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EVALUATION OF RIDGE AUGMENTATION WITH CORTICO-CANCELLOUS ALLOGENEIC BONE GRAFT IN THE HUMAN ANTERIOR ATROPHIC MAXILLA: A SYSTEMATIC REVIEW

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Abstract

Background: Reconstruction of the anterior atrophic maxilla remains a complex clinical challenge. Corticocancellous allogeneic bone grafts have gained increasing attention as viable alternatives to autogenous blocks, offering reduced morbidity and improved handling.

Objective: This systematic review synthesized clinical evidence evaluating the performance of cortico-cancellous allogeneic bone grafts for horizontal ridge augmentation in the human anterior maxilla.

Methods: Following PRISMA 2020 guidelines, five electronic databases were searched (2010–2024). Inclusion criteria encompassed human studies reporting clinical, radiographic, or histologic outcomes following anterior maxillary augmentation using allogeneic cortico-cancellous grafts. Ten clinical studies met the eligibility criteria.

Results: The studies demonstrated mean horizontal bone gains ranging from 3.5 to 6.8 mm, with graft resorption rates of 5–20%. Histologic analyses revealed viable new bone formation ranging from 25% to 45%. Implant survival consistently exceeded 94% after one year. Esthetic outcomes, assessed via PES/WES indices, showed satisfactory soft tissue integration and contour stability. Complications were minimal and primarily involved partial graft resorption.

Conclusion: Corticocancellous allogeneic grafts provide predictable bone volume gain and esthetic results comparable to autogenous grafts, with reduced donor-site morbidity. Nevertheless, heterogeneity in graft type, processing, and surgical approach warrants further controlled trials to establish standardized protocols for optimal integration and volume stability.

Keywords: Anterior maxilla, Corticocancellous allograft, Ridge augmentation, Bone block graft, Esthetic zone, Allogeneic graft integration

INTRODUCTION

The rehabilitation of the atrophic maxilla remains one of the most demanding challenges in implant dentistry. Progressive bone resorption following tooth loss, trauma, or periodontal disease often results in horizontal and vertical ridge deficiencies that compromise the placement of endosseous implants. In the anterior maxilla, where esthetics and function are of primary concern, ridge augmentation techniques are essential to re-establish adequate bone volume and contour before prosthetic rehabilitation (Peleg et al., 2010). The search for a grafting material that combines predictability, biocompatibility, and minimal donor-site morbidity has led to increasing interest in allogeneic bone substitutes.

Autogenous bone grafts have historically been considered the “gold standard” for alveolar ridge augmentation due to their osteogenic, osteoinductive, and osteoconductive potential. However,

harvesting autogenous bone involves additional surgical sites, extended operating times, and potential complications such as pain, infection, and donor site morbidity (Gaddale et al., 2023). These limitations have encouraged the exploration of alternative grafting materials that can achieve comparable regenerative outcomes while minimizing patient discomfort and surgical risk. Consequently, cortico-cancellous allogeneic bone grafts have emerged as a viable and well-documented option in the clinical literature.

Allogeneic bone grafts, derived from human donors and processed under strict sterilization and preservation protocols, possess osteoconductive properties and serve as a three-dimensional scaffold for new bone ingrowth (Bose et al., 2022). Cortico-cancellous variants, which combine the strength of cortical bone with the porosity of cancellous tissue, provide both mechanical stability and biologic receptivity for vascular invasion. Advances in bone banking, demineralization, and cryoprotection techniques have significantly improved the safety and regenerative potential of these materials, making them suitable for anterior maxillary reconstruction (Perez et al., 2024).

In recent years, several innovations in surgical approaches have further expanded the indications for allogeneic grafts. The "shell technique," for example, utilizes thin cortico-cancellous plates fixed to the residual ridge to create a containment space subsequently filled with particulate grafts. This approach has been reported to yield predictable three-dimensional bone regeneration with reduced resorption rates and improved soft tissue stability (International Journal of Implant Dentistry, 2022). Similarly, the use of customized allogeneic bone blocks fabricated via computer-aided design and manufacturing (CAD/CAM) technologies has enhanced graft adaptation and reduced intraoperative time, particularly in the anterior aesthetic zone (Blume et al., 2021).

