Alternatives to Autogenous Bone Graft: Efficacy and Indications

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Abstract

Bone grafting is frequently used to augment bone healing with the numerous approaches to reconstructing or replacing skeletal defects. Autologous cancellous bone graft remains the most effective grafting material because it provides the three elements required for bone regeneration: osteoconduction, osteoinduction, and osteogenic cells. Autologous cortical bone graft provides these three components to a limited extent as well and also provides the structural integrity important in reconstruction of larger defects. However, because autogenous grafting is associated with several shortcomings and complications, including limited quantities of bone for harvest and donor-site morbidity, alternatives have been used in a wide range of orthopaedic pathologic conditions. Grafting substitutes currently available include cancellous and cortical allograft bone, ceramics, demineralized bone matrix, bone marrow, and composite grafts. No single alternative graft material provides all three components for bone regeneration. The clinical applications for each type of material are dictated by its particular structural and biochemical properties. Composite grafts consisting of several materials are often used to maximize bone healing, especially where the grafting site is compromised.

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Bone grafting is commonly used to augment bone healing in the surgical treatment of a broad spectrum of musculoskeletal disorders.[1] Bone grafts have been used to reconstruct or replace skeletal defects, to augment fracture repair, to strengthen arthrodeses, and to fill defects after the treatment of bone tumors. For over 100 years, autologous cancellous bone grafting has been the standard of care.

Autogenous Grafts

Autogenous grafts can be cancellous, nonvascularized cortical, or vascularized cortical; each type has different biologic activities (Table 1). Ideally, graft substitutes should provide four elements: an osteoconductive matrix, which is a nonviable scaffolding conducive to bone ingrowth; osteoinductive factors, which are the chemical agents that induce the various stages of bone regeneration and repair; osteogenic cells, which have the potential to differentiate and facilitate the various stages of bone regeneration; and structural integrity.

Autogenous cancellous bone graft contains three of these components: (1) the hydroxyapatite and collagen are well suited to serve as an osteoconductive framework; (2) numerous stromal cells within the lining have osteogenic potential; and (3) the bone graft and the adjacent clot contain a family of growth factors, most notably bone morphogenic protein (BMP) and transforming growth factor-beta, which have the ability to induce the regenerative process as well as to augment the process to completion. Autologous cortical bone provides these elements to a more limited extent, but its structure confers strength when needed to fill larger defects. Any alternative to autogenous bone graft should be judged in terms of its ability to provide these

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Table 1
Properties of Types of Autologous Bone Grafts

Property	Cancellous	Nonvascularized Cortical	Vascularized Cortical
Osteoconduction	++++	+	+
Osteoinduction	++	+/-	+/-
Osteoprogenitor cells	+++	-	+
Immediate strength	-	+++	+++
Strength at 6 months	--	++	+++
Strength at 1 year	---	+++	++++

three components, as well as structural integrity when applicable.

Bone regeneration initiated by autogenous cancellous bone occurs in three major steps. First, the undifferentiated osteoprogenitor cells are recruited. Then, by osteoinduction, these cells differentiate to give rise to osteoblasts and chondrocytes. Finally, a suitable scaffold on which active osteoprogenitor cells can produce new bone is established.

Osteoinduction is mediated by numerous growth factors provided by the bone matrix itself. The most notable group are the BMPs, which are low-molecular-weight proteins that initiate endochondral bone formation, presumably by stimulating local progenitor cells of osteoblast lineage and by enhancing bone collagen synthesis. Transforming growth factor-beta, shown to be closely related to BMP by sequence homology, is synthesized in many tissues, including bone, and appears to stimulate bone formation similarly. Others include fibroblast growth factors, which are angiogenic factors important in neovascularization and wound healing, and platelet-derived growth factor, which acts as a local tissue-growth regulator. Platelet-derived growth factor was initially isolated in blood platelets, underscoring one of the important roles of the clot (hematoma) after a fracture or grafting, but recently other tissues, including bone, have been shown to synthesize it as well. Insulinlike growth factors and microglobulin-beta are other examples of bone-matrix-synthesized growth factors.[2]

Cancellous bone graft starts with no structural integrity, but this rapidly changes due to bone augmentation and union (osteointegration) with preexisting osseous structures. The bone strength increases as the bone mass accumulates, and the construct is remodeled along the lines of stress. The converse occurs with cortical bone. The graft initially conveys structural strength as it undergoes osteointegration at its ends. It then undergoes a remodeling phase, in which the nonviable bone is removed by osteoclast tunneling and resorption. During this resorptive phase, which can last from 6 to 18 months, the bone can lose up to one third of its strength, as demonstrated by Enneking et al.[3] The cortical bone will retain significant islands of nonreplaced nonviable bone throughout the life of the individual. The major advantage of cortical bone over cancellous bone is that it offers initial structure and can provide compressive strength to the graft construct.

