

Advancements in alveolar bone reconstruction: A systematic review of bone block utilization in dental practice

Sylvia Hnitecka^{1,A–F}, Cyprian Olchowy^{2,A,E,F}, Anna Olchowy^{3,B,D,F}, Paweł Dąbrowski^{4,B,D,F}, Marzena Dominiak^{5,A,E,F}

¹ Clinical Department of Maxillofacial Surgery, Wrocław Medical University, Poland

² Collegium Medicum, Jan Długosz University in Częstochowa, Poland

³ Department of Experimental Dentistry, Wrocław Medical University, Poland

⁴ Division of Anatomy, Department of Human Morphology and Embryology, Wrocław Medical University, Poland

⁵ Department of Dental Surgery, Wrocław Medical University, Poland

A – research concept and design; B – collection and/or assembly of data; C – data analysis and interpretation;

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Address for correspondence

Cyprian Olchowy

E-mail: cyprian.olchowy@gmail.com

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Abstract

Alveolar reconstructive surgery employs a variety of surgical techniques and biomaterials, with a particular focus on bone blocks as a crucial methodology for restoring and augmenting deficient bone structures. Bone blocks are often employed to support periodontal health or as a foundation for future prosthetic rehabilitation with dental implants. This systematic review investigated recent advances in bone blocks for alveolar bone reconstruction, comparing autologous, allogeneic and xenogeneic types. A search of PubMed identified 56 records, of which 21 were included in the qualitative analysis. The studies involved 685 patients in total. Bone blocks are pivotal for three-dimensional bone regeneration, providing a stable scaffold for achieving the desired bone volume during healing. Autologous bone, harvested from the patient, boasts high biocompatibility, excellent osteogenic properties and minimal immunologic risks. However, its drawbacks include the need for an additional surgical site and extended procedural times. Allogeneic bone blocks involve transferring bone between individuals, offering increased graft availability and customization options without requiring a second surgical site. However, they exhibit moderate resorption rates and carry a heightened risk of immunologic reactions and disease transmission. Innovative techniques, such as tunneling, laser osteotomy, graft customization, and platelet-rich fibrin (PRF) application on wound during surgical treatment show promise in enhancing alveolar bone reconstruction efficacy. In conclusion, despite the traditional preference for autologous bone, the review suggests that alternative materials, particularly individualized allogeneic bone blocks, coupled with modern techniques, could emerge as a standard procedure for regenerating alveolar bone defects due to their satisfactory results and potential advantages.

Keywords: alveolar bone loss, allografts, bone regeneration, bone block, reconstruction

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Introduction

The jawbones, including the mandible and maxilla, may be affected by a number of conditions. Such conditions can be extensive, as in the case of trauma or infection, or localized, as is the case with tumors and cysts. Iatrogenic defects may develop as a consequence of applied treatments, such as radiotherapy of malignant lesions.¹ The jawbones can be affected in the course of chronic and general diseases, including osteoporosis and osteomyelitis. Congenital causes include developmental anomalies that may impact the normal growth and formation of the jawbones.² The frequency of jawbone-related issues in clinical dental practice varies based on patient demographics, oral hygiene practices and general health. The prevalence of bone defects is considerable, reaching 91%, and underscores the significance of research in the field of alveolar bone reconstruction.³ Treatment of bone defects is also differentiated. It may include surgical augmentations to protect against additional bone loss and to secure the capacity for future implantation.²

