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Long-Term Survival of Dental Implants Following Horizontal Bone Augmentation: A Systematic Review

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Abstract:

- ***Background:***

Horizontal bone augmentation, by guided bone regeneration (GBR), autogenous or substitute bone grafting, or the split crest technique, is frequently required to permit implant placement in atrophic alveolar ridges. Long-term comparative data on implant survival across these techniques remain limited. This systematic review aimed to synthesize the available evidence on long-term (≥5-year) survival rates of dental implants placed after horizontal bone augmentation.

- ***Methods:***

Following PRISMA 2020 guidelines, a systematic search of PubMed, Google Scholar, Scopus, and the Cochrane Library (January 2010–December 2024) was conducted using a PICO-structured question. Randomized controlled trials, cohort studies, and case-control studies reporting ≥5-year implant survival after horizontal bone augmentation in adults, free of bone-metabolism-affecting disease, were eligible. Methodological quality was assessed using the Joanna Briggs Institute (JBI) critical appraisal checklists for cohort, case-control, and randomized designs.

- ***Results:***

Of 84 records identified across databases (after removal of 6 duplicates) and 2 additional records from manual search, 17 studies (14 cohort, 2 case-control, 1 randomized controlled trial) met inclusion criteria, comprising 931 patients (605 females, 326 males; age range 18–87 years) and 1,747 implants. Bone grafting was used in 66% of patients, GBR in 32%, and split crest in 2%. Reported implant survival ranged from 80% to 100% over follow-up periods of 5 to 20 years: 91.9–100% for GBR, 80–100% for bone grafting, and 97–100% for split crest. The most frequent complications were membrane exposure (GBR), donor-site morbidity including wound dehiscence and sensory disturbance (bone grafting), and, less commonly, cortical plate fracture (split crest); most complications resolved with conservative management. On JBI appraisal, risk of bias was low in 3 studies, medium in 6, high in 4, and could not be determined in 4 due to incomplete reporting.

- ***Conclusions:***

GBR, bone grafting, and split crest techniques all achieve high long-term implant survival (80–100%) with generally manageable complication profiles, supporting their continued clinical use for horizontal ridge augmentation. Technique selection should be guided by defect size, bone quality, and operator expertise. The predominance of retrospective cohort designs and heterogeneous outcome reporting limit the strength of cross-technique comparisons; standardized, long-term randomized trials are needed.

Keywords: *Dental Implants; Horizontal Bone Augmentation; Guided Bone Regeneration; Bone Grafting; Split Crest; Implant Survival; Systematic Review.*

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I. INTRODUCTION

Dental implants have become a reliable and predictable solution for replacing missing teeth and restoring oral function [1]. Implant success, however, depends on adequate alveolar bone height and width, and horizontal bone augmentation by split crest, guided bone regeneration (GBR), or bone grafting is frequently required when ridge width is deficient, to create a stable implant foundation and to allow implant placement in a functionally and esthetically optimal position [2,3].

The split crest technique involves osteotomy and controlled expansion of the alveolar ridge, in some cases permitting simultaneous implant placement [4]. GBR uses barrier membranes, often combined with bone-substitute materials, to exclude soft-tissue cells from a bone defect and promote guided new bone formation [5]. Bone grafting uses autogenous, allogenic, or xenogenic material to augment deficient sites [6]; each technique carries distinct advantages and limitations, and technique choice depends on patient-specific factors and operator preference [7].

Despite widespread use of these techniques, their long-term efficacy and the survival of implants placed in augmented bone remain incompletely characterized. Reported complications include graft exposure and necrosis, membrane exposure, and failure of osseointegration [8]. GBR with resorbable membranes can achieve predictable short-term results, but the long-term stability of augmented bone has been questioned [9]. Split crest techniques, while effective in selected cases, carry a risk of cortical plate fracture and inadequate bone formation [10]. Autogenous bone grafting is considered the osteogenic gold standard, superior in this respect to xenogenic and allogenic grafts [11,12], but donor-site morbidity and limited graft volume remain important drawbacks [13].

Given the growing demand for implant therapy, a comprehensive synthesis of long-term implant survival after horizontal bone augmentation is warranted. This systematic review aimed to synthesize the available evidence on long-term survival rates of dental implants following horizontal bone augmentation by split crest, GBR, and bone grafting, and to characterize the frequency and management of associated complications, in order to provide clinicians with evidence-based guidance for treatment planning.

