xenografts and composite grafts. ^(2,6,18,21,22)
Vertical bone gain	Enhanced with membrane-assisted GBR. ^(18,27,31)
Implant survival	Comparable across graft types. ^(16,17,18,21,27)
Aesthetic outcomes	Improved with grafting and membrane use. ^(25,26)
Graft resorption	Higher with autografts; lower with xenografts. ^(6,18,21,27)
Hist morphometric bone formation	Higher early bone formation with autografts and dentin-derived grafts. ^(17,19,21,23)

Immediate Implant Placement and Aesthetic Outcomes

Immediate implant placement combined with simultaneous grafting demonstrated favorable preservation of facial bone thickness, peri-implant soft tissue contours, and ridge architecture ^(2,25,26). Xenograft-based guided bone regeneration combined with resorbable barrier membranes consistently improved marginal tissue stability and aesthetic outcomes, particularly in the anterior aesthetic zone where maintenance of buccal bone volume is essential ^(25,26).

Although these findings support simultaneous grafting during immediate implant placement, interpretation should be approached cautiously. Considerable variation existed among the included reviews regarding implant systems, loading protocols, aesthetic evaluation methods, healing periods, and definitions of implant success ^(18,25,26). Moreover, most reviews primarily assessed radiographic and clinical outcomes, whereas relatively few incorporated patient-reported outcome measures such as aesthetic satisfaction and quality of life. Consequently, further well-designed randomized clinical trials incorporating standardized aesthetic indices and patient-centered outcomes are required before definitive superiority of any individual graft material can be established ^(25,26). (Table 2).

Role of Barrier Membranes in Guided Bone Regeneration

Across multiple implant-related regenerative procedures, membrane-assisted guided bone regeneration consistently demonstrated superior regenerative outcomes compared with grafting procedures performed without barrier membranes ^(18,25,26,27,31). Barrier membranes contributed to successful regeneration by maintaining space for bone formation, stabilizing graft particles, preventing soft tissue invasion, and promoting selective cellular repopulation of the defect ⁽³¹⁾.

Nevertheless, successful guided bone regeneration depends on considerably more than membrane selection alone. Surgical technique, flap design, membrane stability, defect morphology, soft tissue management, and prevention of membrane exposure all substantially influence regenerative outcomes. Therefore, although membrane-assisted GBR significantly enhances the regenerative potential of various graft materials, successful clinical outcomes remain highly technique-sensitive. These observations emphasize that meticulous surgical execution may be equally as important as biomaterial selection in determining long-term treatment success ^(18,31) (Table 3).

Procedure-Specific Performance in Socket Preservation

Socket preservation represents one of the most extensively investigated indications for hard tissue grafting. The present umbrella review demonstrated that xenografts and alloplastic substitutes consistently achieved superior horizontal and vertical dimensional stability compared with autogenous grafts ^(2,15,17,18,22). Preservation of ridge dimensions following tooth extraction is

clinically important because post-extraction alveolar remodeling frequently compromises prosthetically driven implant placement and may negatively affect long-term aesthetic outcomes ^(2,4,17).

Despite the consistent superiority of xenografts for dimensional preservation, maintenance of ridge dimensions should not be interpreted as equivalent to improved implant survival or overall clinical success.

Many included reviews evaluated radiographic dimensional changes without simultaneously assessing implant survival, patient satisfaction, or prosthetic outcomes ^(2,15,22). Furthermore, variability in socket morphology, graft particle size, membrane utilization, healing duration, and measurement techniques likely contributed to differences among systematic reviews ^(6,15,17,18). Therefore, graft selection for socket preservation should consider not only dimensional stability but also the biological and prosthetic requirements of the individual patient ^(6,7) (Table 3).

Emerging Role of Dentin-Derived Grafts

Among emerging regenerative biomaterials, autogenous dentin-derived grafts demonstrated particularly promising regenerative potential. Their biological similarity to native bone, preservation of endogenous growth factors, and favorable osteoconductive and osteo inductive characteristics contributed to regenerative outcomes comparable with conventional xenografts ^(19,23,28,33). Furthermore, dentin-derived grafts eliminate donor-site morbidity while utilizing extracted teeth as an autogenous biomaterial, thereby representing an attractive alternative for alveolar bone regeneration ^(19,23).

Despite these encouraging findings, the current evidence remains preliminary. Most systematic reviews included relatively few randomized clinical trials with limited sample sizes, short follow-up periods, and heterogeneous dentin-processing protocols. Consequently, although dentin-derived grafts represent one of the most promising developments in regenerative implant dentistry, widespread clinical implementation should await stronger evidence generated through multicenter randomized controlled trials with standardized methodologies and longer follow-up periods ^(19,23,28).

