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Mexican Journal of Medical Research ICSa

Biannual Publication, Vol. 14, No. 28 (2026) 17-25

ISSN: 2007-5235

Cadaveric Donor Bone Grafts: Current challenges and advancements in bone regeneration

Injertos óseos de donantes cadavéricos: desafíos actuales y avances en la regeneración ósea

Saiko Samantha Lima-Almaraz [a], Brenda Camila Falcón-Ortiz [b], Gustavo López-Martínez [c], Raquel Cariño-Cortés [d]

Abstract:

One of the therapeutic alternatives when bone repair is insufficient involves the use of cadaveric donor bone grafts. These are particularly employed in cases of multifragmentary or complex fractures, lytic lesions, or in conditions with bone resorption, nonunion, or pseudarthrosis that do not respond adequately to initial treatment. Currently, in North America, allografts account for approximately one-third of all bone grafts used. An allograft refers to bone tissue obtained from human cadavers, which is sterilized and transplanted into a recipient. It is available in various forms, including cortical, cancellous, and demineralized bone matrix, among others. The rising incidence of bone-related conditions, such as infections and tumors, combined with the global increase in orthopedic surgeries, significantly contributes to the growing demand for bone grafts and substitutes. Bone grafting procedures have become an integral part of current medical-surgical and dental practice worldwide. The increasing number of these techniques, applications, and procedures underscores the importance of musculoskeletal tissue donation—not only for clinical use but also for research and the development of new biomaterials aimed at enhancing osteoinduction, osteoconduction, and osseointegration, ultimately leading to improved patient outcomes and meeting the growing clinical demand. Cadaveric donor bone grafts offer several advantages, including availability in diverse forms and their capacity to promote bone regeneration. However, their clinical success depends on several factors, such as biocompatibility, processing methods, and host response. This article compiles relevant information on the characteristics, clinical applications, and future perspectives of cadaveric donor bone grafts, providing an updated overview that positions them as both an effective and viable alternative for enhancing bone regeneration and improving clinical outcomes across various pathologies and surgical procedures.

Keywords:

Allograft, Autograft, Bone transplantation, Bone regeneration, Allograft processing, Clinical applications of allografts.

Resumen:

Una de las alternativas terapéuticas cuando la reparación ósea es insuficiente implican el uso de injertos óseos de donantes cadavéricos, utilizados especialmente en fracturas multifragmentadas, complejas, lesiones líticas o con secuelas de resorción ósea, no unión o pseudoartrosis que no responden bien al tratamiento inicial. Actualmente, en Norteamérica, los aloinjertos representan alrededor de un tercio de los injertos óseos utilizados. El aloinjerto se refiere al hueso proveniente de cadáveres humanos, el cual se procesa de manera estéril y se trasplanta a un receptor, este se presenta en diversas formas como cortical, esponjoso, matriz ósea desmineralizada, etc. La creciente incidencia de afecciones óseas, como infecciones y tumores, junto con el aumento de las cirugías ortopédicas en todo el mundo, contribuyen significativamente a la demanda de injertos y sustitutos óseos. Estos procedimientos de injerto óseo forman parte integral de las prácticas médico-quirúrgicas y odontológicas en la actualidad en todo el mundo. El creciente número de estas técnicas, usos y procedimientos subrayan la importancia de la donación de tejido musculoesquelético, no

[a] Academic Area of Medicine, Institute of Health Sciences, Universidad Autónoma del Estado de Hidalgo. Pachuca, Hidalgo, México. https://orcid.org/0009-0004-6638-8535, Email: saikoalmaraz@gmail.com

[b] Hospital ISSSTE Columba Rivera Osorio, Coordinación de órganos y tejidos con fines de transplante | Pachuca, Hidalgo, México, https://orcid.org/0009-0008-0207-275, Email: camilafalconortiz@gmail.com

[c] Hospital ISSSTE Columba Rivera Osorio, Traumatología y Ortopedia | Pachuca, Hidalgo | México, https://orcid.org/0009-0002-1762-9959, Email: glm_132@hotmail.com

[d] Corresponding author, Academic Area of Medicine, Institute of Health Sciences, Universidad Autónoma del Estado de Hidalgo. Pachuca, Hidalgo, México. https://orcid.org/0000-0003-4776-3534, Email: raquel_carino4897@uaeh.edu.mx.

