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Bone Graft Types

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Abstract

Bone grafts have been used by surgeons for a variety of purposes including filling bone cysts, reconstruction of bone loss after trauma and tumor resections and osteogenesis in fractures with union problems. In recent years, a significant increase in the use of bone grafts for reconstructive purposes has necessitated bone grafts of much greater shape and size. Although the use of avascular bone transfers is becoming more preferred due to benefits such as good osteogenic properties, resistance to infection and hypertrophy over time, nonvascular bone grafts have a wide range of use in fracture repair and reconstruction, with new developments in bone morphogenetic protein and stem cell support areas resulting in the proliferation of bone banks. Bone grafts are evaluated in three main groups as follows: autografts, allografts and xenografts. We have compiled the types of bone grafts.

Keywords: autografts, allografts, xenografts, review, literature

1. Introduction

Bone grafting is a surgical procedure that has been used for many years, especially in the fields of orthopedics, neurosurgery, and plastic surgery. Bone grafts are used for filling cystic defects, for bone fractures and arthrodesis treatment, and also for traumatic bone defects or loss of bone lesions that occur after removal of the tumor. It has been reported that allograft use increases in revisions of arthroplasty and in vertebral fusions in the last 10 years [1].

Bone grafting is needed and used in orthopedic surgery and plastic surgery for the fracture repair and skeletal reconstruction of the craniofacial region during the first century. Although the first recipe, up to the seventeenth century, continued to improve day by day in terms of better understanding of the pathophysiology of bone grafts and developing new techniques,

especially for the removal of vascular bone grafts. Nonvascular bone grafts are still widely used in fracture repair and reconstruction, along with new developments in bone morphogenetic protein and stem cell-supporting areas, leading to more favorable use of vascular bone transfers due to benefits such as good osteogenic properties, resistance to infection and over time hypertrophy.

The graft is a dead structure, providing new bone formation and replacing the new bone implant. While grafts are rapidly incorporated into the body, others integrate differently. Some of the grafts cause inflammation and are rejected. Some grafts are completely inert. However, successful results are usually obtained with bone grafts.

Bone and periosteum were expressed at the beginning of the nineteenth century with biological potential. Reliable and pioneering clinical applications began with the reconstruction of a diaphysis of a child's arm-bone by Macewen in 1881 [2].

Autogenous cancellous bone graft is now considered the "gold standard" for fracture healing, to fill spine fusions and bone defects. The main reason for this is the essential components [osteoprogenitor cells, osteoconductive hydroxyapatite collagen matrix and bone matrix protein (BMP)] that help bone healing [3].

Grafts are used as a skeleton to provide bone formation and support wound healing. The grafts also act as a mineral reservoir to aid in the formation of new bone. Bone grafting is a surgical procedure. It aims to replace missing bones with the artificial or natural substitute material of the patient's own body. As the natural bone grows, it usually replaces the graft material completely and results in a completely new bone area [4].

Different sources and origins and various bone graft categories and graft replacements are available. Despite the availability of a wide variety of options, the availability of autologous bone grafts may be limited. In addition, the procedure for collecting material is associated with many complications [5].

Bone grafting has been used to stimulate the healing process over a period of 300 years [6], but the mechanisms by which research has emerged over the last 30 years have been uncovered.

Fresh autogenous bone graft stimulates osteogenesis by three main mechanisms [7]. The first is the direct addition of osteogenic progenitor cells to the local population. These cells are necessary for the differentiation of new bone forming cells. Secondly, autogenous bone grafting is a structural cage for the attachment of osteoblasts, and osteoconductivity for matrix support for supporting cells. The third mechanism is osteoinduction. It refers to the ability of the bone graft to pick up the surrounding mesenchymal cells and direct their differentiation to bone and cartilage forming cells.

Autografts contain a large number of bone growth factors that stimulate the growth of new blood vessels into the graft and encourage migration of bone-forming cells to the injury site. Bone grafts also function as structural support.

The healing of the bone graft and healing occurs with the same healing phases such as induction, inflammation, soft callus, hard callus and remodeling. The mechanical conditions around the

fractured have a great effect on the morphology. According to Wolff's law, compression-electro-negative areas during bone remodeling increase bone formation. Tension-electropositive areas increase bone resorption [8]. Mechanical stabilization is very important in the healing of the defect [9].

Autogenous bone grafting can cause significant donor site morbidity if large structural parts are required [10]. Permission to receive grafts in limited quantities of the donor site, variable graft quality, increased the duration of anesthesia, blood loss and cost are important postoperative complications. For these reasons, surgeons have searched for other options for grafting in the management of bowel and skeletal defects.

