

Review

Digital Surgical Guides in Bone Regeneration: Literature Review and Clinical Case Report

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Featured Application

The present article aims to introduce a protocolized method that facilitates the performance of the Split Bone Block technique (SBBT) using allogeneic grafts and digitally designed, 3D-printed positioning guides.

Abstract

The present study describes a digitally guided workflow for the Split Bone Block Technique (SBBT) using standardized cortical and particulate allogeneic grafts in combination with custom-designed, 3D-printed surgical guides. The aim was to illustrate the feasibility of a donor-site-free alternative to the conventional autologous approach, which remains technically demanding and associated with increased morbidity. A narrative literature review and a single clinical case report were conducted to contextualize the proposed workflow. Digital planning was performed by merging DICOM and STL datasets to design cutting boxes for standardized allogeneic laminae and a transporter guide for intraoperative positioning. The technique was applied in a patient with severe horizontal ridge atrophy. Primary wound closure and uneventful healing were achieved. Six-month CBCT evaluation demonstrated an increase in horizontal ridge width from 2 mm to 8 mm. Within the limitations of a single illustrative case, this report suggests that a fully guided allogeneic SBBT workflow is feasible and may facilitate controlled graft adaptation while avoiding autologous bone harvesting. Further controlled clinical studies are required to evaluate accuracy, reproducibility, and long-term outcomes.

Keywords: split bone block technique; allogeneic graft; CAD-CAM; digital workflow; 3D printing; guided bone regeneration



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1. Introduction

The replacement of missing teeth with implant-supported dental prostheses is currently one of the most commonly used and predictable treatment options for restoring oral function and esthetics [1,2]. The long-term success of this therapy largely depends on fulfilling several biological and prosthetic requirements, particularly the presence of an adequate volume of alveolar bone that allows for the correct three-dimensional positioning of dental implants relative to the planned prosthesis. Indeed, the incidence of peri-implant bone loss appears to be lower when implants are surrounded by at least 1.5–2 mm of bone following insertion [3,4].

Therefore, various regenerative procedures are often necessary to restore lost bone architecture either prior to or simultaneously with implant placement, including maxillary sinus elevation, guided bone regeneration, onlay bone grafts, and bone block grafting [5,6].

In 2015, Professor Khoury proposed the SBBT for the treatment of combined three-dimensional bone defects. This technique involves creating a rigid framework, using two thin bone plates (approximately 1 mm thick), obtained from an autologous bone block harvested from the mandibular ramus during surgery, which is then filled with autologous bone particles, achieving stable long-term outcomes [7,8]. Even though autologous bone is accepted as the gold standard in bone regeneration due to its osteogenic, osteoinductive and osteoconductive properties and low complication rates [9], harvesting mandibular blocks and subsequently splitting them is a very operator-sensitive and time-consuming technique.

This increases patient morbidity and the risk of intraoperative complications, such as nerve injury or neurosensory disturbances [7]. However, this technique presents several disadvantages, including prolonged operative time, high morbidity, and limited bone availability. Due to these limitations, several modifications have been proposed to simplify the procedure and improve clinical outcomes. Consequently, the SBBT has evolved toward the use of non-autologous grafts, such as xenografts or allografts, which streamline the procedure and reduce surgical time by eliminating the need for block harvesting [10,11].

Recent studies have demonstrated that allografts possess bone regeneration properties comparable to those of autologous bone [12] and exhibit similar complication rates [13]. However, to date, no studies have reported the use of cortical allogeneic laminae combined exclusively with particulate allogeneic bone grafts.

The application of CAD-CAM technologies in surgical procedures has been increasingly explored over the past decade. The integration of emerging digital technologies into regenerative treatment planning has facilitated the combination of STL and DICOM datasets, optimizing accuracy and reducing operative time in complex bone regeneration procedures. Jacotti (2005) described a technique involving the fabrication of stereolithographic bone models, which allow the preoperative adaptation of bone blocks and the assessment of their fit prior to surgery [14]. Similarly, Venet (2017) reported a technique in which a bone block was manually milled to fit the defect on a 3D stereolithographic model, providing greater stability [15].