II. METHODS

➢ *Protocol and Research Question*

This review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [14]. The research question was structured using the PICO framework:

- Population: adults >18 years;
- Intervention: dental implants combined with horizontal bone augmentation
- Comparators: different horizontal bone augmentation procedures (GBR, bone grafting, split crest)
- Outcome: long-term implant survival
- Study designs: randomized controlled trials, cohort studies, and case-control studies.
- This yielded the research question: “What are the long-term survival rates of dental implants following horizontal bone augmentation?” The working group comprised a university hospital professor (supervision), a university hospital assistant, and the thesis candidate (search, critical appraisal, and data extraction), with regular group meetings.

➢ *Search Strategy*

Four electronic databases — PubMed, Google Scholar, Scopus, and the Cochrane Library — were searched for records published between January 1, 2010 and December 31, 2024 (search conducted November 7, 2024 to February 20, 2025). The PubMed search combined MeSH terms for dental implants (“Dental Implants,” “Dental Implants, Single-Tooth,” “Dental Implantation,” “Dental Implantation, Endosseous”), bone augmentation (“Bone Transplantation,” “Alveolar Bone Grafting,” “Alveolar Ridge Augmentation,” “Guided Tissue Regeneration, Periodontal”), and outcome terms (“Survival Rate,” “Follow-Up Studies”) using Boolean operators, filtered to 2010–2024 and to clinical studies, randomized controlled trials, and controlled clinical trials, yielding 159 records; 17 were selected for abstract screening after title screening. Google Scholar (keywords: dental implants, horizontal bone augmentation, survival rates; 2010–2024 filter, manual title-based selection) yielded 45 records for abstract screening. Scopus (same keywords, 2010–2024 filter, excluding book chapters, conference abstracts, case reports, and clinical trials) yielded 240 records, of which 18 were selected by title for full reading. The Cochrane Library search yielded 5 records after title screening.

➢ *Eligibility Criteria*

- Inclusion criteria: randomized controlled trials, cohort studies, or case-control studies; human subjects; absence of pathology affecting bone metabolism; patients who underwent horizontal bone augmentation followed by dental implant placement; articles published in English or French.
- Exclusion criteria: book chapters; review articles; case series or case reports; follow-up under 5 years; full text unavailable; article did not address the research question; animal studies; uncontrolled systemic disease; history of head and neck radiotherapy; language other than English or French.

Article relevance was assessed in a three-step process [15,16]: (1) title/abstract screening, (2) quality appraisal of pre-selected articles, and (3) data extraction.

➢ *Data Extraction and Quality Assessment*

A structured data extraction grid captured, for each study: bibliographic identification (author, journal, year, country, design); patient demographics (sample size, age, sex, cause of tooth loss); augmentation technique and its characteristics (membrane and graft type for GBR; harvest

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site and technique for block grafting; instrumentation for split crest); implant characteristics (type, primary stability, immediate vs. delayed placement); follow-up duration; and survival rate together with the occurrence and type of complications. Methodological quality of the 17 included studies was assessed using the Joanna Briggs Institute (JBI) critical appraisal checklists appropriate to each design (cohort, case-control, randomized trial). Studies scoring >70% were classified as good quality/low risk of bias, 50–70% as medium quality, and <50% as low quality/high risk of bias.

III. RESULTS

➢ *Study Selection*

Database searching identified 84 records (Scopus n=18, Google Scholar n=45, PubMed n=16, Cochrane n=5); after removal of 6 duplicates, 78 records were screened by title and abstract, of which 57 were excluded. The remaining 21 full-text articles were assessed for eligibility; 6 were excluded and manual searching identified 2 additional eligible articles, yielding a final total of 17 included studies (13 retrospective/cohort, 3 prospective cohort, and 1 randomized controlled trial; 14 cohort studies overall, 2 case-control studies, and 1 RCT).

➢ *Characteristics of Included Studies*

The 17 included studies were published between 2010 and 2023 and originated from Belgium, Italy (n=4), Switzerland (n=2), Germany (n=2), Korea, Denmark, Sweden/Italy, Brazil (n=2), Israel, Australia, and the Netherlands. Follow-up periods ranged from 5 to 20 years (mean/median not pooled given heterogeneity of reporting). Across all studies, 931 patients were included (605 female, 326 male; age range 18–87 years); the most commonly reported causes of tooth loss, where stated, were periodontal disease and trauma. A total of 1,747 implants were placed, of which 331 were sited in the maxilla and 165 in the mandible (site not further specified for the remainder). Bone grafting was the technique used in 66% of patients, GBR in 32%, and split crest in 2%. Among GBR cases, collagen membranes were used most frequently (444 sites), followed by e-PTFE membranes (170 sites) and titanium mesh (20 sites, one study); graft materials included deproteinized bovine bone mineral (DBBM), autogenous bone, and mixtures thereof. For block bone grafting, the harvest site was frequently unreported; where specified, the mandibular ramus, symphysis/chin, and retromolar region were most common. (Table 1).