Bone grafts that are used effectively in the treatment of bone defects are named differently according to the source: autograft, allograft and xenograft.

2. Autografts

Autograft is the transfer of a piece of tissue in the same individual without the veins that will continue to bleed from one place to another. Autogenous bone grafts; osteogenic, osteoinductive and osteoconductive capacities. It also forms a living cell source that is not immunologically rejected. Autografts are better than allografts and xenografts [11].

Autografts are preferred, especially where osteogenesis is the primary goal, because in autografts, "creeping substitution" develops much faster. In addition, autografts contain osteoblasts, bone marrow and blood cells, osteogenetic induction capacities and osteogenesis contributing unions. Other types of grafts cannot contribute to osteogenesis because they stimulate the immune response [12].

There is an important distinction in autografts in terms of osteogenetic activity. In spongy built and compact autografts, "creeping substitution" develops in completely different form and speed. The open and hollow structure of the spongy bone allows for easier diffusion of newly formed vessels during the revascularization phase. Microanastomoses are easier to establish and blood supply to the graft is provided early. However, a more compact bone graft creates a barrier to vascular invasion. Vascular penetration occurs only through Haversian channels. In addition, osteogenesis and callus formation is easier because the large area surface area of the spongy bone contains many more osteoprogenitor cells [13].

The region where autografts are taken also has an importance in terms of osteogenesis. For example, osteoprogenitor cells, such as grafts, iliac crest bone grafts, primitive reticulocytes, immature hematopoietic cells, integrate rapidly into the bone to which they are implanted. In order for all the above rules to be valid, the autograft should first be well established [12].

During the well-established grafting, it is first observed that the new vessels of the grafted microcavities have formed a mesenchymal stem cell pool in the graft. These cells have the capacity to differentiate into osteogenic, chondrogenic or even fibrogenic cell lines.

The direction of this differentiation determines local, nutritional and electromechanical forces. For example, high oxygenation and compression allow mesenchymal stem cells to develop in the direction of osteoblast. Low oxygenation and compression lead to chondroblast, high oxygenation and tensile forces lead to fibroblast growth [14].

Despite these features of autografts, they can exhibit up to 50% resorption, sequestration and inadequate integration [15]. Development of alternatives to bone autografts due to limited donor sites and potential donor-acquired morbidity has been a constant focus [16]. The success of bone grafts is also due to the presence of osteocompetent cells in the graft, the availability of the recipient site and the lack of immunological response [17].

After transplantation of bone autograft, a number of basic histologic events take place in the recipient area [18]. After transplantation, the graft is covered with hematoma, inflammatory events occur in which the inflammatory cells reach the site, and then new blood vessel formation takes place. Nonvascularized autografts turn into necrosis over time. Most of the osteocytes in the graft die, but those with superficial settling can survive [19]. The blood vessels originating from the recipient site proliferate into the remaining graft tissue and the recipient osteocytes mesenchymal stem cells multiply in the graft. Vascular growth occurs from the Haversian channels present in the graft. Initially, osteoclastic resorption activity is increased, resulting in reduced graft porosity and durability. Cancellous bone is revascularized in a short period of 2–3 days due to open structure. Conversely, revascularization of the cortical bone may last up to 2 months. The fact that vascular touch is invasive into the graft, bringing osteoblasts to the site and osteoblasts' new bone production is a "creeping substitution" phenomenon that occurs in normal fracture physiology [20]. Resorption of necrotic bones in the cortical bone graft is incomplete and therefore the final live and dead bone-mixed touch cannot reach the cancellous bone [21].

Autografts; cancellous, nonvascularized cortical, vascularized cortical and bone marrow. Different grades have osteogenic, osteoconductive and osteoinductive properties.

2.1. Cortical and cancellous autografts

Cortical bone grafts are less successful as biocompatibility than autogenous cancellous bone grafts. Due to the low porosity of the cortical bone, it is difficult and slow to move the vascular structures into the graft. The cortical bone contains fewer osteoblastic progenitor cells than the trabecular bone. The cells in the cortical bone are less resistant to transplantation because of the diffuse oxygen and less nutrient transfer [6].

