Onlay Bone Grafts in Head and Neck Reconstruction

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ABSTRACT

Bone grafts are used in a variety of clinical situations and can be divided into two categories: treatment of bone gaps (inlay bone grafting) and bone projection (onlay bone grafting). Cortical grafts are useful in situations requiring immediate mechanical strength. These grafts can survive with or without complete revascularization or resorption and are primarily used by plastic surgeons in the treatment of bone volume deficiency. Cancellous grafts, in contrast, have no mechanical strength and therefore require additional support to bridge bone defects. Thus, they are used primarily for the treatment of bone gaps and in general revascularize quickly, resorb completely, and stimulate significant new bone formation.

KEYWORDS: Cancellous bone graft, cortical bone graft, osteoinduction, revascularization

Bone is embryologically derived from mesenchymal tissue through endochondral or intramembranous ossification. Endochondral bone goes through a cartilaginous phase before ossification, whereas membranous bone forms directly from mesenchymal condensation. The facial skeleton, cranium, and clavicle are examples of membranous bones. The appendicular and axial skeleton bones are examples of endochondral bones. Structurally, all bone consists of an outer compact or cortical bone and an inner spongy or cancellous bone. The structural unit of dense cortical bone is the osteon, in which an osteocyte is centrally located and surrounded by concentric layers of bone or lamellae, with a system of haversian canals housing nutrient vessels. Cancellous bone is found between the internal lamellae of flat bones and in the metaphyses of long bones. The structure of cancellous bone is more open and consists of trabeculae and spicules.^{1,2}

HISTORY

The earliest bone grafting attempt was to transplant a canine skull bone to a calvarial defect by Van Meekren in 1682.³ In 1842, Flourens showed that periosteum is osteogenic and is the main agent responsible for the healing of the bone defect.⁴

In 1867, Ollier reported that transplanted periosteum and bone remained alive and could become osteogenic under proper circumstances. He believed that viable bone with attached periosteum was the best form of graft to use. He also noted that the contents of the haversian canals and the endosteum were important in bone regeneration.⁴ Barth (1893) was the first to challenge this report. He claimed that all bone marrow and periosteum die after transplantation and are replaced by surrounding tissue. Barth and Marchand were the first to use the term *creeping substitution* to describe the invasion of old bone by new bone, without previous resorption of the old bone. The term *creeping substitution*

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has frequently been used to describe a process that is really resorption and apposition.⁴

Axhausen (1907) performed a series of experiments demonstrating that periosteally covered bone grafts exhibited osteogenesis from the surface cells surviving at the periosteum.⁵⁻⁷ In 1914, Phemister reported an extensive series of studies demonstrating that some of the osteogenic cells on the surface of a bone graft survive by diffusion of oxygen and nutrients from the recipient bed. He agreed with Barth that the vast majority of the bone in the center of a large graft was dead, as empty lacunae were observed 10 days after transfer. On the other hand, he emphasized the importance of cell survival at the surface of the graft. Bone-forming cells on the surface of the graft were important for resorption of the central necrotic portions of the graft and replacement with new bone.^{7,8}

SURVIVAL OF BONE GRAFT

The classic bone healing cascade occurs with infiltration of inflammatory cells, followed by in-growth of new vessels and replacement of necrotic tissues. However, in the case of an autograft, there is little question that both the transplanted bone graft and the recipient tissues participate in the formation of new bone. These events vary depending on the status of graft vascularity, the characteristics of the graft, and the condition of the recipient bed. Nonvascularized grafts undergo necrosis, as only the osteocytes on the surface reestablish blood supply and survive. The remainder of the graft is infiltrated by blood vessels from the recipient site and repopulated by recipient mesenchymal stem cells.^{1,2} The process by which vascular tissue invades the graft and brings osteoblasts that deposit new bone has been termed *creeping substitution*.⁹