Bone blocks play a key role in alveolar bone reconstruction, providing a reliable methodology for the restoration and augmentation of deficient bone structures.⁴ Bone blocks have gained significant attention and popularity due to their ability to overcome donor site morbidity and achieve high survival rates. Regenerated tissues play a crucial role in achieving stable, long-term implant rehabilitation, enhancing bone remodeling, and minimizing factors such as early marginal bone loss and inflammation.^{5,6} Different regenerative methods can be used for alveolar ridge or bone reconstructions, ranging from minor augmentations with bone or bone substitute particles to extensive reconstructions with microsurgical free flaps.^{7,8} A variety of surgical techniques and biomaterials are employed in alveolar reconstructive surgery.⁹ The majority of augmentations are performed to maintain the condition of the periodontium (e.g., augmentation of periodontal defects, guided bone regeneration) or to prepare a future prosthetic base for rehabilitation with the use of dental implants.⁸ In cases of severe sagittal discrepancies between the maxilla and mandible resulting in bone defects, orthodontic treatment alone may not be sufficient.¹⁰ Reconstructing the vertical dimensions of the teeth area in patients with preserved dentition to prevent progressive loss of tooth support structures poses its own set of challenges.¹¹ A multidisciplinary approach, involving a surgical, orthodontic and periodontal team is essential for the customized treatment of such cases apart from the application of standard treatment methods. When selecting a surgical technique and material, several factors should be considered. These include the location and size of the defect, the properties of the biomaterial and the ease of obtaining it. Additionally, cost, ease of use, stability, and maintenance of the recipient site are crucial considerations. It is important to be aware of the potential complications associated with selecting a specific treatment method.

Moreover, assessing the long-term effects of the chosen surgical approach and biomaterial is essential. A comprehensive evaluation of these factors is necessary to make an informed decision in clinical practice.

The regeneration of vertical bone defects caused by periodontitis is typically straightforward and tends to yield predictable outcomes. Similarly, augmenting a post-extraction socket or addressing a small defect after removing an osteolytic lesion is not demanding.^{12,13} However, addressing advanced three-dimensional defects poses a significant challenge. Horizontal regeneration in such cases is frequently unpredictable, and attempts at vertical reconstruction often result in less satisfactory outcomes.¹⁰ The process of three-dimensional bone regeneration relies on establishing a stable scaffold to achieve the desired bone volume during the healing phase.¹⁴ Clinicians commonly employ barrier membranes, including stiffer, non-absorbable, personalized membranes⁹ or the increasingly popular bone blocks for this purpose. The implementation of these techniques involves the use of pins or mesh for fixation, and in many instances, biomaterial granules are applied to fill the voids.^{15,16}

Bone blocks have a long history of use, and the existing literature contains numerous reports detailing their indications, methods of use and effects.^{17,18} These involve the use of various graft types, including autologous, allogeneic, xenogeneic, and synthetic bone substitutes. These grafts act as scaffolds for new bone formation, promoting osteoinduction, osteoconduction and osteogenesis to restore natural bone structures.¹⁹ The biomaterial market has experienced significant growth, offering surgeons a range of bone substitutes with similar properties. Despite the potential to choose and combine these substitutes for effective reconstructions with minimal morbidity and rapid healing, variations exist among the most commonly used substitutes in terms of their chemical, physical and morphological features.²⁰ While undoubtedly serving as an excellent scaffold for bone reconstruction, the selection of this reconstructive technique should consider factors such as the choice of biomaterial and other potential aspects to enhance the treatment process and achieve the best possible outcome.¹⁰ This systematic review aimed to investigate recent advances in the use of bone blocks in oral surgery. Qualitative data synthesis was used to compare different types of bone blocks: autologous, allogeneic and xenogeneic. Furthermore, the objective was to explore contemporary methods designed to enhance the effectiveness of these procedures.

Material and methods

A systematic search was conducted in PubMed, and a manual search of review papers identified during the search was also performed. The search was conducted in accordance with the Preferred Reporting Items for

Systematic Reviews and Meta-Analyses (PRISMA) statement,²¹ on November 17, 2023. The electronic search was constructed using the Medical Subject Headings (MeSH) term “Alveolar Bone Loss/Surgery” and the text word “bone block”. The search was limited to studies involving adult participants and articles published in English. However, no restrictions were imposed on geographical scope. The inclusion and exclusion criteria were developed in accordance with the Population, Intervention, Comparison, Outcomes, and Study Design (PICOS) framework.²² All eligibility criteria are outlined in Table 1.

Two reviewers were involved in the screening process, and any discrepancies were resolved through mutual agreement. In cases where a consensus could not be reached, a third independent reviewer was consulted to make the final decision. The data extraction process was carried out by a single reviewer, and then cross-verified by a second reviewer.