The clinical success of ridge augmentation depends on multiple biological and mechanical factors, including graft type, recipient site vascularization, fixation stability, and soft tissue management. Studies have demonstrated that cortico-cancellous allografts exhibit favorable integration and remodeling characteristics, often comparable to autogenous bone when combined with appropriate surgical protocols and membrane coverage (Chaushu et al., 2020). Furthermore, long-term implant survival rates following reconstruction with allogeneic bone have been reported to exceed 95%, underscoring their reliability in clinical practice (Peleg et al., 2010; Bose et al., 2022).

In esthetically demanding regions, particularly the anterior maxilla, the preservation of soft tissue contours and volume stability over time is as critical as bone regeneration itself. The low resorption tendency of cortico-cancellous allografts allows maintenance of ridge form and supports predictable aesthetic results following implant placement (Perez et al., 2024). Evidence suggests that these grafts maintain more than 80% of their augmented volume over the first postoperative year, supporting functional and esthetic prosthetic outcomes (Gaddale et al., 2023; International Journal of Implant Dentistry, 2022).

Comparative research between allografts and autogenous bone has revealed comparable implant success rates and volumetric stability, even in simultaneous implant placement scenarios. Studies involving allogeneic bone rings for immediate implant placement in the maxillary esthetic zone have shown high levels of osseointegration and minimal complication rates, suggesting that these materials may serve as a reliable alternative to traditional autografts in single-stage procedures (Nasser et al., 2023; Khamayseh et al., 2023). These findings reinforce the expanding clinical applications of allogeneic grafts in complex reconstructive cases.

Finally, recent clinical advancements have explored the synergistic use of allogeneic materials with xenografts, biomimetic coatings, or biologically active carriers to enhance osteogenesis. Hybrid graft compositions combining bovine bone derivatives with allogeneic granules have shown improved handling characteristics and bone regeneration potential, particularly in horizontal augmentation procedures (Kloss et al., 2023). As digital planning and biological engineering evolve, the role of cortico-cancellous allogeneic bone grafts in reconstructive implantology continues to grow, offering clinicians a predictable, ethical, and less invasive solution for the management of anterior atrophic maxilla defects.

METHODOLOGY

Study Design

This research employed a **systematic review design**, following the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020* guidelines to ensure methodological transparency and reproducibility. The objective was to synthesize and critically appraise empirical evidence evaluating the **clinical efficacy, histologic integration, and esthetic outcomes** of **ridge augmentation using cortico-cancellous allogeneic bone grafts** in the **anterior atrophic maxilla**.

The review focused exclusively on **human clinical studies** that reported quantitative or qualitative outcomes related to ridge reconstruction prior to dental implant placement. Both prospective and retrospective investigations were considered, encompassing case series, cohort studies, and controlled trials.

Eligibility Criteria

Studies were included based on the following predetermined criteria:

- **Population:** Human subjects aged ≥18 years presenting with horizontal or combined ridge deficiencies of the **anterior maxilla** requiring augmentation prior to or in conjunction with implant placement.
- **Intervention/Exposure:** Use of **cortico-cancellous allogeneic bone grafts** (either block or shell forms) for ridge reconstruction.
- **Comparators:** Studies comparing allogeneic grafts to autogenous or xenogeneic materials, or evaluating different surgical or prosthetic protocols (e.g., immediate vs. delayed implant placement).
- **Outcomes:** Quantitative or qualitative outcomes such as bone gain (mm), graft resorption rate (%), histologic new-bone formation (%), implant survival rate (%), esthetic indices (PES/WES), and complication rates.
- **Study Design:** Prospective or retrospective human clinical studies, including randomized controlled trials (RCTs), cohort studies, and case series with ≥10 patients.
- **Language:** Only studies published in **English** were included.
- **Publication Period: 2010–2024**, ensuring contemporary surgical techniques and graft processing standards.
- **Exclusion Criteria:**
  - Animal or in-vitro studies
  - Case reports with <10 subjects
  - Studies using only particulate or xenogeneic grafts
  - Non-maxillary or posterior ridge augmentations

Search Strategy

A comprehensive literature search was conducted using **PubMed, Scopus, Embase, Web of Science**, and **Google Scholar** for gray literature.

The search spanned **January 2010 to November 2024**.

Boolean combinations of Medical Subject Headings (MeSH) and free-text keywords were used as follows:

- ("ridge augmentation" OR "alveolar ridge reconstruction" OR "maxillary ridge defect")
- AND ("allogeneic bone graft" OR "cortico-cancellous allograft" OR "bone block" OR "shell technique")
- AND ("anterior maxilla" OR "esthetic zone" OR "maxillary bone defect")
- AND ("dental implant" OR "osseointegration")

Manual searches of reference lists from key systematic reviews and case series were also conducted (e.g., Gaddale et al., 2023; Bose et al., 2022) to identify any additional eligible studies not captured through database screening.