Table 1 Summary of the 17 Included Studies: Design, Technique, Follow-up, Sample, Survival, and Main Complications.

Study	Country	Design	Technique	F-up	N	Surv.	Main complications
Wessels et al., 2020 [17]	Belgium	Cohort	GBR / ARP	5 y	18	100%	1 peri-implant mucositis
Sbordone et al., 2015 [18]	Italy	Cohort	Onlay bone graft	5 y	63	96.8% / 94.6%	2 failures; NM detail
Beretta et al., 2015 [19]	Italy	Cohort	Bone graft (mixed)	Mean 78 mo	192	95.6–97.7% (by graft type)	5 failures
Poli et al., 2014 [20]	Italy	Cohort	GBR (Ti-mesh)	88 mo	20	100%	1 early Ti-mesh exposure (CHX rinse)
Thoma et al., 2019 [21]	Switzerland	Case-control	Autogenous bone graft	5–16 y	27	100%	Donor-site: 2 dehiscence, 2 sensory disturbance, 1 both
Pieri et al., 2013 [22]	Italy	Cohort	Bone graft (mandibular block)	5 y	29	100%	1 paresthesia; 2 membrane exposures; 1 partial graft exposure/necrosis
Moukrioti et al., 2019 [23]	Germany	Case-control	Split crest	5 y	87	100%	3 donor/surgical-site infections
Choi et al., 2023 [24]	Korea	Cohort	GBR (porcine xenograft)	67.5 mo	28	95.9%	3 bone loss from infection; 2 lost
Nielsen & Starch-Jensen, 2021 [25]	Denmark	Cohort	Autogenous ramus block	10 y	46 (24 at 10y)	100%	8.3% peri-implantitis
Schwartz-Arad et al., 2016 [26]	Israel	Cohort	Autogenous onlay graft	137 mo	214	93.4%	Infection 4%, dehiscence 2.2%, peri-implantitis 5.8%, exposure 5.2%; 42 failures
Dahlin et al., 2010 [27]	Sweden/Italy	Cohort	GBR (xenogeneic + e-PTFE)	53–72 mo	20	97.5%	1 membrane exposure (CHX gel)
Jung et al., 2013 [28]	Switzerland	Cohort	GBR (resorbable/non-resorbable membrane)	12 y	152 (129 at 12y)	91.9–92.6%	9 failures (CM group), 3 (e-PTFE group)

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Garcez-Filho et al., 2015 [2]	Brazil	Cohort	Split crest	10 y	21 (14 at 10y)	97%	1 early + 1 late fixture failure
Gulinelli et al., 2017 [29]	Brazil	Cohort	Autogenous block graft	5 y	11	94.1%	1 coronoid fracture; 1 paresthesia; 1 lost implant
Voss et al., 2016 [30]	Germany	Cohort	Autogenous mandibular block	10 y	109	97.6%	4 losses (osseointegration failure, peri-implantitis, loading)
Bazrafshan & Darby, 2014 [31]	Australia	Cohort	Simultaneous bone augmentation (mixed)	5 y	73	80%	1 failure (unknown cause)
Meijndert et al., 2017 [32]	Netherlands	RCT	Local ridge augmentation	10 y	93 (76 at 10y)	95.7%	2 osseointegration failures; 2 soft-tissue/bone recession failures

ARP: Alveolar Ridge Preservation; CM: Collagen Membrane; CHX: Chlorhexidine; e-PTFE: Expanded Polytetrafluoroethylene; NM: Not Mentioned; RCT: Randomized Controlled Trial.

➢ *Survival by Technique*

Survival rates ranged from 80% to 100% across all techniques over follow-up periods of 5 to 20 years. For GBR, survival with DBBM combined with collagen or e-PTFE membranes ranged from 91.9% to 100%. For bone grafting, autogenous grafts harvested from the ramus or symphysis achieved survival of 94.1% to 100%, with one outlier series reporting 80% and one reporting 93.4% in the largest cohort (n=214). For split crest, survival ranged from 97% to 100% in the two studies using this technique as the primary approach.