Received: 13/08/2025, Accepted: 16/10/2025, Postprint: 30/01/2026, Published: 05/07/2026

DOI: https://doi.org/10.29057/mjmr.v14i28.15693

solo para su uso clínico, sino también para la investigación y desarrollo de nuevos biomateriales con el objetivo de mejorar la osteoinducción, osteoconducción y osteointegración, para con ello obtener mejores resultados en los pacientes y satisfacer la creciente demanda. Los injertos óseos provenientes de donantes cadavéricos incluyen diferentes ventajas como su disponibilidad en diferentes formas y su capacidad para promover la regeneración ósea. Sin embargo, su éxito depende de distintos factores tales como la biocompatibilidad, el procesamiento y la respuesta del huésped. El presente artículo recopila información relacionada con las características, aplicaciones y perspectivas de los injertos óseos de donantes cadavéricos, proporcionando un panorama actualizado que los posiciona como una alternativa tanto eficaz como viable para potenciar la regeneración ósea y mejorar los resultados clínicos en diversas patologías y procedimientos quirúrgicos.

***Palabras Clave**:*

Aloinjerto, Autoinjerto, Trasplante óseo, Regeneración ósea, Procesamiento de aloinjertos óseos, Aplicaciones clínicas de aloinjertos.

INTRODUCTION

The human skeleton possesses a unique regenerative capacity, allowing it to repair itself following injury. This skeletal repair process follows patterns similar to embryonic development, as both involve the differentiation of undifferentiated mesenchymal cells. During bone repair, specific stimuli guide these cells along the chondro-osteogenic pathway, resulting in the formation of new bone tissue. However, several factors can impair bone repair, including genetic factors, as well as mechanical, vascular, nutritional, and hormonal imbalances. Although bone regeneration occurs naturally in most cases, there are exceptions—such as nonunion, pseudarthrosis, avascular necrosis, periosteal stripping, or bone tumors—that can lead to bone defects in which spontaneous regeneration is unlikely. In such cases, bone grafting is required to induce or conduct regeneration, either to restore the damaged bone or to integrate with the existing skeletal structure.[1,2]

The first use of bone grafts in orthopedic procedures dates back to the 17th century, when Dutch surgeon Job Van Meekeren transplanted a piece of dog bone into a cranial defect of a soldier. This was the first known bone graft; however, due to orders from the church, the graft was to be removed. Nevertheless, this instruction could not be carried out, as the bone had completely integrated into the soldier's skull. Later, in 1879, Sir William MacEwan introduced the concept of allografting by successfully replacing the proximal two-thirds of the humerus in a 4-year-old child using bone obtained from other patients. Currently, approximately one-third of bone grafts used in North America are allografts. An allograft is bone tissue obtained from a deceased donor and transplanted into a recipient. Among the three fundamental mechanisms of bone healing, allografts exhibit osteoconductive and osteoinductive properties. Their main advantage lies in the ability to be prepared in various shapes and sizes, which allows for better coverage of the bone defect. Additionally, they eliminate donor site morbidity, making them a typical alternative to autologous bone.[2-5]

Bone grafting serves as an adjunct to surgical procedures, using this tissue to repair, reconstruct, or stimulate the formation of local bone, thereby supporting consolidation. It is used in traumatic, orthopedic, oncologic, and dental surgeries, placing bone as the second most commonly transplanted tissue in the human body, after blood and blood-derived products. Each year, approximately 2 million bone grafts are performed worldwide. This number could easily double, as bone grafts are increasingly used in orthopedics and traumatology, ranging from complex fracture treatments to limb salvage procedures and complex reconstructions, as well as spinal surgery. This growing use has led to a shortage in donor tissue availability, underscoring the importance of raising awareness among the Mexican population about organ and musculoskeletal tissue donation.[2-4,6]