Cortical bone grafts are a good choice for repair of segmental bone defects smaller than 5–6 cm. Fibula, costa and iliac crest can be used as cortical bone autograft. Osteoprogenitor is poor in cells, osteoconductive and osteoinductive properties are low. They provide strong structural support. The recipient is joined with a creeping substitution process on the tissue. The recipient is fed with plasmatic imbibition from the capillary structures in the wound bed. Complete revascularization does not occur before 1–2 months. This time it is two times that of the cancellous bone. Cortical autografts are less revascularized and less remodeled than spongy autografts. Autologous cortical bone grafts are good choice for bone loss above 5–6 cm. However, vascular grafts are preferred because of the 25–50% failure rate of nonvascular grafts over 12 cm in bone loss [22]. Cortical porosity for revascularization and repair is one of the most important

reasons for the occurrence of graft fracture, delayed union or nonunion, especially in large cortical grafts. Cortical grafts initially have structural durability. But between 6 and 18 months of age, about one-third of your power is lost in the stages of re-vascularization and restructuring. Over time, it approaches normal structure and reaches to the power of normal cortical bone in about 2 years. Nonetheless, nonviable bone islands in the graft continue to survive [23].

Autologous cancellous bone grafts are currently known as the most effective graft material for spinal fusion, filling bone defects and bone healing in fracture treatment. Osteogenic bone and bone marrow cells, osteoconductive collagen and mineral matrix, matrix proteins and osteoinductive matrix proteins are transplanted into autogenous cancellous bone. It has been shown that primitive osteogenic cells survive posttransplantation and transform into osteoblasts in the new bone tissue developed after autograft application [24]. Although the cancellous bone is known to be osteoinductive, there is no evidence that inductive proteins and cytokines are active in autologous cancellous grafts [22].

Cancellous bones are fast revascularized grafts. Surface osteoblasts and endosteal cells can transpicate. Creeping acts as an osteoconductive substrate that effectively supports substitution. The cancellous graft cannot provide the acute structural support provided by the cortical graft. Although cancellous autografts do not initially have carrier-carrying properties, bone grafting builds upon the graft and structural integrity of the bone with the recipient bones begins to form. As bone mass increases, endurance increases and the resulting new texture is restructured in the direction of Wolf's rules. However, it can be strengthened as fast as cortical graft for 6–12 months. Among the sources of cancellous bone, the posterior iliac crest comes first. The most frequent site of grafting is iliac crest. Major complications were reported as 8.6% and minor complications as 20.6% [25]. Other sources of grafts are Gerdy's tubercle, distal radius and distal tibia [22].

2.2. Endochondral and membranous autografts

While endochondral bone is originated from cartilage, membranous bone is originated from mesenchymal tissue. While craniofacial skeleton is formed by membranous ossification, most of the axial skeleton is formed by endochondral ossification. In graft viability, the interaction between the local mechanical environment and the cortical or cancellous nature of the bone, rather than the embryonic origin of the bone, has been shown to be important [26]. Membranous bone is generally preferred when grafting to the endochondral bone.

2.3. Vascularized autograft

With the progress of microsurgical techniques, autografts are frequently used in vasculature. When both artery and vein are anastomosed during transplantation, approximately 90% of the osteocytes survive and there is no osteoclastic resorption of the bone for incorporation and boiling. Areas where grafts can be removed: fibula, costa, tibia, olecranon and iliac wing. The most preferred graft is fibula graft [27]. McKee [28] reported the first microvascular anastomotic bone graft transfer at a meeting. Then the first free bone grafting articles were published [29]. In 1977, the first bone skin free flap was published [30]. Although bone grafting with vascular anastomosis using microsurgical techniques is described in the literature, "free bone graft" is used, although "free vascular bone graft" has been used in the terminology [31].

Resorption and subsequent osteoconduction and remodeling are not observed as in nonvascular autografts and therefore are more resistant to the first 6-week period than nonvascular autografts. Osteogenic cells in vascularized bone grafts undergo less resorption. More cells live in grafts than nonvascularized grafts [32]. They do not need a good vascular space where they are transported. Vascularized bone grafts have been shown to be biomechanically superior [33].

Vascularized bone graft acts as if there is a simple fracture on the contact surfaces of the field. Bone healing in the fracture line “Creeping substitution” occurs here. These grafts can maintain 60 min of life at room temperature. There are publications that show that reperfusion grafts will partially return in up to 6 h of ischemia [34].

2.3.1. Vascularized fibula autograft

It is the gold standard in bone free skins because it can provide bone mass, pedicle length and skin pedicle. Both endosteal and periosteal circulation are provided. Bone healing is very good. It is the type of flap that should be considered when the receiving bed is not very good due to radiotherapy, infection and scar. Disadvantages include the possibility of damage to the peroneal nerve and tibial arteries.