➢ *Complications*

Complications were relatively infrequent and, where reported, were generally managed successfully with conservative measures. In GBR, membrane exposure was the most frequent complication (reported in at least 4 patients across studies): an early titanium-mesh exposure was managed with chlorhexidine mouthwash for 2 months; two partial membrane exposures related to flap-margin tension resolved with topical 1% chlorhexidine gel over 2–3 weeks; a further membrane exposure was managed similarly. In bone grafting, donor-site morbidity was the principal complication category, including wound dehiscence and sensory disturbance, resolving spontaneously without further therapy, one case of graft necrosis requiring surgical re-entry and a course of antibiotics, and one case of paresthesia treated with vitamin B complex and corticosteroids, resolving after 2 years. Infection, where it occurred, was generally managed with systemic antibiotics; prophylactic perioperative antibiotics were used in most studies and have been associated with reduced postoperative infection risk.

➢ *Methodological Quality*

Among the 14 cohort studies, a JBI score could be calculated for 10; of these, risk of bias was low in 2 [18,28], medium in 4 [17,19,20,27], and high in 4 [22,25,29,30]. For 4 cohort studies [Beretta et al., Choi et al., Schwartz-Arad et al., and Gulinelli et al.], incomplete reporting in the source data precluded calculation of a composite score. Both case-control studies [21,23] scored 70%, corresponding to low risk of bias. Quality appraisal of the single RCT [32] was not completed in the source material.

IV. DISCUSSION

This systematic review synthesized data from 17 studies (14 cohort, 2 case-control, 1 RCT; 7 focused on GBR, 7 on bone grafting, 1 on split crest, and 2 on mixed/various methods) reporting long-term (5–20-year) outcomes of implants placed following horizontal bone augmentation. All three techniques achieved high survival, with generally infrequent and manageable complications, supporting their continued clinical use.

Horizontal bone augmentation is indicated when ridge width is insufficient for implant placement of adequate diameter [3,40], when ridge defects result from trauma, tumor resection, or periodontal disease [35], in congenital ridge deficiencies, for esthetic site development in the anterior maxilla [34], and for ridge preservation immediately after extraction [35]. Technique selection is generally guided by defect size: GBR is typically favored for minor defects (<3 mm), split crest for moderate defects (3–6 mm, particularly with ridge width >4 mm and favorable bone density) [63,64], and block bone grafting for severe defects (>6 mm) [3,13]. Anatomical site also influences technique choice: anterior maxillary defects often require combined horizontal and vertical augmentation due to the characteristic resorption pattern, whereas posterior maxillary resorption typically produces isolated ridge narrowing managed by lateral augmentation, complicated by sinus proximity [37]. In the mandible, the position of the inferior alveolar nerve is a key determinant — GBR is preferred when residual bone height above the nerve is under 3 mm, while block grafts or osteotomy-based techniques are contraindicated in this setting owing to the risk of neurosensory injury [35,49].

The GBR results in this review — survival of 91.9–100% with DBBM and collagen or e-PTFE membranes — are consistent with prior reports of comparable success for horizontal ridge augmentation with GBR [41]. This predictability is attributable to the combination of an osteoconductive graft material with a barrier membrane that excludes soft-tissue ingrowth [36,45], although outcomes remain dependent on avoiding membrane exposure, which was the most frequently reported complication in this technique group [71]. For bone grafting, autogenous grafts

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from the ramus or symphysis achieved survival of 94.1–100%, with donor-site morbidity (wound dehiscence, sensory disturbance) as the principal drawback, consistent with previous literature highlighting this trade-off despite autogenous bone's favorable osteogenic profile [54,55]. Xenografts and allografts, sometimes combined with autogenous bone to limit donor-site morbidity, produced comparable results [9,53]. For split crest, survival of 97–100% was achieved, in line with a systematic review and meta-analysis reporting similarly favorable long-term outcomes for this technique [63]; this technique avoids donor-site surgery altogether but requires precise, skill-dependent osteotomy technique to avoid cortical plate fracture [61,62].

Complication patterns differed meaningfully by technique. GBR was associated with early-stage complications, chiefly premature membrane exposure, which — when detected early — was generally managed conservatively (chlorhexidine rinses or gel) without compromising long-term survival; non-resorbable (e-PTFE) membranes offer superior space maintenance but require a second surgical procedure for removal and carry a documented risk of soft-tissue dehiscence, whereas resorbable collagen membranes avoid a second surgery but may degrade prematurely [9,46]. Membrane exposure has been shown in a meta-analysis to reduce, but not necessarily eliminate, augmentation success when managed promptly [71]; classification systems for GBR complications have been proposed to standardize reporting and guide management [68]. Bone grafting carried a higher burden of donor-site morbidity, including sensory disturbance reported in the literature as occurring more frequently after chin harvest than after ramus harvest [54,55], but was associated with comparatively low long-term graft resorption once integrated. Split crest outcomes appeared most dependent on operator skill and precision, with cortical plate fracture as the principal technique-specific risk; the adoption of piezoelectric instrumentation has been associated with a reduced risk of this complication relative to conventional osteotomes and chisels [61].