Bone consolidation is a dynamic, cellular, and multivariate process. It requires a proper construct that provides mechanical stability, as well as respect for the surrounding soft tissues to allow for revascularization, thereby enabling osteogenesis, osteoinduction, and osteoconduction. Osteogenesis refers to the process of bone formation; osteoinduction to the stimulation of primitive, undifferentiated, pluripotent cells to become bone-forming lineages; and osteoconduction means that bone grows on a surface that permits bone formation on its surface or into pores, channels, or conduits. An ideal bone graft should possess three essential characteristics: an osteoconductive matrix, osteoinductive factors, and osteogenic cells, to ensure a successful bone repair process.[3,4]

There are two main types of bone grafts: autografts and allografts. An autograft involves harvesting healthy bone tissue from a donor site within the same individual to transplant it into the area where it is needed. In terms of bone consolidation, this type of graft has greater integration potential and is considered by many clinicians and authors to be the "gold standard." However, certain conditions—such as the need for two simultaneous surgical procedures, limited availability of donor bone, the risk of bleeding, increased surgical time, and risk of infection—have led to growing interest in a suitable alternative: allografts.[4,6]

FUNCTION OF BONE GRAFTS

Bone Repair Process

Bone remodeling occurs through two different consolidation pathways: primary and secondary healing. Primary bone healing takes place when the bone fragments are in close contact, with minimal interfragmentary space, and requires

absolute stability. This process enables direct bone growth without the formation of a fracture hematoma or subsequent callus formation. In contrast, secondary bone healing is the most common mechanism and involves the formation of a fracture hematoma, followed by callus formation. This process comprises several phases: inflammation, proliferation, and remodeling. In both types of healing, bone grafting can serve as an adjunctive support. During the inflammatory phase, the cascade of growth factors stimulates mesenchymal stem cells (MSCs) to differentiate into osteoblasts, ultimately leading to the formation of a callus, known as bone callus. In the proliferative phase, angiogenesis occurs, giving rise to granulation tissue. Subsequently, bone is formed through intramembranous ossification. Finally, the remodeling phase produces bone tissue that is biocompatible and structurally similar to native bone, with comparable porosity and mechanical strength.[2,3]

In order for fracture consolidation to occur, several biological mechanisms must be in place—mechanisms that also justify the use of bone grafts, as each plays a specific role in bone regeneration.[2]

Osteogenesis

Osteogenesis represents the initial and most critical phase of bone repair and remodeling, as it encompasses the development and formation of new bone from specific cellular elements within the graft. Compared to other types of grafts, cancellous bone grafts exhibit excellent osteogenic potential because they contain all the necessary components to stimulate osteogenesis, including a large surface area lined with osteoblasts, thereby enhancing their capacity to generate new bone.[2,3]

Osteoinduction

A key process in this regenerative cascade is osteoinduction, defined as the stimulation of undifferentiated mesenchymal cells to become osteoprogenitor cells capable of forming new bone. This phenomenon, first described by Marshall R. Urist in the 1960s, demonstrated that demineralized bone matrix possesses properties that can induce bone formation when implanted in extraskeletal sites.[7] Following this discovery, Urist and collaborators identified specific proteins responsible for osteoinduction, known as bone morphogenetic proteins (BMPs). These proteins belong to the larger transforming growth factor-beta (TGF-β) superfamily, with at least 15 variants identified by the mid-1990s. BMPs promote the differentiation of mesenchymal stem cells at and around the recipient site, recruiting them to differentiate into osteoblasts and chondroblasts, thus triggering osteogenesis. Other growth factors involved in this process include platelet-derived growth factor (PDGF), fibroblast growth factor (FGF), and various interleukins (ILs). In addition to these, autologous bone grafts, bone marrow aspirate concentrate (BMAC), and platelet-rich plasma (PRP) also contribute to osteoinductive processes.[2,3,7,8]