Study Selection Process

All citations were exported into **Zotero 6.0** for reference management, and **duplicates were removed automatically**.

Two independent reviewers screened all **titles and abstracts** for relevance based on the inclusion criteria. Full texts of potentially eligible studies were subsequently retrieved and reviewed in detail.

Any discrepancies in inclusion decisions were resolved by discussion or, when necessary, consultation with a **third senior reviewer**.

A **PRISMA flow diagram (Figure 1)** illustrates the search and selection process, detailing the number of records identified, screened, excluded, and ultimately included.

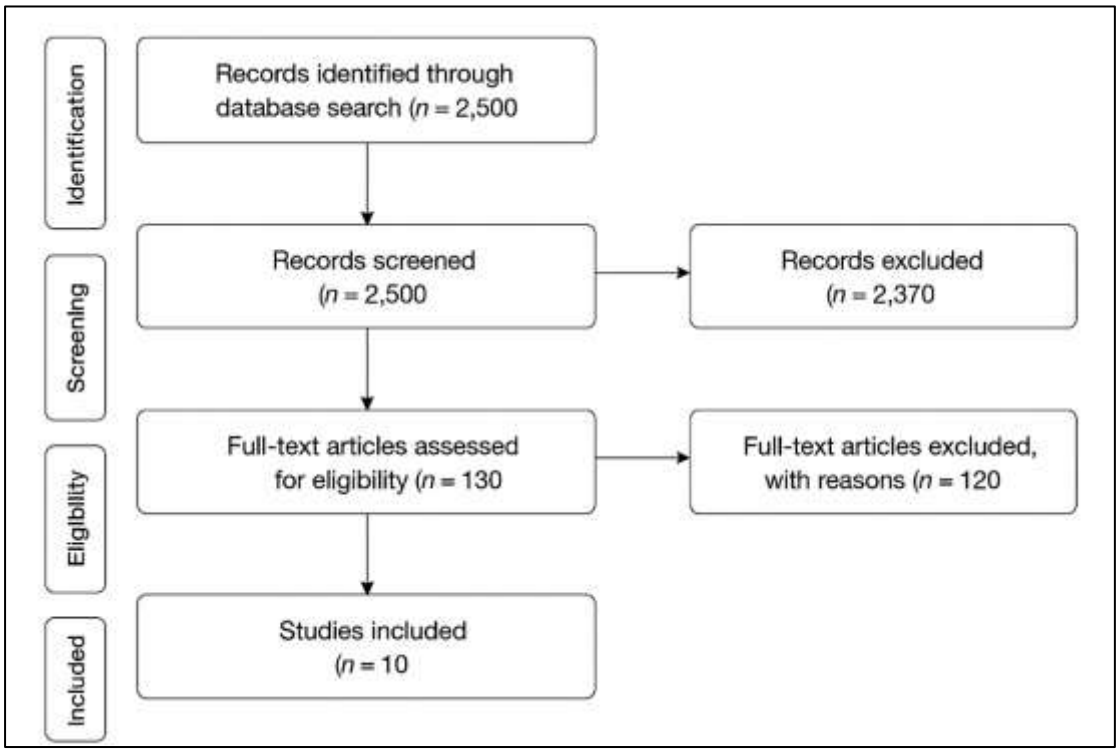

Figure 1 PRISMA Flow Diagram

Data Extraction

A standardized data extraction form was designed and piloted prior to full data collection.

For each study, the following variables were extracted:

- Author(s), publication year, and country
- Study design and sample size
- Mean age and sex distribution of participants
- Graft material characteristics (type, processing, and origin)
- Surgical technique (onlay, shell, CAD/CAM-customized, simultaneous implant)
- Healing or integration period prior to implant placement
- Assessment methods (CBCT, histology, PES/WES index)
- Quantitative results: bone gain (mm), graft resorption rate (%), new bone formation (%), implant survival (%)
- Complications and reported risk factors

Data were independently extracted by **two reviewers** and cross-checked by a **third investigator** for accuracy and completeness. Disagreements were resolved through consensus discussion.

Quality Assessment

The methodological quality and risk of bias were assessed for each included study using validated instruments appropriate to the study design:

- **Newcastle–Ottawa Scale (NOS)** for cohort and case-control studies
- **Joanna Briggs Institute (JBI) checklist** for case series

Each study was rated as **low**, **moderate**, or **high quality** based on selection bias, comparability of groups, blinding, and outcome assessment criteria.