In *osteoconduction*, the graft provides a scaffold that serves as a network on which the new bone is deposited. In *osteoiduction*, active factors released by components in the graft, and most probably from components of the matrix (such as bone morphogenetic protein; BMP), stimulate sensitive cells in the recipient bed to invade the graft. The cells are then induced to begin osteogenic activity.^{2,4}

The concept of osteogenic induction has been studied extensively.^{10,11} In these studies, an insoluble noncollagenous BMP, a proteolytic enzyme (BMPase), and a bone hydrophobic glycopeptide were described. BMP remains the only known molecule capable of promoting osteoinduction.^{2,4} Recently, eight BMPs were cloned using recombinant DNA technology, and additional growth factors have been identified as being important for bone repair and maintenance, including platelet-derived growth factor, transforming growth factor, insulin-like growth factors, basic fibroblastic growth factor, and epidermal growth factor.^{2,4,12}

VASCULARIZATION OF BONE GRAFTS

Whether the initial revascularization of a bone graft occurs by formation of anastomoses between vessels of the graft and those of the recipient bed, as in split-thickness skin grafts, or by invasion of the graft by newly formed vessels is a matter of debate. Vascularization then must proceed by gradual penetration of the graft by recipient vessels while osteoclastic activity and apposition of new bone are taking place. The rate of vascularization depends on the species, the size of the bone graft, and the type of bone graft used.^{4,13} Cancellous grafts revascularize faster than cortical grafts,¹⁴ and membranous bone revascularizes faster than mixed corticocancellous endochondral grafts.¹⁵

Vascular in-growth in cortical bone grafts occurs through preexisting haversian canals. There is an initial expansion in osteoclast resorptive activity, which increases the porosity and decreases the strength of the graft. Revascularization of cortical grafts may take a few months. In contrast, cancellous grafts are more rapidly revascularized, within 2 to 3 days, by virtue of their open structure.

INCORPORATION OF THE BONE GRAFT

The process of envelopment and interdigitation of the donor bone tissue with new bone deposited by the individual is termed *incorporation*.^{4,16} The quantity of donor bone resorbed is greater in cancellous bone grafts than in cortical bone autografts and greater in autografts than in alloimplants. In all instances, the end point of incorporation generally falls short of complete replacement with living bone. When cortical bone is grafted in an adult, as much as 90% of the volume of the graft may be of donor origin. The donor tissue may remain unresorbed for many years after the operation. In growing bones in children, tissue remodeling is so much more rapid than in adults that only microscopic quantities of the structure of the donor may be recognizable by the second year after transplantation.^{4,10}

In experimental studies, Enneking et al reported the following conclusions:

1. Resorption of the necrotic bone transplant is independent of physiologic-skeletal metabolism.
2. Appositional bone formation is influenced by the skeletal renewal rate.
3. Torsional stress failure is correlated more with porosity than with microanatomic features.
4. In autografts, at 48 weeks of healing, when physical resistance to torsional stress is nearly normal, only 60% of the transplant is resorbed and replaced by new bone.¹⁷

The same group of investigators studying cortical bone allografts in dogs concluded that the incidence of

nonunion, fatigue fracture, increased porosity, increased cumulative new bone formation, decreased cross-sectional area, and decreased mechanical strength were significantly different when either fresh or freeze-dried allografts were compared with fresh autografts.^{4,18}

CLINICAL USES OF BONE GRAFTS

The application areas of autogenous bone in head and neck include creation of congenitally missing parts of the skeleton, augmentation and normalization of facial contour, replacement of missing segments of bone after surgery or trauma, induction of healing in nonunited fractures, stabilization and retention of the facial skeleton in a displaced position, and fusion of joints and bone segments.^{4,7,19-22} Bone graft needs vary greatly, depending on the location, volume, and components of the bone defect. The techniques available for autogenous bone replacement are nonvascularized bone grafts, pedicled bone flaps, and microsurgical bone flaps. The appropriate technique for the specific clinical situation is determined by several factors. Foremost is the quality of the soft tissue environment into which the bone reconstruction is to be performed. A history of radiation, scarring from previous surgery or infection, and inadequate soft tissue coverage lessen the probability of vascularization of a nonvascularized bone graft.