In 2017, De Stavola proposed the use of surgical guides for harvesting mandibular blocks with digitally preplanned dimensions, thereby reducing the risk of complications [16]. However, the precise final positioning of the graft, the division of the bone block into laminae of the desired size and shape, and the limited availability of intraoral donor bone remain clinical challenges, as bone block placement and its division into thin sheets are still performed manually.

Recently, several authors have reported studies employing digitally designed guides to facilitate the precise placement of grafts in their preplanned positions. Ureel et al. (2024) described the successful application of a customized, stackable, in-house-manufactured surgical guide system for mandibular reconstruction with immediate prosthetic rehabilitation, demonstrating the potential of digital workflows to enhance accuracy and streamline complex osseous regenerative procedures [17]. Other authors have reported similar techniques in the field of dental surgery. Nevertheless, these methods continue to rely on autologous bone—either through harvesting a bone block from the mandibular retromolar area, subsequently sectioning it into laminae to construct a framework filled with autologous bone particles following the original protocol [18], or by using autologous bone particles to fill a scaffold composed of allogeneic cortical laminae [19]. Although these innovative

approaches improve accuracy and reduce intraoperative time, they still require a secondary donor site for graft harvesting, thereby compromising postoperative recovery.

Despite these technological advances, the simultaneous digital planning of graft morphology and intraoperative placement devices has been scarcely investigated.

This article aims to review the current evidence regarding the use of digital surgical guides and CAD/CAM devices in guided bone regeneration procedures, and to illustrate their clinical application through a case report.

This case report introduces a fully guided split bone block regeneration workflow utilizing cortical allogeneic laminae in combination with particulate allogeneic bone grafts. To the best of our knowledge, no previous reports have described an exclusively allogeneic and fully guided workflow integrating both lamina preparation and guided intraoperative positioning.

2. Material and Methods

This study was conducted as a narrative literature review complemented by a clinical case report to contextualize the described digital workflow for a fully guided allogeneic SBBT. The aim of this narrative review was to collect, analyze, and synthesize selected literature on the evolution of the SBBT, to justify the use of allogeneic bone grafts, and to describe the integration of CAD–CAM technologies in regenerative bone procedures. The review was intended to provide a contextual and illustrative overview of the existing evidence rather than a systematic or exhaustive synthesis. Accordingly, no formal risk-of-bias assessment, quality grading of evidence, or quantitative synthesis (meta-analysis) was performed. Study selection and interpretation were focused on supporting the conceptual framework and clinical rationale of the proposed workflow.

2.1. Literature Search Strategy

The literature search was conducted between June and September 2025 across the following electronic databases: PubMed/MEDLINE, Scopus, Web of Science, and the Cochrane Library. The search strategy included the following terms: “split bone block technique,” “Khoury technique,” “autologous bone graft,” “allogeneic bone graft,” “digital workflow,” “guided bone regeneration,” and “CAD-CAM in bone reconstruction.” Filters were applied to include only peer-reviewed articles, human studies, and publications available in English or Spanish, published between 2000 and 2025.

References of selected papers were also manually screened to identify additional relevant studies not captured through the electronic search. To ensure completeness, studies describing surgical techniques or technological developments related to bone block grafting and digital planning in maxillofacial surgery were considered.

2.2. Inclusion and Exclusion Criteria

Inclusion criteria comprised studies that

- Focused on the Khoury SBBT or its modifications;
- Evaluated clinical outcomes of allogeneic or xenogeneic cortical laminae used for alveolar ridge reconstruction;
- Reported digital or guided approaches for block graft preparation and positioning.

Exclusion criteria involved

- Animal studies, in vitro experiments, technical notes without clinical application, and publications without accessible full text.

2.3. Study Selection and Review Process

All yielded articles were screened independently by two reviewers based on titles and abstracts, followed by full-text assessment to determine eligibility. Discrepancies were resolved through discussion until consensus was achieved. The final selection included 48 articles that met the inclusion criteria and provided substantive data on the evolution and outcomes of SBBT and its digitally guided variations (Table 1).