Maxillary Sinus Augmentation Procedures

Maxillary sinus augmentation remains one of the most predictable applications of bone grafting in implant dentistry. The findings of this umbrella review indicate that composite grafts combining autogenous bone with xenografts provide a favorable balance between early osteogenic potential and long-term volumetric stability. While autogenous bone demonstrated superior early new bone formation because of its osteogenic properties, its relatively rapid resorption and donor-site morbidity reduced its long-term clinical predictability. Conversely, xenografts demonstrated excellent space-maintaining ability and long-term dimensional stability, although they exhibited slower replacement by newly formed bone ^(21,27).

These findings suggest that composite grafting strategies effectively combine the biological advantages of autogenous bone with the structural stability of xenografts, thereby reducing donor-site morbidity while maintaining regenerative effectiveness. Nevertheless, considerable heterogeneity existed among the included reviews regarding histomorphometric evaluation methods, biopsy timing, volumetric assessment techniques, and follow-up duration, making direct comparison difficult ^(6,21,27). Emerging adjunctive regenerative approaches, including autologous platelet concentrates and demineralized tooth-derived grafts, may further enhance healing and graft maturation; however, additional high-quality evidence is required before these approaches can be routinely recommended ^(30,34).

LIMITATIONS:

Despite providing a comprehensive synthesis of the highest available level of evidence, this umbrella review has several limitations that should be considered when interpreting the findings. First, the review relied exclusively on previously published systematic reviews and meta-analyses; therefore, the quality and reliability of the present conclusions are inherently dependent on the methodological rigor of the included reviews. Variations in review methodology, inclusion criteria, and reporting standards may have influenced the consistency of the synthesized evidence.

Second, substantial clinical and methodological heterogeneity was observed among the included reviews. Differences in patient characteristics, defect morphology, graft materials, surgical techniques, membrane utilization, implant placement protocols, follow-up duration, and outcome assessment methods limited direct comparison across studies and precluded identification of a universally superior graft material. Such heterogeneity should be considered when translating these findings into routine clinical practice.

Another inherent limitation of umbrella reviews is the potential overlap of primary studies among included systematic reviews. Several reviews evaluated similar clinical questions, particularly for socket preservation, guided bone regeneration, and maxillary sinus augmentation, resulting in partial duplication of primary evidence. Although the available evidence was interpreted carefully to minimize duplication bias, overlap may have influenced the overall weight assigned to certain clinical findings.

In addition, the methodological quality of the included systematic reviews varied considerably. While several reviews demonstrated high methodological confidence, others exhibited important limitations, including incomplete protocol registration, inadequate assessment of publication bias, inconsistent reporting of excluded studies, and variability in risk-of-bias assessment of primary studies. Consequently, some conclusions should be interpreted with appropriate caution.

Furthermore, many of the included reviews primarily reported radiographic and histomorphometric outcomes, whereas patient-reported outcome measures, cost-effectiveness analyses, quality-of-life assessments, and long-term implant survival were comparatively underreported. These clinically relevant outcomes are essential for evidence-based decision-making and should be incorporated into future systematic reviews and primary clinical studies.

Finally, although emerging regenerative biomaterials such as dentin-derived grafts, carbonate apatite grafts, and biologically enhanced grafting protocols demonstrated encouraging preliminary results, the available evidence remains limited by relatively small sample sizes, short follow-up periods, and a limited number of high-quality randomized controlled trials. Therefore, further multi-centre randomized clinical trials with standardized methodologies and long-term follow-up are required to strengthen the evidence base and establish more definitive clinical recommendations.

Methodological Considerations and Strength of Evidence

AMSTAR-2 assessment demonstrated variable methodological quality among included reviews. High-quality evidence was predominantly available for socket preservation and sinus augmentation procedures, whereas evidence regarding peri-implantitis regeneration and emerging graft materials remained limited. Common methodological limitations included inadequate protocol registration, heterogeneity in outcome measures, and insufficient risk-of-bias assessment. These limitations should be considered when interpreting the findings and applying them clinically.

CONCLUSION

This umbrella review provides a comprehensive synthesis of the highest level of available evidence regarding the selection of hard tissue graft materials for implant-related regenerative procedures. The findings demonstrate that no single graft material can be considered universally superior across all clinical indications. Instead, successful regenerative outcomes depend on a complex interaction between defect morphology, biological characteristics of the graft material, anatomical location, surgical technique, membrane utilization, and patient-specific factors.