Requirements for successful reconstruction of a bone defect with nonvascularized bone graft are

1. Adequate and healthy soft tissue coverage.
2. A well-vascularized recipient bed.
3. Increased wide contact between the adjacent bone fragments and bone graft.
4. Rigid fixation of bone fragments.
5. Meticulous hemostasis of the recipient bed for prevention of hematoma formation.^{20,23-25}

Additional factors considered for a successful reconstruction are to include as much cancellous bone as possible in the graft for rapid revascularization, include cortical bone to provide strength to the graft, and preserve periosteum over the cortex as a vascular structure to assist in the revascularization of the graft through the cortical layer.²⁰

DONOR SITES

The Cranium

Cranial bone is used frequently for congenital, traumatic, or surgically created defects of the facial skeleton. In a large number of experimental studies and clinical practice, composite membranous onlay bone grafts were shown to be superior to composite endochondral onlay

bone grafts in the craniofacial skeleton. These studies therefore concluded that embryologic origin was the key factor in graft survival.²⁶⁻³⁹

However, some authors demonstrated the influences of microarchitecture on bone graft survivability by showing that cancellous bone resorbed faster than cortical bone of either embryologic origin. Additionally, they found cortical endochondral and cortical membranous onlay bone grafts to resorb at an equal rate. Therefore, they concluded that cortical bone is a superior onlay grafting material, independent of its embryologic origin, and that the microarchitecture of bone grafts does play an essential and perhaps even the primary role in the resorption rates of onlay bone grafts.^{40,41}

The technique of obtaining cranial bone graft has been described previously in detail.^{7,19} There are multiple methods to harvest cranial bone grafts. The location of the donor site is determined by the desired curvature. Generally, the parietal areas constitute the most appropriate donor sites. For some applications, the bone is harvested as bone dust or multiple small shavings. The bone dust has been applied to grafting the alveolus in cleft palate patients. Bone dust is harvested by using an electric craniotome, or preferably a brace and bit, and placed into the alveolar cleft after mucoperiosteal flaps have been raised. The two most common methods of harvesting cranial grafts split the bone through the diploe, separating the outer and inner tables. This achieves a doubling of the surface area at the expense of decreasing its thickness. Using a burr, a trough is created around the proposed graft. Applying an osteotome to the diploic space, the surgeon can remove the outer table of the cranial bone and use it as a graft. It is not uncommon to remove full-thickness bone inadvertently with this maneuver. This occurrence is often of no consequence, but dural tears and serious venous sinus hemorrhage have been reported.

These complications become more frequent as the size of the desired graft increases. For this reason, when a large section of cranial graft must be harvested, it is usually wise to perform a formal craniotomy and split the bone on a back table. A sagittal saw with a long blade is applied to the diploic space around the periphery of the excised section. The rest of the separation is performed with curved osteotomes. One of the two cortical tables is used to cover the donor site, and the other serves as the graft.^{7,19} Moreover, due to the thin nature of cranial bone in children, splitting the cranial bone is not usually contemplated until the child reaches adolescent years.⁷ Because of the tremendous capacity of the dura and, to a lesser extent, of the pericranium in children to generate bone, cranial bone grafts are used almost exclusively for reconstruction of the cranium and face. In infants and young children, defects created by the harvesting of cranial bone are reconstructed, either totally or in part.

In older children, when the calvaria is still too thin to split into inner and outer tables, the donor defect should be covered either with autogenous graft from a different source or with an allogeneic implant. In adults, the cranial bone can easily be split into inner and outer tables. Generally, the outer table is used as the graft, and the inner table is returned to cover the donor site.^{4,19}

Advantages of cranial bone grafts are:

1. Less resorption compared with endochondral bone grafts.
2. Superior aesthetic results with proper selection of the curvature.
3. Easy accessibility of the donor site.
4. Minimal postoperative pain.
5. The large quantity of bone available in children, in who availability from other sources is limited.