2.3.2. Vascularized iliac crest autograft

The ileum may be transferred as a deep circumflex iliac artery based bone autograft or as a superficial gluteal artery based bone autograft. With this autograft, up to 4–10 cm of bone can be carried. They are used in mandibula and sub-articular reconstructions. Continuation of endosteal and periosteal circulation, donor site morbidity is low and long pedicle is a very useful flap. Hypoesthesia due to the injury of the lateral femoral cutaneous nerve and the risk of herniation are disadvantages. Posterior iliac crest is a potential source of bone used when there is segmental bone loss, such as radiotherapy, trauma and tumor resection. It is also used in diaphyseal pseudoarthrosis treatment of long bones. The bone segment that can be transferred is limited to 4–6 cm.

2.3.3. Vascularized rib autograft

Flaps can be prepared via endosteal or periosteal pedicles. It limits the use of the vascular pedicle short.

2.3.4. Vascularized scapula autograft

The lateral part of the scapula can be transferred so that the circumflex scapular artery is fed from musculoperiosteal branches. Scapula autograft can be preferred for mandibular, orbital and maxilla reconstructions.

2.3.5. Vascularized calvarial autograft

Vascularized calvarial autograft can be transferred with the scalp. Vascularized transfer of calvarial bone is especially preferred for craniofacial reconstructions. Bone quality is very good. The risk of intracranial injury is the disadvantage.

2.3.6. Vascularized metatarsal autograft

This graft is commonly used for the first finger of the foot. It is also applied in the form of composite tissue transfer of the first and second fingers of the foot.

2.3.7. Vascularized radius autograft

The radial artery gives periosteal and skin perforator branches. These vessels are fed with radial side forearm bone skin blade. A 6–12 cm of the radial bone may be included [35].

2.3.8. Vascularized wrist dorsal and volar autograft

Vascularized bone grafts are widely used in the repair of many carpal pathologies. Many pedicle grafts such as radial volar, radial dorsal and second metacarpal have been described [36].

2.3.9. Vascularized medial femoral condyle autograft

The flap was first populated by Sakai [37]. Eighty per cent of the cases of the major pedicle of the flap are descending genic artery with medial branch of superficial femoral artery. The corticoperiosteal bone graft can be removed from the medial femoral condyle up to $8 \times 13 \text{ cm}^2$. It is a source of grafts for the repair of relatively small bone defects.

2.4. Nonvascularized bone autografts

2.4.1. Nonvascularized iliac crest autograft

It is a very good resource for cortical and cancellous bones. Easy to reach, can be taken in any amount. The disadvantage is that the donor area is also postoperative pain. Anterior grafts can be taken from superior iliac spine and crest tubercle. No damage to the tendinous ligaments is important to prevent the possibility of gait disturbance. The lateral femoral cutaneous nerve may be damaged during graft retrieval. Paresthesia on the outside of the leg results in hypoesthesia. If large segments are taken from ileum, herniation due to inguinal ligament integrity may occur.

2.4.2. Nonvascularized calvarial autograft

Calvarial bone split grafts are used. In an adult patient, the average thickness of the calvarium is assumed to be 7 mm. The thickest part of the bone is the parietal area behind the coronal suture. Calcium is not preferred in children and adolescents because of the risk of dura and brain damage during graft ingestion.

2.4.3. Nonvascularized costa autograft

Costa grafts are used for mandibular or craniomaxillary zone reconstructions. Unlike whole-layer costa grafts, partial thickness jeans grafts provide cortical bone with a larger surface area. The regeneration ability of the casts allows the partial autogenous cortical graft to be taken several times over the same donor site.

2.4.4. *Nonvascularized autografts of radius, trochanter major and olecranon*

Cortical and cancellous bone needs are not among the preferred donor sites. They are preferred in situations where the iliac crest is unavailable.

2.4.5. *Bone marrow*

Bone marrow can be used alone as an osteogenic graft. Bone marrow obtained after aspiration; cytokines, osteoblastic progenitors such as other bone marrow-derived cells, and a rapidly revascularized absorbable biological fibrin matrix. An average of 1400 connective tissue progenitors was found in the iliac crest aspirated bone marrow [38]. Bone marrow should be used immediately after aspiration.

3. Allografts

Bone transfers are genetic characteristics made between different individuals. The first literature report was made by MacKewen [39]. Allografts; porous structures contain many chemical domains that are retained by progenitor cells and endothelial cells. They also contain growth factors in the bone matrix that are released when resorbed by osteoclasts. The allograft bone also contains a small amount of bone morphogenic protein with osteoinductive properties.

Demineralization increases the bioavailability of growth factors in the allograft bone matrix. In addition, demineralization prevents HIV infection [40].