Osteoconduction

Osteoconduction is a fundamental biological process in bone regeneration, whereby an implanted material provides a three-dimensional scaffold that supports the migration, adhesion, and proliferation of osteogenic cells, thus facilitating the formation of new bone tissue. This phenomenon occurs when a graft or biomaterial enables the colonization of osteoblasts and progenitor cells from the adjacent bone tissue, promoting inward bone growth and subsequent integration with the surrounding tissue. To be considered osteoconductive, a material must exhibit appropriate physicochemical properties, such as an interconnected porous structure, bioactivity, and biocompatibility. These characteristics allow for vascular infiltration, cellular proliferation, and matrix deposition, thereby supporting bone healing. Among the most commonly used osteoconductive materials in clinical applications are autologous, allogeneic, and xenogeneic bone grafts, as well as synthetic biomaterials such as hydroxyapatite, calcium phosphate, and bioactive glasses.[2,3,9-11]

The combination of osteoconductive materials with osteoinductive agents—such as bone morphogenetic proteins (BMPs) or mesenchymal stem cells—can enhance bone regeneration and improve clinical outcomes. Recent studies have shown that the design and surface modification of biomaterials can optimize their osteoconductive capacity, promoting better cell adhesion and integration with the host bone tissue. Therefore, the development of novel strategies based on tissue engineering and nanotechnology remains a major focus in the field of regenerative medicine.[12]

IMMUNOLOGY OF ALLOGRAFTS

An allogeneic bone graft is considered the best alternative when autologous bone grafting is not feasible.[13] Most allografts are regarded as having low immunogenic risk, and donated musculoskeletal tissues typically undergo various cleansing procedures to remove cellular components or are preserved through specific processing methods. Allografts can be stored for weeks to years prior to use, and therefore must be processed in a way that preserves their safety and clinical efficacy over extended periods. In general, allograft preservation involves the use of storage media, cryopreservation, or lyophilization, allowing storage at room temperature, refrigeration, or freezing conditions.[13,14]

Unlike other types of transplanted tissues, HLA (human leukocyte antigen) haplotype matching is not required for these grafts. However, it has been proposed that residual cellular material may trigger an immune response, potentially leading to suboptimal graft incorporation due to activation of major histocompatibility complex (MHC) antigens. Therefore, any immunogenicity concerns should be minimized to ensure optimal biocompatibility of the allograft at the time of implantation. Different tissue types exhibit varying degrees of immunogenicity, which is primarily measured by their antigenicity. Commonly, skin tissue is more immunogenic

than bone or tendon tissues, the latter displaying lower immunogenicity that can typically be addressed through standard allograft cleansing procedures.[13,14]

PROCESSING OF ALLOGENEIC BONE GRAFTS

Tissue obtained from cadaveric donors must comply with the provisions established in the General Health Law, Title Fourteenth, Chapter I, as well as the Regulations of the General Health Law on Sanitary Control of the Disposal of Organs, Tissues, and Human Corpses, published in the Official Federal Gazette on March 16, 1987, including its current amendments, under the supervision of the Secretariat of Health of the Federal Government of the United Mexican States. Additionally, the procedure must adhere to the standards of the American Association of Tissue Banks (AATB), specifically those outlined in its most recent technical guide. Tissue procurement is performed using aseptic surgical techniques, while both processing and packaging are conducted under strictly controlled conditions, in accordance with applicable national and international regulations.[15-17]

Reduction of Disease Transmission Risk

The providers reduce the risk of disease transmission through three main ways:

1. Minimizing the processing of tissues from donors with unacceptable biological risk.

Prior to donation, a thorough review of the donor's clinical history is conducted to identify medical conditions or disease processes that may contraindicate tissue donation, such as cancer or autoimmune diseases, following established procedures and criteria approved by the medical director of the tissue bank. Additionally, medical and social histories are evaluated to detect high-risk behaviors in order to prevent transmission of infectious diseases, adhering to the guidelines set by COFEPRIS, CENATRA, and international tissue bank standards.[14,15]

Donors also undergo serological testing with samples collected before tissue procurement, including:

- Hepatitis B surface antigen (HBsAg)
- Anti-HIV 1 and 2 antibodies
- NAT detection tests for HIV and hepatitis C
- Rapid Plasma Reagin (RPR) test for syphilis
- Hepatitis C antibody
- IgG/IgM antibodies against hepatitis B core antigen
- IgG antibody against *Trypanosoma cruzi*

Microbial cultures are additionally performed to detect aerobic and anaerobic contaminants.