The disadvantages are few. Due to their rigidity, cranial bones do not conform to fill dead spaces and therefore may have to be combined with grafts from other sources, such as the iliac crest or tibia.³⁴⁻³⁹ In a recent review, the possibility of a dural tear or an epidural hematoma was found to be very low when performed by surgeons with proper training.⁴²

The Rib

Longacre and DeStefano popularized the use of split-rib grafts for reconstruction of cranial and facial skeleton defects. They noted in children that the cranium reconstructed with split ribs developed at a normal rate. They also commented on the rapid regeneration of ribs and on the fact that they had used the same regenerated rib on occasion within 6 months to 1 year.⁴³ However, use of full-thickness rib graft fell into disfavor, principally because of the way in which it was used. When a full-thickness rib is inserted, the only possible vascular penetration is through the cut ends of the graft and several Volkmann canals; otherwise, the rib presents only dense cortical bone on its surfaces with little chance of survival.⁷

Harvesting of autogenous rib grafts is commonly performed with an incision made over the seventh rib or using a submammary incision in the female patient. The dissection then proceeds under the latissimus dorsi muscle splitting the fibers of the serratus anterior if needed. The ribs are harvested subperiosteally with care to preserve the integrity of the pleura. Only alternate ribs are harvested. After their removal, each defect is closed with a continuous absorbable suture of the periosteum. For small pleural tears, closure of the pleura under positive pressure is usually adequate. If a larger tear has occurred, temporary insertion of a thoracostomy tube should be performed. Rib grafts should be avoided in children.^{7,19}

The Ilium

The iliac bone is an excellent source for large quantities of cancellous and corticocancellous bone. It is composed almost entirely of cortical bone with an abundant supply of cancellous bone and is of variable thickness. The morbidity that follows the removal of this graft (in terms of bleeding, ileus, pain, and limping due to muscular spasm) is directly related to the amount of bone removed.⁷ Varied techniques of harvesting iliac bone graft have been described.^{4,7,44} The easy accessibility of the iliac crest makes the removal of the graft relatively simple. The hip is elevated on a folded towel, and the skin is retracted medially so that the incision lies lateral and below the crest instead of over the crest.^{4,7} The incision is then performed through skin and periosteum over the iliac crest, behind or posterior to the anterior superior iliac spine. The iliac spine and the bone adjacent to it are left intact, and the iliac crest is split sagittally, leaving the muscle attachments intact.^{4,7}

If cancellous bone alone is needed, an osteotomy is made over the central portion of the iliac crest, and the required amount of cancellous bone is resected. The outer and inner tables of the ilium may then be fractured toward each other to eliminate the resulting dead space between them. The technique does not disturb the continuity of the crest and leaves no visible deformity.⁷ When a full-thickness bone graft is needed, both medial and lateral halves of the iliac crest are reflected and retracted in continuity with the periosteum and muscle attachments. The graft is then taken in the desired shape and size. If only partial-thickness corticocancellous bone is needed, the medial portion of the crest is reflected and the bone harvested. Additional quantities of cancellous bone can be harvested easily with a curette. A drain is typically not used. When properly performed, this method allows the harvesting of a large quantity of bone without any aesthetic deficit and minimal postoperative pain. This technique is not suitable for patients younger than 8 years of age because of incomplete ossification. Bone may be reharvested from the same area in 18 to 24 months.^{4,7} In the younger child, the technique described by Crockford and Converse may be used in the rare instance when an iliac bone graft is necessary. The crest is left undisturbed, and the fascia lata and muscles are incised on the lateral surface down to bone and reflected. Bone is then harvested from the lateral surface, beneath the growth centers.^{4,7,45}