Results

Characteristics of patients and study procedure

The PubMed search identified 56 records, of which 21 were included in the qualitative analysis. The studies were relatively small, with sample sizes ranging from 8 to 101 participants, and involved a total of 685 patients. The majority of studies ($n = 9$) were conducted in Italy. Two studies each originated from Brazil, China, Sweden, and Israel, while 1 study each came from Spain, Portugal, Egypt, and the Netherlands. The study selection process is presented in Fig. 1.

The studies were categorized according to the type of bone biomaterial into autologous,^{23–38} allogeneic^{39–41} and xenogeneic^{26,31,33,34,42} groups to facilitate the description of each type. It should be noted that a single study may investigate more than 1 type, which allows for a comprehensive description of each. Figure 2 depicts the characteristics of different types of bone blocks.

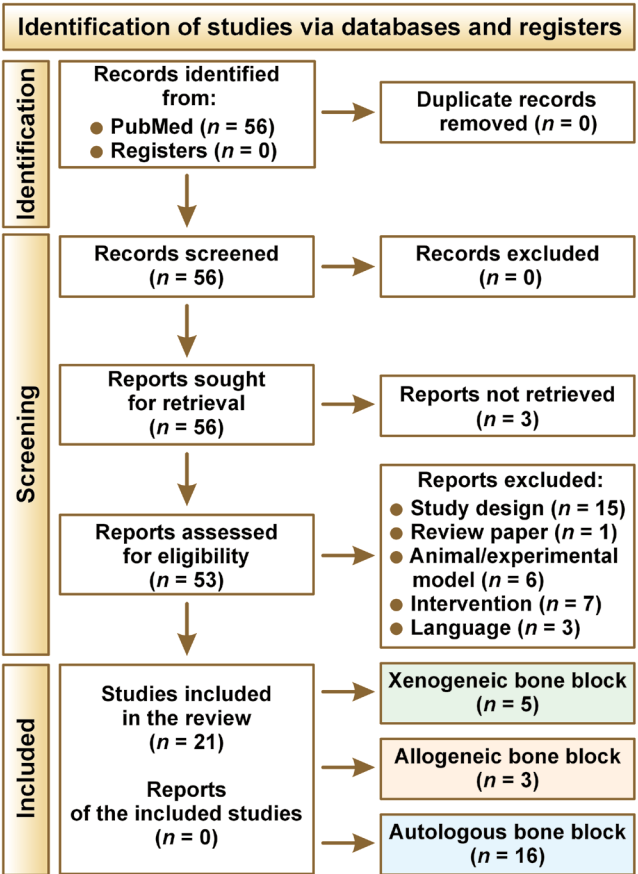


Fig. 1. Flow chart of the study in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement²¹

Autologous bone blocks

Autologous bone refers to bone tissue harvested from the same patient. The procedure for bone reconstruction using autologous bone blocks involves harvesting the block, shaping or fitting it, and placing and fixing it in the defect in a single operation. Autologous grafts for the reconstruction of the jawbones can be obtained from intraoral or extraoral donor sites.^{2,27} Intraoral sites are considered more suitable for graft harvesting due to the absence of scarring on the skin and reduced graft resorption, attributed to the similarity in embryological origin and microarchitecture.

Table 1. Eligibility criteria according to the Population, Intervention, Comparison, Outcomes, and Study Design (PICOS) framework²²

PICOS	Inclusion criteria	Exclusion criteria
Population	– otherwise healthy individuals with alveolar bone deficiency that does not allow placement of dental implants – adults (≥ 18 years of age)	– patients with chronic diseases
Intervention	alveolar ridge augmentation/reconstruction with a bone block graft	–
Comparison	different types of bone block grafts with the focus on the source of the graft material, i.e., autologous, allogeneic and xenogeneic grafts	–
Outcomes	– efficacy outcomes – safety outcomes	–
Study design	– comparative study – cohort study	– experimental/animal study – case report – proof-of-concept study – review