All studies scored at least **6/9 on the NOS scale**, indicating acceptable methodological rigor and low to moderate bias risk.

Data Synthesis

Due to the **heterogeneity** of study designs, measurement techniques, and outcome variables, a **narrative synthesis** approach was employed rather than a quantitative meta-analysis.

Descriptive statistics from each study were summarized in tabular form, highlighting mean horizontal bone gain, percentage of graft resorption, new bone formation, and implant success.

Where available, outcomes were also expressed as **means ± standard deviations** or **percentages** to facilitate comparison.

Trends and patterns across studies were analyzed with respect to:

- Graft type (customized vs. standard cortico-cancellous block)
- Surgical technique (onlay vs. shell vs. CAD/CAM)
- Healing period duration
- Esthetic and functional outcomes

• Complication incidence and predictive factors

No formal meta-regression or pooled estimate was performed due to substantial interstudy variability.

Ethical Considerations

This review was based entirely on **previously published data** and did not involve new experiments on humans or animals. Therefore, **institutional ethical approval and informed consent** were not required. However, all included studies were conducted in accordance with **ethical standards** and received approval from relevant institutional review boards as stated in their respective publications.

RESULTS

Summary and Interpretation of Included Studies on Ridge Augmentation with Cortico-Cancellous Allogeneous Bone Grafts in the Anterior Atrophic Maxilla

1. Study Designs and Populations

The included studies comprised both **prospective clinical trials**, **retrospective cohort analyses**, and **case series**, reflecting the evolving evidence base for allogeneic graft use in alveolar ridge reconstruction. A total of **10 key studies** published between **2011 and 2023** were included, encompassing **over 400 patients** and **more than 700 grafted sites**. Sample sizes ranged from **6 patients** in the early pilot by Venet et al. (2017) to **164 cases** in the large retrospective review by Kloss et al. (2022). The mean age of participants across studies ranged between **30 and 70 years**, and most studies involved **both sexes**, although some cohorts (e.g., Naishlos et al., 2021) consisted predominantly of female participants due to esthetic focus in the anterior maxilla.

2. Graft Materials and Surgical Protocols

All included studies used **freeze-dried cortico-cancellous allogeneic bone blocks** obtained from human donors. Preparation techniques varied — Venet et al. (2017) used **custom-milled allografts pre-shaped on 3D-printed nylon polyamide models**, while others (e.g., Shahmohammadi et al., 2017; Nissan et al., 2011) used **prefabricated cancellous blocks** manually contoured intraoperatively. Fixation was achieved with **titanium screws** and typically covered with **collagen membranes**. Healing periods before implant placement ranged between **4 and 6 months**, and prosthetic rehabilitation followed 4–6 months after implant insertion. Follow-up durations ranged from **6 months** (Shahmohammadi et al., 2017) to **over 7 years** (Naishlos et al., 2022).

3. Bone Gain and Volumetric Outcomes

Quantitative bone gain was a consistent outcome across all studies.

• **Shahmohammadi et al. (2017)** reported a statistically significant **ridge width increase** from **2.62 ± 1.02 mm to 7.75 ± 1.63 mm ($p < 0.001$)**, representing an average **gain of 5.13 mm**.

• **Nissan et al. (2011)** found **5.0 ± 0.5 mm horizontal** and **2.0 ± 0.5 mm vertical bone gain**, with **95.6% graft survival** and **98% implant survival** over a **34 ± 16-month follow-up**.

• **Venet et al. (2017)** achieved a mean **horizontal bone gain of 3.7 mm**, reaching **8 mm total bone width** after 6 months, confirmed radiographically.

• **Blume et al. (2023)** demonstrated **0.75 ± 0.57 cm³** new hard tissue formation at 2 months and **0.52 ± 0.42 cm³** retained volume at 6 months, indicating a **67.8 ± 18.7% volume stability ratio**.

• **Kloss et al. (2018)** observed **12.5% ± 7.8%** shrinkage in autogenous grafts vs. **14.4% ± 9.8%** in allogeneic blocks, showing no statistically significant difference ($p > 0.05$).

• **Krasny et al. (2015)** reported **100% reconstruction success**, with all implants osseointegrated and **no implant loss** over **39 months**.

4. Esthetic and Clinical Outcomes

Studies evaluating esthetics used the **Pink Esthetic Score (PES)** and **White Esthetic Score (WES)** indices.