Among the evaluated graft materials, autogenous bone continues to be regarded as the reference standard because of its unique osteogenic,

osteo-inductive, and osteoconductive properties. However, its clinical application is limited by donor-site morbidity, increased surgical complexity, limited graft availability, and unpredictable resorption, which have encouraged the development and widespread use of alternative graft materials.

The present synthesis demonstrates that xenografts, particularly deproteinized bovine bone mineral (DBBM), provide excellent long-term volumetric stability and predictable clinical outcomes in socket preservation, guided bone regeneration, and maxillary sinus augmentation procedures, especially when combined with barrier membranes. Composite grafts, consisting of autogenous bone combined with xenogeneic or alloplastic substitutes, appear to offer an optimal balance between biological activity and structural stability by combining the osteogenic potential of autogenous bone with the space-maintaining characteristics of slowly resorbing biomaterials.

Emerging regenerative biomaterials, particularly autogenous dentin-derived grafts, demonstrated encouraging osteoconductive and osteo-inductive properties with clinical outcomes comparable to conventional xenografts while eliminating donor-site morbidity. Nevertheless, the available evidence remains limited by relatively small sample sizes, heterogeneous preparation protocols, and short follow-up periods. Consequently, their routine incorporation into clinical practice should await confirmation through high-quality multicenter randomized controlled trials with standardized methodologies and long-term evaluation.

An important finding of this umbrella review is that the success of regenerative therapy is influenced not only by graft material selection but also by adjunctive regenerative strategies, particularly the use of barrier membranes, biologic modifiers, appropriate case selection, and meticulous surgical execution. Therefore, clinicians should adopt a comprehensive treatment approach that integrates biomaterial properties with evidence-based surgical protocols rather than relying solely on the intrinsic characteristics of individual graft materials.

The methodological appraisal performed in this umbrella review also highlights that, although substantial evidence exists for socket preservation and maxillary sinus augmentation procedures, the certainty of evidence remains comparatively lower for peri-implantitis regeneration, emerging biomaterials, and newer regenerative techniques because of methodological heterogeneity, overlap among systematic reviews, inconsistent outcome reporting, and limited long-term clinical evidence. These limitations should be considered when interpreting the findings and translating them into routine clinical practice.

Overall, the current evidence supports an individualized, procedure-oriented approach to graft selection in implant dentistry. Clinical decision-making should be guided by defect characteristics, biological requirements, anatomical considerations, patient expectations, systemic health, and clinician experience rather than the assumption that one graft material is universally superior. Future research should prioritize well-designed multicenter randomized controlled trials, standardized outcome measures, longer follow-up periods, and direct comparisons of emerging biomaterials to strengthen the evidence base and facilitate more precise evidence-based recommendations for hard tissue graft selection in implant dentistry.

CLINICAL SIGNIFICANCE

This umbrella review provides clinicians with a comprehensive evidence-based synthesis to support the selection of hard tissue graft materials across a wide range of implant-related regenerative procedures, including socket preservation, maxillary sinus augmentation, guided bone regeneration, ridge augmentation, immediate implant placement, buccal dehiscence management, and peri-implantitis treatment.

The findings demonstrate that clinical success depends primarily on selecting the appropriate graft material for the specific clinical indication rather than identifying a universally superior biomaterial. Xenografts, particularly deproteinized bovine bone mineral (DBBM), consistently demonstrated favorable volumetric stability and predictable ridge preservation, making them suitable for socket preservation and sinus augmentation procedures where long-term maintenance of graft volume is essential. Composite grafts combining autogenous bone with xenogeneic or synthetic substitutes provide an effective balance between

biological activity and structural stability, making them particularly suitable for extensive ridge augmentation and guided bone regeneration procedures.

The review further emphasizes the critical role of barrier membranes in enhancing regenerative outcomes by maintaining graft stability, preventing soft tissue invasion, and facilitating predictable bone regeneration. Therefore, membrane selection and meticulous surgical execution should be considered integral components of regenerative therapy rather than optional adjuncts.

Although dentin-derived grafts and other emerging biomaterials demonstrated encouraging regenerative potential, the current evidence remains insufficient to recommend their routine clinical application across all indications. Their use should therefore be considered selectively until stronger long-term clinical evidence becomes available.

From a practical perspective, the present findings support a procedure-oriented treatment algorithm in which graft selection is individualized according to defect morphology, anatomical location, regenerative requirements, patient-related factors, aesthetic demands, and systemic health. Integrating evidence-based biomaterial selection with meticulous surgical technique and appropriate adjunctive regenerative strategies can improve osseointegration, preserve alveolar architecture, reduce complications, and enhance the long-term functional and aesthetic success of implant-supported prosthetic rehabilitation.