Autologus bone blocks	Allogeneic bone blocks	Xenogeneic bone blocks
 DONOR • Intraoral or extraoral sites of the same patient ADVANTAGES • High biocompatibility • Osteogenic, osteoinductive and osteoconductive properties • Low risk of immunologic reactions DISADVANTAGES • Requires additional surgical site for harvesting • Limited graft availability • Prolonged surgical time, sometimes requires general anesthesia • High-cost procedure	 DONOR • Material from the same species, obtained from authorized tissue banks ADVANTAGES • No need for a second surgical site • Greater graft availability compared to autologous bone blocks • Possibility of customization DISADVANTAGES • Moderate resorption rates • Risk of immunologic reactions • Potential for disease transmission (minimized with proper screening) • Lack of guidelines for tissue harvesting and storing	 DONOR • Material from a different species (e.g., equine, bovine, porcine grafts) ADVANTAGES • No need for a second surgical site • Greater graft availability compared to autologous bone blocks DISADVANTAGES • High resorption rates, fibrosis • Differences in biomechanical qualities • Risk of immunologic reactions • Potential for disease transmission (minimized with proper processing)

Fig. 2. Characteristics of bone blocks according to the biomaterial type

With regard to extraoral donor sites, bone can be harvested from the calvarium, anterior iliac crest, tibia, fibula, rib, and olecranon (proximal ulna).^{26,28,30–33,35} Intraoral donor sites encompass the mandible (chin/symphysis, ramus, retromolar area), zygoma and maxilla (tuberosity).^{23–25,29,34,36–38,43,44} With regard to one of the most common donor sites, the mandible, the utilization of the ramus as a donor site, as opposed to the symphysis, has been associated with several advantages. These include increased postoperative comfort and a lower risk of paresthesias, pulp necrosis of the inferior incisors, and labial ptosis.

The key factors for the successful incorporation of a bone block include the preparation of the recipient site and the effective adaptation of the bone blocks.³¹ Autologous bone blocks are typically harvested subperiosteally with sufficient visualization of the donor site. This involves identifying crucial nearby anatomic structures, particularly neurovascular bundles and dental roots, and the implementation of adequate protection measures for these structures, in conjunction with the surrounding soft tissue. Subsequently, the osteotomy process, which involves cutting the bone, is performed, followed by the release of the graft. In order to ensure proper contouring of the graft, its size should be 2 mm larger than the size of the defect. Graft osteotomies are commonly executed using saw disks. The osteotomies are then connected, and the graft is elevated using a chisel and hammer.³⁸ Subsequently, the block must be shaped and contoured under abundant irrigation. Round fissure burs are commonly employed for this purpose, facilitating the removal of all sharp edges. The prepared graft is then stored in a cold, sterile aqueous solution of 0.9% sodium chloride until the recipient site is ready. It is crucial to consistently monitor the fit of the block and its adhesion to the bone surface at the recipient site. If needed, reshaping may be necessary. The adapted block is secured with bicortical titanium screws, which are applied using either a hammer or a screwdriver.^{37,40} An alternative method involves the use

of resorbable pins in the BoneWelding® technique. In this method, a resorbable pin is applied using ultrasound and heating during insertion into the drill hole. The pin penetrates the drill hole and subsequently melts laterally into the spongy bone structures beneath the cortical bone layer.⁴⁵

Advantages and disadvantages of autologous bone blocks

The primary advantage of autologous bone blocks is a diminished risk of immune rejection, as the graft material originates from the same individual. This results in the graft material possessing good osteogenic, osteoinductive and osteoconductive properties.² Autologous bone blocks are considered a safe and reliable method, offering good long-term stability with minimal resorption and donor-site morbidity. The vital properties and the ability of the bone block to function as a scaffold for neoangiogenesis and tissue ingrowth, in addition to providing immediate mechanical stability, contribute to the smooth incorporation, healing and success of the bone graft.^{29,34}