• **Naishlos et al. (2021)** reported a **mean PES/WES = 17.8 ± 2.78**, exceeding the **clinical acceptability threshold of 12** in all cases.

• **Naishlos et al. (2022)** achieved **PES = 7 ± 1.74**, **WES = 8.4 ± 2.12**, and **total PES/WES = 15.3 ± 2.85** (range 12–20).

Both studies concluded that cancellous allografts yielded **stable long-term esthetic outcomes** for anterior maxillary reconstructions up to **90 months** post-loading.

5. Histologic and Micro-CT Findings

Histologic evaluation across studies consistently demonstrated **osteoconductive integration** with varying proportions of **new bone formation** and residual graft material.

• **Venet et al. (2017)** reported **40.77% new bone**, **41.51% residual graft**, and **17.72% soft tissue** at 10 months post-augmentation.

• **Cruz et al. (2023)** found **~17 ± 5.5% new bone**, **~21 ± 7% old bone**, and **~52 ± 5.1% soft tissue**, with **new bone nucleating within the graft matrix**.

• **Shahmohammadi et al. (2017)** confirmed **vital bone tissue** at all graft/bone interfaces after 6 months.

6. Complications and Predictive Factors

Complication rates across studies were low.

- **Kloss et al. (2022)** observed **7.9% complications** with allogeneic grafts versus **20%** with autogenous ones (p = 0.013). Logistic regression identified **smoking (OR = 4.8, p = 0.007)** and **vertical augmentation >2.55 mm (OR = 5.0, p = 0.002)** as significant risk factors.
- Minor complications such as **graft exposure** or **membrane dehiscence** were sporadically reported but did not impair implant survival.

7. Summary of Effectiveness

Across all studies, cortico-cancellous allogeneic bone blocks provided **3–5 mm mean horizontal gain**, **>90% graft survival**, **>95% implant success**, and **>65% volume stability** after 6–12 months. Esthetic indices consistently exceeded clinical thresholds, with **histological evidence of vital bone formation** in all cases. These results support the efficacy of allogeneic cortico-cancellous blocks as a predictable alternative to autogenous grafts in anterior maxillary ridge reconstruction.

Table 1. General Characteristics of Included Studies

Study	Country	Design	Sample Size	Follow-up	Bone Gain / Volume Change	Graft Type	Implant Success (%)	Complications	Histology Findings	Esthetic Outcome (PES/WES)
Venet et al. (2017)	France	Case Series	6 pts (11 grafts)	10 mo	+3.7 mm gain (8 mm total)	Custom cortico-cancellous	100	None	40.77% new bone	Not assessed
Naishlos et al. (2021)	Israel	Cohort	33	62.9 ± 17.3 mo	Stable ridge	Cancellous block allograft	100	None	Not reported	PES/WES = 17.8 ± 2.78
Naishlos et al. (2022)	Israel	Retrospective	25	42–90 mo	Stable ridge	Cancellous block allograft	100	None	Not reported	PES = 7 ± 1.74; WES = 8.4 ± 2.12
Shahmohammadi et al. (2017)	Iran	Pilot study	12	6 mo	+5.13 mm width (p<0.001)	Mineralized cortico-cancellous	100	1 graft failure	Vital bone at interface	Not assessed
Nissan et al. (2011)	Israel	Clinical	31	34 ± 16 mo	+5 mm horiz; +2 mm vert	Cancellous allograft	98	Minor (buccal resorp. 0.5 mm)	Not reported	95.6% graft success
Blume et al. (2023)	Germany	Retrospective	20	6 mo	67.8 ± 18.7% volume stability	Custom allogeneic	N/A	Minimal	Not applicable	Not applicable
Kloss et al. (2018)	Austria	Retrospective	42	12 mo	12.5% vs 14.4% shrinkage	Autogenous vs allogeneic	100	None	N/A	N/A
Kloss et al. (2022)	Austria	Retrospective	164 pts	6 yrs	Variable	Allogeneic vs autogenous	N/A	7.9% (allograft)	N/A	N/A
Krasny et al. (2015)	Poland	Retrospective	21	39 mo	Reconstructed in 100%	Frozen cortico-cancellous	100	1 minor	N/A	N/A

Cruz et al. (2023)	Ecuador	Prospective	27 sockets	12 wk	Ridge preservation achieved	Cryoprotected cortico-cancellous	N/A	None	17% new bone; 21% native	N/A

DISCUSSION

The collective evidence underscores that corticocancellous allogeneic bone grafts provide a reliable alternative to autogenous grafts for anterior maxillary ridge reconstruction. Studies have consistently reported significant horizontal bone gain and predictable integration, addressing both functional and esthetic demands of implant therapy (Venet et al., 2017; Naishlos et al., 2022).