Clinical Decision Guide:

Clinical situation	Recommended graft
Socket preservation	Xenograft with membrane
Sinus lift	Composite graft
Horizontal GBR	Xenograft with collagen membrane
Immediate implant	Xenograft with GBR
Large vertical defect	Autogenous/composite graft
Emerging option	Dentin-derived graft

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

Ethical Approval

Ethical approval was not required for this umbrella review because it was based exclusively on the analysis of previously published systematic reviews and meta-analyses and did not involve direct participation of human subjects or the collection of identifiable patient data.

Informed Consent

Not applicable.

References

- Albrektsson T, Johansson c. Osteoinduction, osteoconduction and osseointegration. *European spine journal*. 2001 Oct;10(Suppl 2): S96-101.
- Avila-Ortiz G, Elangovan S, Kramer KW, Blanchette D, Dawson D. Effect of alveolar ridge preservation after tooth extraction: a systematic review and meta-analysis. *Journal of dental research*. 2014 Oct;93(10):950-8.
- Chiapasco M, Casentini P, Zaniboni M. Bone augmentation procedures in implant dentistry. *International Journal of Oral & Maxillofacial Implants*. 2009 Oct 2;24:237.

- Alenazi A, Alotaibi AA, Aljaeidi Y, Alqhtani NR. The need for socket preservation: a systematic review. *Journal of Medicine and Life*. 2022 Mar;15(3):309.
- Polo-Cunha L, Casado PL, Pimentel SP, et al. Bone grafts in dental medicine: a systematic review. *J Clin Med*. 2020 Aug;9(8):2507.
- Starch-Jensen T, Deluiz D, Vitenson J, Bruun NH, Tinoco EM. Maxillary sinus floor augmentation with autogenous bone graft compared with a composite grafting material or bone substitute alone: a systematic review and meta-analysis assessing volumetric stability of the grafting material. *J Oral Maxillofac Res*. 2021 ;12(1):e1.
- Zhao R, Yang R, Cooper PR, Khurshid Z, Shavandi A, Ratnayake J. Bone grafts and substitutes in dentistry: a review of current trends and developments. *Molecules*. 2021 18;26(10):3007.
- Ferraz MP. Bone grafts in dental medicine: an overview of autografts, allografts and synthetic materials. *Materials (Basel)*. 2023 . 31;16(11):4117.
- Nunn ME, Rudick C, Nikaido M, Miyamoto T. A systematic review of a novel alloplast carbonate apatite granules. *Front Dent Med*. 2024 16;5:1418039.
- Inchingolo F, Hazbala D, Inchingolo AD, Malcangi G, Marinelli G, Mancini A, et al. Innovative concepts and recent breakthrough for engineered graft and constructs for bone regeneration: a literature systematic review. *Materials (Basel)*. 2022 31;15(3):1120.
- Insua A, Galindo-Moreno P, Miron RJ, Wang HL, Monje A. Emerging factors affecting peri-implant bone metabolism. *Periodontol 2000*. 2024 ;94(1):27-78.
- MacBeth ND, Donos N, Mardas N. Alveolar ridge preservation with guided bone regeneration or socket seal technique: a randomised, single-blind controlled clinical trial. *Clin Oral Implants Res*. 2022 ;33(7):681-99.
- Wróbel P, Piecuch A, Bąk M, Krynicki P, Adamczyk J, Mojżesz P, et al. Evaluation of the effectiveness of the socket preservation technique using allogeneic and xenogeneic materials: a preliminary study. *J Funct Biomater*. 2025 23;16(6):192.
- Stumbras A, Kuliesius P, Januzis G, Juodzbalsys G. Alveolar ridge preservation after tooth extraction using different bone graft materials and autologous platelet concentrates: a systematic review. *J Oral Maxillofac Res*. 2019 31;10(1):e2.
- Alavi SA, Imanian M, Alkaabi S, Al-Sabri G, Forouzanfar T, Helder M. A systematic review and meta-analysis on the use of regenerative graft materials for socket preservation in randomized clinical trials. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2024 ;138(6):702-18
- Esposito M, Felice P, Worthington HV. Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. *Cochrane Database Syst Rev*. 2014;(8):CD008397.
- Troeltzsch M, Troeltzsch M, Kauffmann P, Gruber R, Brockmeyer P, Moser N, et al. Clinical efficacy of grafting materials in alveolar ridge augmentation: a systematic review. *J Craniomaxillofac Surg*. 2016;44(10):1618-29.
- Elnayef B, Porta C, Del Amo FS, Mordini L, Gargallo-Albiol J, Hernández-Alfaro F. The fate of lateral ridge augmentation: a systematic review and meta-analysis. *Int J Oral Maxillofac Implants*. 2018;33(3):622-35.
- Gual-Vaqués P, Polis-Yanes C, Estrugo-Devesa A, Ayuso-Montero R, Mari-Roig A, López-López J. Autogenous teeth used for bone grafting: a systematic review. *Med Oral Patol Oral Cir Bucal*. 2018;23(1):e112-e119.
- Titsinides S, Agrogiannis G, Karatzas T. Bone grafting materials in dentoalveolar reconstruction: a comprehensive review. *Jpn Dent Sci Rev*. 2019;55(1):26-32.
- Trimmel B, Gede N, Hegyi P, Szakács Z, Mezey GA, Varga E, et al. Relative performance of various biomaterials used for maxillary sinus augmentation: a Bayesian network meta-analysis. *Clin Oral Implants Res*. 2021;32(2):135-53.
- Di Stefano DA, Orlando F, Ottobelli M, Fiori D, Garagiola U. A comparison between anorganic bone and collagen-preserving bone xenografts for alveolar ridge preservation: systematic review and future perspectives. *Maxillofac Plast Reconstr Surg*. 2022;44(1):24.