Autologous block grafts, sourced from the patient's own bone, typically exhibit lower resorption rates in comparison to allogeneic and xenogeneic grafts.²⁶ However, it is important to note that higher rates of resorption have been observed with autologous bone blocks derived from the iliac crest.³³ Nevertheless, some researchers have reported similar rates of volume gain regardless of the donor site.³⁶ Harvesting autologous bone carries a certain risk of donor site morbidity, which is applicable to both extraoral and intraoral donor sites. The complication rates are comparable across different donor sites, and in the majority of patients, healing proceeds uneventfully.²⁸ While patients generally experience infrequent and minor side effects, they can be as high as 35.7% for calvarial grafts and 33.3% for iliac crest grafts.⁴⁶ Bone harvesting from an intraoral site may lead to numbness of the teeth,

neurosensory disturbances, postoperative discomfort, and aesthetic issues such as contour changes and soft tissue recession. On the other hand, bone harvesting from an extraoral site is associated with a number of complications, including scarring, postoperative pain, hematomas, delayed muscle motility, the risk of cutaneous nerve injury, and higher hospitalization costs.^{28,47–49} Furthermore, general anesthesia, particularly when grafts are harvested from calvarial donor sites,^{30,32} may result in increased stress for patients, leading to increased postoperative pain and an extended hospital stay.⁴²

Differences between cancellous and cortical autografts should be considered in the decision-making process for managing bone augmentation. The process of molding can pose a challenge when using autologous bone grafts, particularly with cortical autografts, which are less vascularized and more rigid. This characteristic increases the risk of cracking or fracturing the bone graft. However, this risk can be mitigated by the use of custom-made guides.³⁰

Allogeneic bone blocks

Allogeneic bone blocks entail the transfer of bone from one individual to another, which involves an exchange of genetic material between different people. Allografts contain numerous chemical domains, endothelial cells and growth factors within the bone matrix released during resorption by osteoclasts. Additionally, allograft bone contains a small amount of bone morphogenic protein with osteoinductive properties.⁵⁰ As demonstrated by scanning electron microscopy (SEM), the morphology of the material surface can vary depending on the biobank. Materials sourced from cancellous bone exhibit a spongy structure with holes ranging from 100 to 350 μm in diameter. The surface is smooth, without collagen fibers. In the material sourced from cortical bone, small osteocyte canaliculi holes with an average diameter of 38 μm occur. The bone surface surrounding these holes is smooth, predominantly consisting of strongly bonded collagen fibers, with microcracks and layered particles across the entire surface.²⁰ The potential for antigenicity in allografts may not be entirely eliminated, as the formation of alloantibodies can complicate bone transplantation. Nevertheless, the quantification of major histocompatibility complex (MHC) molecules in various allogeneic bone grafting materials for alveolar ridge reconstruction revealed trace amounts of MHC molecules. These quantities are considered clinically irrelevant, and there is no evidence of late complications or rejections in clinical practice.⁵¹

Despite the relatively low risk of antigenicity and potential disease transmission, the significance of allografts increases due to constraints in the size of autologous block grafts from intraoral and extraoral sites. The associated morbidity with graft harvesting often restricts the range of treatment options and may influence patient acceptance.^{41,50,52}

In terms of the efficacy of allogeneic bone blocks, while autologous bone block grafts are considered the gold standard in oral surgery, bone substitutes like bone allografts demonstrate comparable effectiveness. There were no significant differences observed in the rate of bone formation between allogeneic materials and autologous bone in maxillary sinus lift procedures.⁵³ Stability for subsequent fixed prosthetic rehabilitation was ensured when utilizing fresh-frozen iliac crest allografts for augmenting the atrophic maxilla. In addition, allogeneic bone grafts exhibited low resorption rates at 5 months.⁴¹ The maintenance of consistent histological, histomorphometric and immunohistochemical features, along with the preservation of good vascularization, was observed in several studies.^{39–41} Finally, allografts represent the optimal choice in terms of safety, as the use of allogeneic bone blocks eliminates donor site morbidity and allows for the acquisition of bone material from tissue banks.⁴¹