Table 1. Summary of key studies on autologous SBBT, allogeneic cortical laminates and digital workflows, including study design, materials used, main outcomes, and clinical relevance.

Domain	Study (Year)	Design/Material	Main Outcomes	Clinical Relevance
Autologous SBBT	Khoury & Hanser (2015) [7]	Prospective clinical series; autologous cortical laminae	High horizontal gain; stable long-term results	Foundational description of SBBT
Autologous SBBT	Khoury & Hanser (2019) [8]	Long-term evaluation; autologous thin plates	Predictable remodeling; low exposure rate	Confirms biological reliability of SBBT
Autologous SBBT	Cha et al. (2016) [5]	Clinical study; autogenous block grafts	Successful augmentation; donor-site morbidity noted	Reinforces effectiveness but highlights drawbacks
Autologous SBBT	Tolstunov (2019) [6]	Narrative review; ridge defect classification	Standardized categories for treatment planning	Indication framework
Autologous SBBT	McAllister (2001) [9]	Review on autogenous graft biology	Osteogenic, osteoinductive, osteoconductive properties	Biological rationale for using autografts
Allogeneic Cortical Laminae	Kloss et al. (2018) [13]	Clinical study; allogeneic blocks	Comparable complication rates to autografts	Supports safety and predictability
Allogeneic Cortical Laminae	Starch-Jensen et al. (2020) [12]	Systematic review	Similar horizontal gain vs. autografts; no severe complications	Evidence base for allogeneic alternatives
Allogeneic Cortical Laminae	Iglesias-Velázquez et al. (2021) [11]	Case series; allogeneic laminae	Satisfactory ridge gain; reduced morbidity	Promising alternative to autogenous SBBT
Allogeneic Cortical Laminae	Puigpelat et al. (2023) [19]	Guided lamina scaffold + autologous particulate	Improved precision; limited operative time	Hybrid approach demonstrating feasibility
Allogeneic Cortical Laminae	Wang et al. (2023) [20]	Customized CAD/CAM allografts	Greater horizontal gain; reduced resorption	Supports individualized allograft design
Digital Workflows	Jacotti et al. (2016) [14]	Three-dimensional stereolithographic planning	Improved block adaptation; lower intraoperative adjustments	Early adoption of digital planning
Digital Workflows	Venet et al. (2017) [15]	Preoperative 3D model milling	Enhanced stability and reduced operative time	Advances graft preadapting techniques

Table 1. Cont.

Domain	Study (Year)	Design/Material	Main Outcomes	Clinical Relevance
Digital Workflows	De Stavola et al. (2017) [16]	CAD-guided autologous block harvesting	Reduced donor-site risk; standardized block size	Introduces guided harvesting protocols
Digital Workflows	Ureel et al. (2024) [17]	Fully digital, stackable guides	High positional accuracy; successful mandibular reconstruction	Demonstrates advanced digital workflows
Digital Workflows	Cebrián et al. (2025) [18]	Digitally guided lamina placement (autologous)	Increased accuracy; reduced chair time	Digital lamina positioning concept

2.4. Methodological Framework

The methodological framework adhered to the SANRA (Scale for the Assessment of Narrative Review Articles) guidelines to ensure clarity, rigor, and transparency in the review process. Special attention was given to maintaining objectivity by presenting both supportive and critical findings regarding the use of allogeneic grafts and digital workflows.

2.5. Aim and Scope of the Narrative Review

The final narrative aimed to identify current challenges, advantages, and gaps in the literature surrounding the fully guided application of cortical allogeneic laminae combined with particulate grafts. This integrative approach provided a scientific framework supporting the clinical case presented and outlined potential future directions for research and clinical standardization of digital bone regeneration protocols.

2.6. Patient Information

A 38-year-old female patient presented for implant-supported rehabilitation. Medical history included rheumatoid arthritis and glaucoma. No allergies or deleterious habits were reported.

Clinical examination revealed multiple edentulous spaces and a Type 4 ridge defect per Benic and Hämmerle [21], characterized by severe horizontal atrophy precluding primary implant stability. The patient exhibited a normal mouth opening and a stable, reproducible occlusion.