2. Controlling the environment and tissue handling practices to prevent contamination.

Biological contamination is controlled by aseptic manipulation techniques during tissue recovery and processing to avoid pathogen contamination. Moreover, microbial control assays are performed on tissues during procurement, processing, and packaging.[15,18]

3. Reducing any remaining biological load through disinfection and sterilization techniques.

Biological load can be further diminished by cleaning and disinfecting the tissue; these procedures vary by tissue type and may include:

- Debridement
- Low-dose pre-irradiation (irradiation before other chemical processing steps)
- Physical methods such as washing, centrifugation, and zonation
- Chemical methods involving various substances such as antibiotics, hydrogen peroxide (H_2O_2), peracetic acid, ethanol, ethylene oxide, and other broad-spectrum biocides.

These cleaning processes can remove bone marrow components, lipids, and low molecular weight proteins, thereby reducing the graft's potential immunogenicity as well as bacterial, viral, and fungal contamination.[14,18,19]

Sterilization by irradiation

This method offers greater penetration capacity compared to other sterilization techniques. Irradiation methods rely on ionizing radiation, a term encompassing all forms of energy-rich radiation (e.g., X-rays, gamma rays, and high-speed electrons) capable of generating ionization cascades within matter.

The effectiveness of sterilization using ionizing radiation lies in its excellent penetrability and its high efficacy in the inactivation of pathogenic microorganisms, without the complications associated with heat exchange, pressure differentials, or diffusion barriers. Gamma irradiation is the most commonly employed sterilization method for allografts and is also widely used for most processed tendons, either as a terminal sterilization step or as an intermediate process.

Ionizing radiation induces only a moderate increase in temperature, which can be managed for temperature-sensitive biological materials, and remains effective at room temperature or even at subzero conditions. Furthermore, ionizing radiation allows for the sterilization of materials in sealed packaging, preventing recontamination during storage or handling prior to implantation.[18,19]

TYPES OF ALLOGRAFTS AND THEIR VARIOUS APPLICATIONS IN THE HEALTHCARE FIELD

Allografts can be presented in fresh, frozen, or lyophilized forms and may contain cortical or cortico-cancellous bone tissue. Physicians determine the most appropriate form for each patient based on the clinical condition, whether in the form of whole bone segments, cancellous bone chips, or even powder, depending on the surgical procedure to be performed.[19,20]

Upon reviewing the available literature on allografts, some discrepancies may be observed due to ambiguous

classification systems used to describe the different types of allografts.

Scientific publications frequently reference mineralized bone allografts (MBA), fresh-frozen bone allografts (FFB), freeze-dried bone allografts (FDBA), demineralized bone matrix (DBM), and decellularized extracellular matrix (dECM). In fact, FDBA and MFDBA appear to represent the same material under different names, as they are essentially MBA subjected to lyophilization. Similarly, the terms DFDBA and DBM have been used interchangeably in various contexts.[20]

Broadly speaking, MBA, DBM, AAA Allograft, and dECM can be considered distinct derivatives of allograft tissue. Therefore, for the purposes of this article, we will classify them accordingly. See Figure 1.[20]

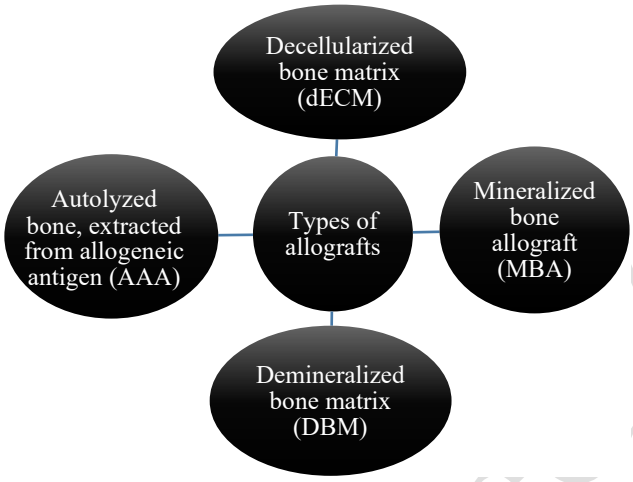

Figure 1. Different of allografts.[20]