Xenogeneic bone blocks

Bones from various animal species, known as xenogeneic grafts, have been explored as an alternative to allografts due to the financial implications associated with the latter. However, they are used infrequently due to high immunogenicity, inadequate biomechanical qualities and the occurrence of foreign body reactions.⁵⁰ In contrast to human bone, the SEM images of animal-bone-derived material reveal a rough surface characterized by statically aggregated particles arranged in a two-stage structure. The first stage comprises particles with an average diameter of 0.353 μm , while the second stage involves larger particles with an average size of 1.395 μm . The material displays particle holes and pores, which increases its overall surface area.²⁰

Xenogeneic bone blocks exhibit lower efficiency than other types of bone blocks. In an experimental model, after a 6-month healing period, the alveolar ridge was integrated into the target area.⁵⁴ However, significant peripheral resorption was observed, resulting in approx. 30% height and 50% length replacement with connective tissue. Furthermore, grafts containing a cancellous bovine bone mineral scaffold maintained their dimensions, with only moderate new bone formation observed at the graft base.⁵⁴ However, some researchers have reported favorable outcomes with the use of xenogeneic bone blocks. In a study involving 20 subjects, the success rate of the interpositional technique using cancellous equine bone blocks appeared to be higher than that of autologous onlay blocks, with an overall success rate of 93.8% for the interpositional technique compared to 82.4% for the onlay technique.²⁶ In another small study involving 15 patients with single or multiple tooth gaps and severe horizontal collapse of the alveolar ridge, a novel collagenated xenogeneic bone block demonstrated substantial gains in horizontal crestal width. However, this approach was associated with an increased risk of soft tissue dehiscence and early implant loss.⁵⁵

Discussion

Grafting bone blocks is a novel technique with a limited number of large-scale studies. In our review, we identified several proof-of-concept studies and case reports. These preliminary investigations were designed to demonstrate the feasibility and viability of specific methods of block bone grafting and provide evidence that such methodologies are safe and effective in alveolar bone augmentation. Such studies are frequently conducted in the early stages of research to assess the potential efficacy of the treatment of bone defects. Furthermore, case reports were equally prevalent, indicating that considerable research is currently in the pilot stages of bone grafting. Our systematic review was intentionally focused, with the search limited to a single MeSH term. We aimed to identify a comprehensive range of alveolar bone reconstruction methodologies over time while limiting the inclusion of papers that repeatedly evaluated similar approaches.

The feasibility and safety demonstrated in the preliminary investigations of grafting bone blocks from various sources suggest potential advancements in alveolar bone augmentation, with significant implications for clinical practice. It is recommended that clinicians adopt a cautious approach to these emerging technologies, anticipating further research to establish their efficacy and broader applicability in routine clinical settings. Alongside advancements in bone grafting, new techniques are being developed to enhance their effectiveness. This review will discuss tunneling techniques, Er:YAG laser osteotomy, customization, and the supplementary use of platelet-rich fibrin (PRF). The ease of implementation and benefits for patients will be highlighted. These techniques were partially employed by the authors of the identified studies.

Tunneling techniques

Tunneling techniques have been used to increase the effectiveness of bone augmentation procedures conducted with diverse bone sources. This approach minimizes the necessity for extensive soft tissue reflection, potentially reducing surgical trauma and promoting faster healing. The technique involves creating a tunnel or channel in the recipient site's bone without fully exposing it, and then passing the bone graft material through this tunnel to the desired location.²⁹ The data suggests that employing a tunneling technique enhances bone formation in the context of xenogeneic bone block placement for vertical ridge augmentation. A study comparing flap and tunneling procedures for vertical ridge augmentation using xenogeneic bone blocks in a canine mandible model revealed that the tunneling group exhibited significantly greater new bone formation within the graft sites ($46.6 \pm 23.4\%$) compared to the flap group ($15.3 \pm 6.6\%$).⁵⁶ In clinical settings, the management of alveolar crest vertical defects in 10 patients using the tunneling technique and autologous bone blocks before

the implant resulted in all individuals healing without complications. The study demonstrated a mean overall vertical bone remodeling of 0.55 ± 0.49 mm (8.4%) after 8 months, thereby confirming the efficacy of this minimally invasive approach for bone regeneration in vertical defects.²⁹