These findings have direct clinical implications. Technique selection should integrate defect size, bone quality, and patient factors, alongside operator expertise — particularly for split crest, which demands specific surgical training [62,65]. Meticulous postoperative care, including infection control and monitoring for membrane or graft exposure, and structured management of complications when they occur [71], is central to achieving the high survival rates observed across the included studies.

V. LIMITATIONS

This review has several limitations. First, substantial heterogeneity existed across included studies in follow-up duration, implant success/survival criteria (clinical versus radiographic), and patient populations, limiting direct cross-study and cross-technique comparison. Second, several studies had small sample sizes, constraining the generalizability of individual survival estimates. Third, the evidence base was dominated by retrospective and prospective cohort studies (14 of 17), with only one randomized controlled trial and two case-control studies, introducing potential selection and reporting bias; a composite JBI quality score could not be calculated for 4 cohort studies and the single RCT because of incomplete methodological reporting in the source data, which itself constitutes a limitation of the underlying evidence base rather than of this review's appraisal process. Fourth, harvest site and several technique-specific variables (e.g., membrane type, graft composition) were frequently not reported in the primary studies, limiting sub-group analysis. Finally, given the marked heterogeneity in design and outcome reporting, a formal meta-analysis with pooled effect estimates was not performed; findings are therefore presented narratively rather than as a pooled quantitative synthesis, consistent with recommendations that methodological heterogeneity be explicitly assessed before pooling systematic review data [15,16].

VI. FUTURE RESEARCH

Priority areas for future research include long-term, adequately powered randomized controlled trials directly comparing GBR, bone grafting, and split crest under standardized surgical and postoperative protocols; adoption of standardized (clinical and radiographic) implant success criteria to permit valid cross-study comparison; and incorporation of patient-reported outcomes (satisfaction, function, esthetics, quality of life) alongside conventional survival endpoints. Comparative studies extending beyond 10 years are also needed to clarify the durability of augmented bone under long-term functional loading.

VII. CONCLUSION

This systematic review indicates that horizontal bone augmentation, whether by guided bone regeneration, autogenous bone grafting, or the split crest technique, can achieve dental implant survival rates of 80–100% over follow-up periods of 5 to 20 years, supporting the clinical reliability of these approaches for rehabilitating atrophic alveolar ridges. Each technique carries distinct trade-offs: GBR offers predictable outcomes with biomaterials such as DBBM but carries a risk of membrane exposure; autogenous block grafting remains the osteogenic gold standard, with the ramus graft particularly suited to larger defects owing to its cortical density and anatomical adaptability, at the cost of donor-site morbidity; and the split crest technique minimizes surgical invasiveness but demands precise operator technique to avoid cortical fracture. Comparing complication profiles across techniques using studies with ≥5-year follow-up suggests that autogenous grafts carry greater donor-site morbidity but lower long-term resorption, GBR shows more early-stage complications (particularly premature membrane exposure) with comparable long-term (10-year) survival, and split crest outcomes are heavily operator-dependent. Standardized surgical and outcome-reporting protocols, and long-term (>10-year) comparative studies, are needed to further reduce complications and clarify the durability of augmented bone under functional loading. Horizontal bone

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augmentation remains a cornerstone of implant dentistry, and aligning technique selection with the available evidence and individual patient needs allows clinicians to optimize outcomes while mitigating risk.

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- *Not applicable*

➢ *Conflict of Interest Statement*

The authors declare no conflict of interest related to this work.

➢ *Ethics Statement*

This systematic review analyzed previously published data and did not involve direct patient contact, new human-subjects research, or identifiable patient information; institutional ethics committee approval and patient consent are therefore not applicable. No ethics approval or waiver statement was reported in the source thesis, consistent with standard practice for systematic reviews of published literature.

➢ *Abbreviations*

ARP: alveolar ridge preservation; CHX: chlorhexidine; CM: collagen membrane; DBBM: deproteinized bovine bone mineral; e-PTFE: expanded polytetrafluoroethylene; GBR: guided bone regeneration; JBI: Joanna Briggs Institute; NM: not mentioned; PICO: Population, Intervention, Comparator, Outcome; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RCT: randomized controlled trial.

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