Mineralized Bone Allograft

The most basic form of an allogeneic graft is the fresh, unprocessed bone block, which can be cryopreserved (fresh-frozen bone, FFB), freeze-dried (freeze-dried bone allograft, FDBA or MFDBA), or implanted fresh. Since allograft processing techniques reduce mechanical strength, fresh unprocessed allografts retain superior mechanical properties compared to processed bone. However, due to the high risk of disease transmission and immunogenic response from the host, fresh allografts are rarely used in current clinical practice.[2,20]

During the freeze-drying process, most of the tissue's water content is removed, which decreases mechanical resistance and destroys osteogenic cells, as well as class I major histocompatibility complex (MHC) molecules found on the surface of osteoblasts. A key advantage of this process is the reduction in both immunogenicity and disease transmission risk. The characteristics of mineralized allografts vary depending on whether they are composed of cortical, cancellous, or mixed bone tissue. In general, authors agree that both cortical and cancellous allografts exhibit osteoconductive properties (*Table 1*).[2,20]

Cortical Allograft

Cortical allografts possess higher density, overall structural strength, and superior mechanical properties compared to cancellous allografts, resulting in a more favorable osteoconductive effect. Vascular ingrowth and bone formation in these grafts occur primarily along the spaces between particles. Cortical allografts remodel slowly and exhibit slower resorption rates, but they offer the highest long-term volumetric stability among all allograft types. They are typically used in structural or load-bearing areas of the body or to fill large defects, commonly in the form of whole bone segments, blocks, or struts.[5,20,21]

Cancellous Allograft

Cancellous bone allografts are derived from the processed trabecular component of donated bone. On their own, they do not provide sufficient mechanical strength for most clinical applications. However, the trabecular porosity offers ample space for cellular infiltration, angiogenesis, extracellular matrix deposition, and new bone formation. Consequently, cancellous allografts are often used in situations requiring rapid bone healing, as the large intertrabecular space enables faster and more complete incorporation. These grafts are typically available in the form of chips, wedges, dowels, or powder.[5,20-22]

Cortico–Cancellous Bone Allograft

Neither cortical nor cancellous bone alone possesses osteogenic properties. To combine the benefits of both types of tissue, cortico-cancellous bone blocks are often used. The compressible cancellous layer allows for a precise fit of the graft, while the cortical component provides mechanical strength and protection during the early stages of healing. These grafts are commonly used to reconstruct small bone segments, requiring precise shaping to ensure optimal mechanical support. Clinical applications include prosthetic revision surgeries, corrective osteotomies, and vertebral body replacements.[4,19,22]

Table 1. *Different clinical applications of mineralized bone allografts. Adapted from references.*[23,24]

	Cancellous bone	Processed Wedges	Processed Strips
Source	Any section of spongy tissue.	Fibula, ulna, radius, femur, tibia, and humerus.	Femur, tibia, and fibula
Uses	Spinal fractures, spinal fusion, hip prosthesis revision, total knee replacement, correction of bone filling defects or bone resorption, maxillofacial surgery, and tumors.	Spinal fractures, surgical correction of scoliosis, spondylolisthesis, etc., spinal fusion, internal fixation of fractures with bone loss or malunion, and maxillofacial surgery.	Spinal fractures, lumbar fusion, thoracic fusion, surgical correction of scoliosis, spondylolisthesis, and similar conditions, surgical repair of fractures with bone loss or malunion, maxillofacial surgery, total knee replacement, and internal fracture fixation.
Types	Bone chips: Their high concentrations of osteoblasts and osteocytes confer superior osteogenic potential, and their large trabecular surface promotes revascularization and integration into the recipient site.		
	Bone powder: Provides a scaffold matrix that stimulates bone formation through a highly efficient osteoconductive process. Its natural bone structure facilitates cell attachment, proliferation, and vascular growth in the niches where it is placed.		
Others			It is processed from cancellous or cortico-cancellous bone. The mineralized bone matrices provide a biocompatible osteoconductive scaffold that supports new bone formation. This product is non-hemolytic, compatible with surrounding blood cells, and suitable for the seeding of stem cells and pre-osteoblasts.