Er:YAG laser osteotomy

In the regeneration of alveolar bone using autologous bone blocks, the harvesting technique is of paramount importance. Inappropriate osteotomy techniques may result in mechanical and thermal damage, impacting the bone's vital potential. While standard methods involving saws, drills and burs are associated with disadvantages such as a limited cut geometry and a risk of soft tissue injury, laser ablation presents advantages like unconstrained positioning, allowing for precise osteotomy without mechanical pressure or stress on the bone. The potential benefits of laser ablation in overcoming limitations associated with traditional osteotomy methods in oral surgery translate into improved efficiency in clinical practice.⁵⁷ A pilot study evaluated the feasibility, benefits and limitations of using a variable square pulse Er:YAG laser for harvesting intraoral bone grafts. The results demonstrated excellent cutting efficiency with minimal damage to adjacent soft tissues and no impairment of wound healing. However, limitations, such as the difficulty in achieving a well-defined osteotomy line without irregularities and the necessity for careful laser beam positioning, suggest that the use of an Er:YAG laser may be most appropriate for regions where safe and fixed guidance of the laser beam is feasible. A meta-analysis was conducted to evaluate complications and donor site morbidity, which confirmed the growing utilization of Er:YAG lasers. Patients expressed satisfaction with the graft harvesting method, with higher acceptance reported for procedures involving harvesting from the ascending mandibular ramus.⁵⁸

Customization

In the customization of the bone augmentation procedure for a single-tooth restoration, advanced backward planning can be used, involving preprosthetic bone and soft tissue augmentation. The treatment plan involves manufacturing an allogeneic bone block, which is a collaborative effort between the dentist, the implantologist and the dental laboratory. The optimal implant position and necessary block volume were determined using cone-beam computed tomography (CBCT) data and three-dimensional planning tools. A customized block graft, comprising processed freeze-dried cancellous bone from living donors, was obtained during arthroplasty surgery. The procedure can be supported by soft tissue optimization and tunneling of the recipient gingiva during implantation.⁵⁹ In terms of treatment expenses, both the use of stereolithographic models and computer-aided design (CAD) have been shown to improve individualization and increase costs. However, these

additional costs can be balanced by reduced surgery time. It should be noted that while there will be an increase in material expenses, when compared to autologous bone blocks harvested from extraoral donor sites, the overall treatment costs may appear significantly lower. Additionally, the surgical procedure for using customized allogeneic bone blocks might be simpler than trimming and adapting autologous bone blocks.

Platelet-rich fibrin

Autologous PRF is widely utilized in oral surgery. This is a blood-derived material, processed from whole blood containing high platelet and growth factor concentrations.⁶⁰ While primarily employed to alleviate pain, reduce edema and expedite healing after tooth extractions,⁶¹ researchers are exploring its potential in reconstructive surgery.⁶² Notably, key features of PRF include enhanced healing, improved graft stability, and acting as a natural scaffold, facilitating bone graft integration and improving the condition of adjacent tissues. These properties, coupled with PRF's ability to reduce inflammation, increase vascularization and potentially enhance bone density, make it a promising material for alveolar bone reconstruction and augmentation.^{26,63}

Conclusions

Autologous bone has traditionally been considered the gold standard due to its inherent properties. However, the need for a second surgical site, increased discomfort, potential complications, intraoperative shaping, and extended surgical time raise the question of whether alternative materials could offer a better solution. Allogeneic blocks lack osteogenic properties, yet their final treatment results are often satisfactory. Overcoming the drawbacks associated with autologous blocks, such as low patient comfort and prolonged procedure time through modern techniques for individualizing blocks, raises the question of whether individualized allogeneic bone blocks could become the new gold standard.

Ethics approval and consent to participate

Not applicable.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

ORCID iDs

Sylvia Hnitecka  <https://orcid.org/0000-0002-1171-9817>
Cyprian Olchoway  <https://orcid.org/0000-0002-6559-3973>
Anna Olchoway  <https://orcid.org/0000-0002-5601-7173>
Paweł Dąbrowski  <https://orcid.org/0000-0001-6016-9201>
Marzena Dominiak  <https://orcid.org/0000-0001-8943-0549>

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