3. Results

3.1. Narrative Synthesis

The included studies were categorized into three main domains: (1) autologous SBBT, (2) allogeneic cortical lamina techniques, and (3) digitally assisted workflows (Table 1).

Autologous SBBT studies reported favorable horizontal bone gain and high implant survival rates; however, outcomes were strongly operator sensitive and associated with donor-site morbidity. Variability in cortical thickness, block splitting accuracy, and intraoperative handling were frequently cited limitations, reducing reproducibility.

Studies evaluating allogeneic cortical laminae demonstrated comparable short-term bone gain while eliminating donor-site morbidity and reducing surgical complexity. Nevertheless, the available evidence remains heterogeneous, with limited controlled trials and short follow-up periods.

Digitally assisted workflows were primarily described in technical reports and case series. These procedures suggest improved intraoperative control and workflow efficiency;

however, quantitative assessments of accuracy, deviation from virtual planning, and long-term clinical outcomes are largely lacking.

Overall, the literature reflects a progressive shift toward standardization and digital assistance in alveolar bone reconstruction. However, no controlled studies to date have evaluated a fully guided allogeneic SBBT workflow, highlighting a significant gap that the present case report aims to illustrate at a feasibility level.

3.2. Timeline of Clinical Case

The clinical course progressed uneventfully throughout the observation period. Digital records and virtual planning were completed at baseline, followed by guided surgical intervention at week 0. Soft tissue healing was favorable, with no complications observed during early follow-up. Stable keratinized tissue without dehiscence was noted at 1 month, and ridge contour remained stable at 3 months with no signs of infection or graft exposure. Radiographic evaluation at 6 months confirmed the treatment outcome (Table 2).

Table 2. Timeline of diagnostic, surgical, and postoperative events of the clinical case.

Time Point	Key Events
Day 0	Digital records (STL/DICOM), virtual planning, diagnostic wax-up
Week 0	Surgery: guided lamina preparation, transport, fixation, particulate grafting
Week 2	Suture removal; uneventful soft tissue healing
1 Month	Stable keratinized tissue, no dehiscence
3 Months	Ridge contour stable; no signs of infection or exposure
6 Months	CBCT outcome assessment

3.3. Clinical Course

Healing progressed uneventfully. No lamina exposure, infection, or soft-tissue complications occurred.

3.4. Radiographic Outcome

Six-month CBCT demonstrated horizontal ridge augmentation from 2 mm preoperatively to 8 mm, representing a net gain of 6 mm. The regenerated compartment exhibited homogeneous radiopacity with stable lamina alignment.

3.5. Current Status

Implant placement has not yet been performed and is planned for a later phase of treatment. Long-term loading outcomes are not available

4. Discussion

Several authors have proposed alternative methods to optimize block harvesting, positioning and fixation of cortical bone plates at the recipient site [16,18]. These approaches aim to improve surgical efficiency, reduce intraoperative complications and enhance the precision of graft adaptation. Despite these innovations, the autogenous SBBT remains highly operator-sensitive. The variability inherent to cortical and cancellous bone thickness, combined with the anatomical morphology of the donor region, often compromises the standardization and reproducibility of the final laminae obtained. Differences in bone density and cortical thickness between patients—or even between different regions of the same donor site—can lead to inconsistencies in graft quality, potentially affecting the stability and long-term success of the regenerative procedure. Moreover, harvesting autologous blocks from intraoral donor sites introduces potential complications, including

neurosensory disturbances, bleeding and prolonged postoperative discomfort, which may limit patient acceptance and increase surgical morbidity [7,9].

In this context, allogeneic block grafts have emerged as a viable alternative, offering distinct advantages in terms of standardization, predictability and surgical simplicity. A recent systematic review and meta-analysis demonstrated that allogeneic grafts achieved success rates of 98–100% and implant survival rates of 95–100% in short-term follow-up, indicating that they can provide clinical outcomes comparable to those of autologous grafts [22]. These findings suggest that allogeneic bone not only eliminates the need for a secondary donor site—thereby minimizing patient morbidity and surgical complexity—but also achieves equivalent regenerative outcomes. Furthermore, patients receiving customized allogeneic grafts have been shown to experience greater horizontal bone gain and reduced resorption six months postoperatively compared with those treated with autologous grafts, along with significantly shorter operative times [20].