Demineralized Bone Matriz (DBM)

DBM was first extracted from the human body in 1975. The original freeze-dried forms of DBM were difficult to handle, as the material lacked cohesiveness, was not moldable, and tended to disperse in a hemorrhagic environment. This led researchers to combine DBM with various carriers such as glycerol, starch, hyaluronic acid, collagen, and saline solution. These combinations improve the consistency and handling characteristics of DBM by enabling the composite to harden, thereby enhancing its clinical usability.[20,23]

DBM is produced through acid extraction of allograft bone, theoretically facilitating natural bone formation by increasing the surface area available for osteoconductive and osteoinductive cellular attachment. However, the osteoinductive properties of individual DBM batches can vary significantly depending on donor characteristics. The manufacturing process involves pulverizing the allograft bone to a fine particle size (74–420 μm), followed by demineralization using 0.5 N HCl at a ratio of mEq/g for three hours. Residual acid is then removed through rinses with sterile water, ethanol, and ethyl ether. Through this process, type I collagen from the cortical bone matrix and non-collagenous proteins—including osteoinductive growth factors such as bone morphogenetic proteins (BMPs), transforming growth factor (TGF), insulin-like growth factor (IGF), and fibroblast growth factor (FGF)—become more bioavailable. For this reason, DBM exhibits superior osteoinductive characteristics compared to mineralized allografts, whether cortical or cancellous. However, DBM lacks mechanical strength and is therefore often combined with other allograft types or grafting materials.[20,23]

While DBM shows promise in clinical use and efficacy, the evidence supporting its use as a standalone bone substitute remains limited. Its effectiveness improves when combined with cancellous allograft or autologous bone marrow. The most successful grafts often consist of DBM mixed with autogenous bone graft and used in conjunction with stable

fixation. DBM is commercially available in various forms, including putty, paste, blocks, particles, and powder (*Table 2*).[20,23]

Table 2. *Different clinical applications of Demineralized Bone Matrix. Adapted from references* [23,24]

POWDER DMB	
It is a demineralized bone matrix obtained from human cortical bone with osteoinductive potential.	
Form	Lyophilized powder
Uses	It can be presented in the form of a gel or putty, according to the surgeon's needs or the surgical procedure. Bone tumors that cause defects in bones or cavities requiring filling. Fractures that cause loss of bone tissue due to the trauma that originated them. Reconstruction of mandibular defects or loss of bone tissue in the mandible or maxilla. Alveolar defects in the maxilla or mandible that require additional bone tissue support

Autolysed Antigen-Extracted Allograft Bone (AAA)

AAA bone is a derivative of allogeneic bone graft created by incubating demineralized bone matrix in phosphate-buffered neutral solutions, which induces the autolytic digestion of cellular components. This process yields a fully osteoinductive biomaterial, making it useful for bone regeneration and repair. However, postoperative resorption of the grafted bone is often evident, and its osteogenic effect is not considered ideal. Bone tissue is highly vascularized; its regeneration involves an interplay between osteogenesis and angiogenesis, resulting in bone formation and tissue repair. Enhanced vascularization promotes bone regeneration throughout the repair process. Although literature on AAA bone remains limited, some studies have explored different repair strategies for bone defects using AAA combined with VEGF (vascular endothelial growth factor), aiming to offer new insights and practical methods for the clinical application of allogeneic bone grafts.[20,25]

Decellularized Extracellular Matrix (dECM)

Decellularized extracellular matrix refers to various types of allogeneic biomaterials obtained from human or animal tissue after the removal of cellular components, which would otherwise elicit undesirable immune responses. In simple terms, decellularization aims to eliminate all cellular and nuclear material from tissue while preserving the composition, biological activity, and mechanical integrity of the extracellular matrix (ECM). Tissue engineering has emerged as an alternative to current treatment options by developing structures designed to restore or enhance damaged tissues and organs. Entire organs such as the lungs and the heart have been successfully decellularized for future transplantation, including bone tissue.[20,26,27]