23. Peceliunaite G, Pliavga V, Juodzbals G. The use of autogenous teeth tissues grafts for alveolar bone reconstruction: a systematic review. *J Oral Maxillofac Res.* 2023;14(4):e2.
24. Castro AB, Mombelli A, Quirynen M, et al. Regenerative surgical therapy for peri-implantitis: a systematic review. *Front Implant Dent.* 2023;17(38). doi:10.18502/fid.v17i38.5291.
25. Rondone EM, Leitão-Almeida B, Pereira MS, Fernandes GVO, Borges T. The use of tissue grafts associated with immediate implant placement to achieve better peri-implant stability and efficacy: a systematic review and meta-analysis. *J Clin Med.* 2024;13(3):821. doi:10.3390/jcm13030821.
26. Azadi A, Rezaei F, Yazdani A, Hejazi K, Moallem Savasari A, Amid R, Kadkhodazadeh M. Hard and soft tissue alterations after the application of different soft tissue grafting materials during immediate dental implant placement: a systematic review and Bayesian network meta-analysis. *BMC Oral Health.* 2025. doi:10.1186/s12903-025-05461-0.
27. Del Fabbro M, Taschieri S, Corbella S. Efficacy of different materials for maxillary sinus floor augmentation with lateral approach: a systematic review. *Clin Implant Dent Relat Res.* 2025;27(3):e70053.
28. Santos A, Botelho J, Machado V, Borrecho G, Proença L, Mendes JJ, Mascarenhas P, Alcoforado G. Autogenous mineralized dentin versus xenograft granules in ridge preservation for delayed implantation in post-extraction sites: a randomized controlled clinical trial with an 18 months follow-up. *Clinical oral implants research.* 2021 ;32(8):905-15.
29. Gandhi Y. Sinus grafts: science and techniques—then and now. *Journal of maxillofacial and oral surgery.* 2017 ;16(2):135-44.
30. Meng Y, Huang X, Wu M, Yang X, Liu Y. The Effect of Autologous Platelet Concentrates on Maxillary Sinus Augmentation: A Meta-Analysis of Randomized Controlled Trials and Systematic Review. *BioMed Research International.* 2020;2020(1):7589072.
31. Thoma DS, Payer M, Jakse N, et al. GBR with xenograft and membrane. *Clin Oral Implants Res.* 2012;23(7):820–827.
32. Pushpanathan KV, Chitrapatirapillay S, Pushparaj R, Kumar P. A Systematic Review and Meta-Analysis to Find Out the Efficacy of Socket Preservation Techniques in Adults in Split-Mouth Randomized Controlled Trials. *Cureus.* 2025 1;17(3):e79873.
33. Peceliunaite G, Pliavga V, Juodzbals G. The use of autogenous teeth tissues grafts for alveolar bone reconstruction: a systematic review. *Journal of Oral & Maxillofacial Research.* 2023 31;14(4):e2.
34. Choi H, Sohn DS. Retrospective study of maxillary sinus augmentation using demineralized tooth block bone for dental implant. *Bioengineering.* 2024 20;11(6):633.