The availability of standardized plates with predefined thicknesses and dimensions further enables the fabrication of digitally customized cutting devices, enhancing the reproducibility of virtual planning and improving clinical outcomes [19]. Digitally guided workflows allow for a more precise trimming and adaptation of allogeneic laminae to patient-specific anatomy, facilitating optimal graft-to-recipient site contact and reducing the risks of exposure, micromotion, and resorption [15]. This level of precision is often difficult to achieve with manually prepared autologous grafts, particularly in challenging anatomical scenarios such as severely atrophic maxillae, posterior mandibles with limited access, or cases managed by less-experienced clinicians.

From a biological perspective, the traditional advantage of autologous bone grafts has been attributed to the presence of viable osteogenic cells, osteoinductive factors, and an intact extracellular matrix capable of regulating cellular migration, proliferation, and differentiation. However, it is well established that most cells within autologous grafts do not survive the harvesting and transplantation process, with only approximately 10% of osteogenic cells remaining viable postoperatively [23]. Interestingly, studies comparing allogeneic and autologous grafts have reported comparable bone gain and resorption rates, despite the absence of viable cells in allografts [12,24]. This phenomenon can be attributed to the preserved structural integrity of the allogeneic extracellular matrix, which provides a scaffold rich in collagen and signaling proteins that guide host cell migration and vascular ingrowth. Additionally, the intrinsic properties of the allogeneic matrix appear to elicit a host response favoring gradual integration rather than an inflammatory reaction, ultimately promoting bone formation and remodeling [25]. These findings underscore the concept that the regenerative capacity of bone grafts is not solely dependent on the survival of donor cells but also on the quality of the matrix and its ability to stimulate host-mediated bone formation.

Nevertheless, certain limitations of allogeneic grafts must be acknowledged. Although the risk of disease transmission is extremely low due to rigorous donor screening, processing, and sterilization protocols, slight differences in osteoinductive potential and resorption kinetics compared with autologous bone may influence long-term outcomes in specific clinical scenarios [13]. Cases of partial resorption or delayed remodeling have been reported, particularly in large or critical-size defects, emphasizing the need for careful patient selection, meticulous surgical technique, and close postoperative monitoring. Moreover, the long-term biological behavior of allogeneic grafts in combination with different fixation methods and prosthetic loading protocols remains an area requiring further investigation [26].

The integration of digital technologies in regenerative procedures seems to enhance the precision and efficiency of complex grafting protocols. The use of computer-aided

design and computer-aided manufacturing (CAD-CAM) facilitates virtual planning of graft morphology, cutting guides, and intraoperative positioning devices, enabling surgeons to anticipate potential challenges and tailor grafts to patient-specific anatomy. Surgical guides have been shown to reduce operative time, improve accuracy, and streamline workflow during bone block placement [19]. However, these benefits are largely restricted to the intraoperative phase, as digital planning requires a substantial preoperative investment of time and expertise. Meticulous virtual planning—including accurate alignment of CBCT and intraoral scan datasets, 3D segmentation, and the creation of STL files—is essential to achieve the precision required for customized biomaterials. Variability in 3D design software, printing technologies, and resin materials can also influence the dimensional accuracy and mechanical performance of printed devices, potentially affecting clinical adaptation and outcomes. However, without standardized acquisition protocols, validated segmentation workflows, and controlled printing parameters, the accuracy achieved in isolated clinical reports cannot be reliably reproduced across practitioners or clinical environments.