Bone-derived scaffolding materials from decellularized tissue have been investigated for bone repair strategies. Bone-derived dECM is obtained from live or cadaveric human or animal donors through the decellularization process. Multiple studies have demonstrated the osteoinductive capacity of dECM matrices, which can induce osteogenic differentiation and bone formation both in vitro and in vivo. These matrices retain tissue-specific memory and thus promote targeted cellular differentiation.[18,23,24]

Regarding preparation, dECM is subjected to various physical, chemical, and enzymatic treatments configured to completely remove cellular components without compromising the structure and properties of the native bone ECM. Following decellularization, post-processing is necessary to eliminate toxic residues and improve biocompatibility. Sterilization and disinfection methods include gamma irradiation, electron beam sterilization, ethylene oxide gas, antibiotic treatment, and peracetic acid washing. Once sterilized, dECM scaffolds may be recellularized with host-derived stem cells. In bone tissue specifically, mesenchymal stem cells (MSCs), which have the capacity to differentiate into osteoblasts, show particular promise. The ability to seed immunocompatible stem cells onto dECM bone scaffolds offers a highly promising perspective, enabling clinicians and patients to benefit not only from osteoconductive and osteoinductive properties but also osteogenic ones. Additionally, dECM is often combined with collagen, hydroxyapatite, BMPs, and other relevant growth factors to enhance osteogenesis and bone formation. Notably, bone from elderly donors has demonstrated superior support for the osteogenic differentiation of stem cells, whereas MSCs from younger donors exhibit greater differentiation potential.[20,26,27]

TISSUE BANKING

Tissue and bone banking initiatives in Mexico date back to the period between 1940 and 1952, with banks operating in institutions such as Hospital Juárez, the Central Military Hospital, and Clínica Primavera. Tissue banking has been steadily growing in the country. As of 2024, 602 active facilities related to donation were registered with CENATRA (National Transplant Center), of which 457 are licensed for procurement, 435 for transplantation, and 48 as tissue banks.[28,29]

Organ and tissue transplantation, along with the development of advanced biomedical therapies such as those mentioned in this article, currently represent some of the most impactful

therapeutic options for restoring function and improving quality of life. In Mexico, the rapid advancement and complex development of musculoskeletal tissue banks is paralleled by ongoing updates to their regulatory framework.[22,28,29]

The primary functions of tissue banks include quality control and either conservative or chemical processing to obtain human-derived graft materials (bone chips, demineralized bone matrix, ceramics, and other tissue derivatives), ensuring the health, safety, and efficacy of these products. The regulation of musculoskeletal tissues as health supplies falls under the Health Supplies Regulation, enforced by the Federal Commission for the Protection Against Sanitary Risks (COFEPRIS), given that these materials undergo manufacturing processes requiring sanitary oversight.[22,29]

CONCLUSIONS

Allografts or bone grafts, derived from cadaveric sources, have proven to be an essential tool in modern medicine, playing a key role in specialties such as traumatology and orthopedics, reconstructive surgery, and dentistry. Thanks to these grafts, thousands of people have been able to regain their mobility, relieve pain, and significantly improve their quality of life after suffering severe fractures, bone defects, or degenerative diseases. However, despite their well-documented benefits, their availability remains a challenge, as it depends directly on tissue donation, which is still a topic that does not receive the attention and recognition it deserves both globally and within our Mexican population.

Unlike organ donation, which has been considerably promoted both nationally and worldwide through public health campaigns, tissue donation, particularly musculoskeletal tissue, remains little known among the population. Beyond availability, another crucial aspect in the use of cadaveric bone grafts is safety. The safety of these grafts is ensured through rigorous processes such as decellularization and sterilization by radiation, and research in tissue engineering is advancing with the use of stem cells, growth factors, and biomaterials. These innovations aim to accelerate integration, reduce recovery time, and decrease complications, representing significant progress in regenerative medicine and the treatment of complex bone injuries.

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