In the early allograft use, the graft cells were completely destroyed and the skeleton of the bone roof served as a scaffold. Fresh bone allografts result in both humoral and cellular immunological responses, which allow the graft to be recognized by the recipient. Antibody production results in cell lysis and vascular destruction resulting in graft rejection. The frequency of allograft rejection depends on the degree of antigen mismatch between the graft and the recipient. Vascularized bone allograft rejection is seen on postoperative third day. The first affected members have been shown to be osteocytes and vascular endothelium [41]. Rejection can be suppressed by the use of cyclosporine. Every allograft causes an immunological reaction in the recipient.

The alignment of allografts is different than that of autografts. Both vascular invasion and perivascular new bone formation are slower. This adaptation also affects the size of the graft, the level of immunological response to the graft and the conditions under which allograft is stored [12].

The immunological response to allografts results in the sensitization of the recipient to histocompatibility antigens in osteogenic and hematopoietic cells, leukocytes, blood vessels, nerves and connective tissue matrices within the graft. Therefore, this is a secondary immunological response. This is a cellular immune response [42]. Herndon et al. allografts have found widespread use, demonstrating that the immune response with frozen allografts decreases. Attention has shifted to allograft preservation techniques [43].

If allografts are separated from their cells, they are prevented by immunological reactions. The bones obtained from cadavers are used as osteoconductive skeleton by decellularization [19]. Thus, the disease is prevented from passing between people. Among the processes used are irradiation, debridements, ultrasonic washing, liquid nitrogen, ethylene oxide and deep freezing. Allografts are prepared and maintained in tissue banks.

Frozen-dried bones are poorly immunogenic to both the humoral and cellular immune system. However, passing the bone through these processes destroys osteoinductivity when changing mechanical properties [44]. Bone banks were needed for the use and development of these methods and bone banks were established in many parts of the world.

3.1. Bone banks

The preferred age range for choosing donors for bone banks is from 16 to 65 [45]. Donors; acute or fatal chronic infection, malignancy, exposure to radiation in the area to be caught, venereal disease, hepatitis, slow virus diseases, AIDS or HIV infection, drug use, steroid use for more than 1 week, diffuse osteoporosis, immune complex disease, connective tissue disorders and long-term insulin-dependent diabetes should not have an anamnesis such as grafting with live virus vaccine in the near future [46, 47]. Donors can live in cadaver. Live donors require adequate physical examination and a good anamnesis, and a detailed autopsy is required for cadavers.

3.2. Demineralize bone matrix

Demineralized bone matrix (DBM) is used to fill bone defects and voids as an osteoconductive and osteoinductive material. DBM is rapidly re-vascularized and is also a good carrier for autologous bone marrow. There are differences between tissue banks and firms according to DBM acquisition phases [22]. Studies have shown that DBM results in long bone pseudoarthroses and bone loss similar to autologous bone grafts [48]. DBM can be used by mixing with cancellous graft to increase and intensify autologous bone graft when bone loss is large. It can also be considered as an alternative in patients who cannot use autologous bone graft [22].

3.3. Morselized and cancellous allografts

They are osteoconductive. They provide mechanical support against compression. They are prepared by freeze-drying (lyophilization) and vacuum packaging. It can be used to fill cavities formed after curettage in bone cysts and to remove bone surfaces in periarticular metaphyseal fractures.

3.4. Osteochondral and cortical allografts

They are obtained from the pelvis, costume, femur, tibia and fibula and used in major bone and joint loss. They also provide both structural and mechanical support for the treatment of periprosthetic fractures. They carry osteoconductive properties.

4. Xenograft

Another species is the use of the bones of living things. Bones from various animal species have been tested since allograft is an expensive method of providing. However, they were abandoned because of their high immunity, insufficient biomechanical qualities and foreign body reaction [49].

Dog tibia, calvarial bone transplants have been reported for the defect in human bones [49]. But it has been understood that it is not useful in the human body [50]. Cell-free and demineralized xenografts have been used but have been shown to destroy bone morphogenic proteins and other growth factors [51].

5. Conclusion

Bone grafting is the most commonly used method for increasing bone regeneration in surgical procedures [52]. More than 2 million bone grafting procedures have been performed worldwide every year. Immediately after blood transfusions, it is the second most common tissue transplant [52]. Important when deciding on the use of bone grafts; patient factors, environmental factors, the experience of the surgeon and the economic dimension of graft use.

Conditions limiting the use of autografts and allografts have accelerated the development of bioceramic technology. As the future of bone grafting procedures, new technologies will emerge in the isolation and production of recombinant human bone morphogenic proteins and growth factors and in the application of autogenous stem cells.

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