Despite the potential advantages of digitally guided regenerative workflows, several limitations and sources of inaccuracy must be acknowledged. Moreover, these findings must be interpreted within the limitations of a narrative review, which does not allow formal assessment of evidence quality, risk of bias or quantitative comparison between techniques. First, the accuracy of virtual planning is highly dependent on CBCT image quality and segmentation reliability. Factors such as voxel size, scatter artifacts, partial-volume effects, and operator-dependent threshold selection may introduce discrepancies between the segmented digital bone model and the actual intraoral anatomy, potentially affecting graft design and guide adaptation. Second, errors may arise during dataset registration and intraoperative guide positioning. Inaccurate alignment between DICOM and STL datasets, as well as incomplete seating of tooth- or bone-supported guides due to soft-tissue interference, occlusal contacts, or limited surgical access, can result in deviations from the planned graft position.

From a manufacturing perspective, stereolithographic surgical guides are subject to dimensional changes related to polymerization shrinkage, post-curing deformation, and potential distortion during sterilization procedures. Variability in printer calibration, resin properties and environmental conditions may further influence the dimensional accuracy and mechanical stability of printed devices. In addition, digitally guided workflows entail a substantial operator learning curve, requiring proficiency in segmentation, dataset alignment, virtual design, and guide verification. These steps introduce operator-dependent variability and increase preoperative planning time. Finally, economic and logistical considerations—including the cost of high-resolution imaging, CAD software licenses, 3D-printing equipment, consumables, and trained personnel—may limit the accessibility and routine clinical implementation of such protocols. Importantly, these sources of inaccuracy may be cumulative, such that small deviations at each digital step can compound and influence the final clinical outcome. Consequently, standardized acquisition protocols, validated digital workflows, and future quantitative accuracy studies are essential to define the reproducibility and clinical reliability of digitally guided allogeneic bone regeneration techniques.

Beyond this preliminary technical efficiency, the integration of digital planning with standardized allogeneic grafts could represent a paradigm shift in clinical practice, avoiding donor site morbidity, reducing surgical complexity, and enabling precise anatomical reconstruction to contribute to enhanced patient outcomes, faster recovery, and more predictable regenerative results. Moreover, the use of banked allogeneic materials ensures quality control, regulatory compliance, and reproducibility across diverse clinical environments, supporting the sustainability of advanced regenerative protocols. This approach also aligns

with the growing trend toward minimally invasive, patient-centered care, where reducing postoperative discomfort and operative burden are key priorities.

5. Conclusions

Within the inherent limitations of a narrative review and a single clinical case report, this study illustrates the feasibility of a fully guided allogeneic SBBT using digitally planned cutting guides and a graft transporter. The described workflow enabled controlled design and positioning of cortical laminae while avoiding autologous bone harvesting. Six-month radiographic evaluation demonstrated substantial horizontal ridge augmentation in this case. However, these findings remain preliminary and should be interpreted as illustrative rather than confirmatory. Costs, technique sensitivity, and the absence of long-term controlled data currently limit broad clinical adoption. Prospective studies are required to validate accuracy, reproducibility, biological behavior and implant outcomes associated with digitally guided allogeneic SBBT.

6. Future Directions

Future research should focus on the rigorous validation of digital workflows. Quantitative assessments of CBCT-derived segmentation accuracy, surface registration reliability, and 3D-printing tolerances are needed to determine how deviations at each digital step affect the final fit and stability of allogeneic laminae. The integration of robotic-assisted procedures and dynamic navigation systems with preoperative digital planning may further improve intraoperative precision and reduce operator-dependent variability, particularly in anatomically constrained regions [27]. In parallel, advances in biodegradable 3D-printed scaffolds and custom polymeric membranes offer opportunities to combine standardized allogeneic laminae with patient-specific regenerative architectures, enabling tunable mechanical properties and controlled resorption profiles that may enhance graft stability [28].

Artificial intelligence is also expected to play a substantial role in the evolution of digitally guided reconstruction. Machine learning algorithms may support automated segmentation, predict ideal graft morphology based on defect geometry and biomechanical demands, and optimize lamina thickness, curvature, and fixation strategies, thereby improving planning standardization and reducing variability among operators [27]. Ultimately, prospective clinical studies with long-term follow-up remain essential to evaluate implant survival, graft remodeling, resorption kinetics, and functional outcomes following digitally guided allogeneic SBBT. Such investigations will determine the reproducibility, accuracy, and clinical value of integrating digital planning with modern biomaterials in regenerative implant therapy.

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