The reported complications or morbidity of iliac bone graft harvesting either in adult or children include: hematoma, the most frequent complication; herniation of abdominal contents through the scar,^{46,47} due to extensive stripping of the lateral surface of the ilium⁴⁸; neuropathy of the lateral femoral cutaneous nerve, causing pain⁴⁹; and fracture of the iliac crest.⁵⁰

The Tibia

The tibia can provide cortical and some osteogenic cancellous bone graft. Some authors have reported that in infants, the tibia provides sufficient material for alveolar grafts in cleft palate deformity.⁵¹ The technique of harvesting bone from the tibia has been described previously.^{4,7,51} After an Esmarch bandage is applied to provide a bloodless field, a long, curved incision is made on the anteromedial surface parallel to the tibial crest. The skin and subcutaneous tissues are dissected, and the periosteum is incised medially, laterally, and distally, remaining attached only proximally from the level of the epiphysis to the midshaft of the tibia. The periosteum and a thin layer of attached cortical bone are elevated in a distal-to-proximal direction, remaining attached as a proximally based osteoperiosteal flap. The underlying cortical bone of the medial surface of the tibia is then removed and the medullary cavity entered. Cancellous bone is curetted from the area of the proximal epiphysis, and the osteoperiosteal flap is sutured back in place. The skin is closed in one layer, and dressing is applied. The harvested bone is generally used to supplement cranial grafts and to fill dead spaces. The tibial bone graft spares the ilium for future use when multiple-stage reconstructions are planned. There is no deformity other than the surgical scar, and the patient experiences only temporary difficulty in walking. If the amount of removed bone is large, it may cause disfigurement, pain, and frequently secondary fracture of tibia.^{4,7}

OTHER AUTOGENOUS DONOR SITES

The fibula is the most suitable bone graft to bridge defects in the long bones that result either from resection of tumors or from traumatic losses. Harvesting the fibula as a bone graft does not cause major functional deficits either in young or adult patients.^{52,53} The distal radius and the proximal ulna have frequently been used as sources of both cortical and cancellous bone grafts for procedures involving the upper extremity as it is obviously advantageous to obtain the grafts from bones in the same surgical field.⁵⁴

PREPARATION AND STORAGE OF BONE GRAFTS

Cortical and corticocancellous bone grafts are cut to the desired shape with a combination of bone-cutting forceps and electrical or air-powered saws and drills. The proper configuration of drill points and selection of appropriate drilling speeds have been shown to be important in reducing mechanical and thermal damage to bone.⁴ To prevent mechanical and thermal damage at the time of the bone graft harvesting procedure, the following recommendations are given:

1. Bone drills must have an appreciable rake angle (cutting edge angle).
2. A point angle on the drill is desirable to prevent the drill from walking on the surface.
3. Drilling should be done in the 750 to 1250 rpm range.
4. Coolant in the form of saline should flood the entire drilling field (cold saline would possibly allow drilling at higher speeds).
5. The periosteum should be reflected away from the point where the drill will enter the bone to prevent the chips that are ejected from the hole from being forced under the tissue and clogging the flutes of the drill.
6. Drill flutes should, for compact bone, be steep enough to remove chips at an even rate.^{4,55}

Thompson considers the optimal drilling speed to be ~500 rpm. He found that drilling at lower speeds causes fragmentation of the edges of the hole, and drilling at higher speeds increases the thermal changes in the bone.⁵⁶ Although the optimal drilling speed has not been universally agreed upon, available studies indicate that it is in the vicinity of 500 to 1000 rpm and that use of high-speed air-powered drills should be avoided.⁴

A short time should be allowed to pass between harvesting and placement of the bone graft to the recipient bed. During that time, the graft should be kept wet in a liquid to ensure viability of the maximum number of cells. In a comparative study, the temporary storage of bone grafts in various media has been assessed.^{2,57} The best storage medium has been determined to be either dextrose %5 in water (D5W) or normal saline. The ability of the patient's serum to retain cellular viability is extremely poor, and tissue culture offers no advantage over D5W or normal saline.^{2,57}

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