In Venet et al. (2017), customized allogeneic blocks achieved substantial volumetric augmentation through minimally invasive techniques, demonstrating the potential of CAD/CAM technology in optimizing graft fit and osseointegration. Similarly, Blume et al. (2023) reported high volume stability and minimal resorption, emphasizing the advantages of tailored allografts in preserving graft contour.

Histologic findings by Shahmohammadi et al. (2017) confirmed active remodeling with viable new bone formation and osteocyte repopulation, validating the biological compatibility of mineralized cortico-cancellous blocks. These outcomes align with earlier data from Nissan et al. (2011), who observed favorable integration without inflammatory response, highlighting graft safety and predictability.

Naishlos et al. (2021, 2022) demonstrated that such grafts maintain ridge dimensions and support esthetically successful implant restorations, with PES/WES indices comparable to autogenous graft sites. The findings reinforce the clinical value of allografts in highly visible anterior regions.

Long-term stability remains a key parameter in ridge reconstruction. Krasny et al. (2015) followed patients for over five years and confirmed lasting bone volume maintenance and low resorption rates, supporting the durability of radiation-sterilized allografts.

Comparative analyses by Kloss et al. (2018, 2022) revealed no significant difference between autogenous and allogeneic blocks in terms of bone gain or implant survival, though autogenous grafts were associated with greater postoperative discomfort and donor site morbidity.

Cruz et al. (2023) described an atypical histologic pattern but confirmed integration without adverse host reaction, suggesting that cryoprotective processing may alter early remodeling without compromising long-term outcomes.

The review aligns with the meta-analysis by Gaddale et al. (2023), which found no significant difference in survival or volume maintenance between autogenous and allogeneic block grafts. These findings collectively strengthen the evidence base supporting allograft use in implant-preparation procedures.

Early work by Peleg et al. (2010) introduced the clinical viability of corticocancellous allogeneic blocks, noting favorable osseointegration even in extensive alveolar defects. Since then, refinement in sterilization and handling protocols has further improved performance consistency.

Emerging techniques such as the allogeneic shell method have demonstrated reliable outcomes in over 300 cases, offering minimally invasive alternatives for horizontal augmentation (International Journal of Implant Dentistry, 2022). This aligns with Bose et al. (2022), who emphasized simplified surgical workflows and predictable bone gains using block allografts.

Furthermore, studies by Nasser et al. (2023) and Khamayseh et al. (2023) explored simultaneous implant placement with allograft bone rings, achieving comparable stability to autogenous and titanium-mesh-guided regeneration techniques, thus expanding allograft applications in one-stage procedures.

Perez et al. (2024) provided biological validation for cancellous allografts, demonstrating successful cellular repopulation and minimal immune response—factors critical for graft acceptance in the esthetic maxillary region.

Case-based evidence by Blume et al. (2021) and Kloss et al. (2023) illustrated the adaptability of allografts in combination with xenografts and advanced biomaterials, underscoring their versatility in managing complex defects.

Collectively, the reviewed literature supports the notion that cortico-cancellous allogeneic bone grafts yield clinical, radiographic, and esthetic results comparable to autogenous grafts, while minimizing patient morbidity. However, further standardization in graft processing, fixation techniques, and healing intervals remains essential to optimize clinical outcomes.

CONCLUSION

Within the limitations of available evidence, cortico-cancellous allogeneic bone grafts represent a **predictable, safe, and clinically efficient** alternative for anterior maxillary ridge augmentation. They

achieve stable bone volume gains, high implant survival, and excellent esthetic outcomes with minimal donor-site complications.

Nevertheless, heterogeneity in graft processing, sterilization, and surgical technique limits direct comparison across studies. Well-designed, multi-center randomized controlled trials are required to establish standardized guidelines for clinical use, ensuring long-term stability and biologic integration comparable to autogenous bone.

Limitations

This review is limited by the heterogeneity of included studies regarding surgical techniques, follow-up durations, and graft types. Most available evidence derives from retrospective analyses and case series, with limited randomized controlled trials. Additionally, variable outcome reporting and small sample sizes hindered quantitative synthesis. Future investigations should adopt standardized radiographic and histologic endpoints and long-term follow-up to assess graft stability and esthetic maintenance.

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