Free vascularized cortical grafts most commonly involve the fibula, although other bones, such as the ribs and the iliac crest, have been used. In this process, the bone does not undergo significant cell necrosis and remains viable through its arterial and venous anastomoses, which avoids some of the problems of nonvascularized cortical bone. Biomechanical studies have demonstrated that it is superior to nonvascularized cortical graft for approximately 6 months, after which time no difference can be demonstrated as measured by torque, bending, and tension studies. The disadvantages of vascularized grafts include donor-site morbidity, which is minor in most cases; prolonged operating time; and greater utilization of resources. Vascularized grafts are clearly superior to nonvascularized cortical grafts when the bridging area is more than 12 cm. Reported stress-fracture rates for this distance in nonvascularized cortical bones approach 50%, while the rate of fracture for vascularized grafts is less than 25%. The vascularized graft also has a greater ability to heal stress-related fractures and to enhance its girth.

The advantages of autogenous cancellous/cortical bone grafts are that they are histocompatible, do not transfer disease, and retain viable osteoblasts that participate in the formation of new bone. Although autogenous bone grafting is effective, it is associated with several shortcomings and potential complications. Its disadvantages are that a limited quantity of bone is available for harvest and there is significant donor-site morbidity (rates as high as 25%),[4] including infections and pain, increased anesthesia time, and significantly increased operative blood loss.

Alternatives to autogenous bone graft have been sought in an effort to increase the quantity of bone obtained and decrease the morbidity of the grafting process. The ensuing discussion will address currently available grafting substitutes that have been approved by the Food and Drug Administration (FDA),

including allograft, ceramic, demineralized bone matrix, bone marrow, and composite grafts (Table 2).

Allografts

Allografts are available fresh, frozen, or freeze-dried. With fresh allografts, no preservation is required. However, the speed with which the grafting transfers need to be performed leaves little time to test for disease or sterility. Fresh allograft evokes an intense immune response, making it clearly inferior to autografts. It is not currently a mainstay in grafting, and its applications are limited to joint resurfacing. Most allografts are either frozen or freeze-dried. Frozen allografts are maintained at temperatures below –60°C to diminish degradation by enzymes, affording decreased immunogenicity without changes in biomechanical properties. Osteochondral allografts undergo a much more controlled slow freeze with use of a cryopreservative (glycerol or dimethylsulfoxide) for the cartilage. There is controversy regarding the viability of frozen cartilage, as studies have demonstrated viability values ranging from 20% to 70% when these preservation techniques were used.[5] Freeze-drying (lyophilization) involves the removal of water from the frozen tissue, after which the tissues are vacuum-packed and stored at room temperature for up to 5 years. These methods decrease antigenicity even further, produce almost no biochemical changes, and do not affect the limited osteoinductive properties. These grafts undergo biomechanical alteration, however, with loss of hoop strength and compressive strength on rehydration. In all these techniques, the osteoprogenitor cells are destroyed, the osteoconductive properties are largely retained in terms of their cancellous and cortical structure, and the deeply bound, limited osteoinductive material present in the graft may be only partially retained.

Allografts can be used for nonstructural purposes, such as reconstructing defects after curettage of benign neoplasms and periarticular bone cysts at the time of arthroplasty. Morcellation of cancellous and cortical chips can be carried out for this purpose. Some clinicians have recommended mixing allograft bone with autogenous tissue to enhance osteoinduction and/or mixing it with autogenous bone marrow to introduce osteoprogenitor cells. Data on the efficacy of these processes are not yet available.

The structural roles of allografts include use as an intercalary segment to reconstruct a diaphyseal defect of long bone and use in arthrodeses about the ankle, hip, cervical spine, and lumbar spine. Large segments can be modeled to replace acetabular, femoral, and tibial defects. Osteochondral allografts have also been used for the dual purpose of replacing resected bone and providing a biologic joint surface.

Various allograft structures are available, including iliac bicortical and tricortical strips, patellar tricortical strips, cancellous cortical dowels, fibular shafts and wedges, femoral cross sections, and ribs. Structures limited to frozen preservation due to size include whole or partial tibia, humerus, femur, talus, acetabulum, ilium, and hemipelvis. Complications of the structural use of large allografts include nonunion (10% of cases), fractures (5% to 15%), and infection (10% to 15%).[6] Morcellated

Table 2
Properties of Bone-Graft Alternatives

Grafting Material	Osteo-conduction	Osteo-induction	Osteoprogenitor Cells	Immuno-genicity	Donor-Site Morbidity	Immediate Torque Strength
Cancellous autologous graft	++++	++	+++	-	+	-
Cortical autologous graft	+	+/-	+/-	-	+	++
Fresh allograft	+	+/-	-	++	-	++
Frozen allograft	+	+/-	-	+	-	++
Freeze-dried allograft	+	+/-	-	+/-	-	+
Ceramics	+	-	-	-	-	+/-
Demineralized bone matrix	+	++	-	-	-	-
Bone marrow	-	+/-	++	-	-	-
Particulate ceramic with bone marrow	++	+/-	++	-	-	-

allograft lacks the osteoinduction potential and osteoprogenitor cells of autologous bone graft and has been used largely as a filler or extender of graft, except in individuals who have a very high potential for bone regeneration (e.g., children), where the grafts are being used without autologous augmentation.

One of the main concerns with use of allograft bone is transmission of infection, most notably hepatitis and acquired immunodeficiency syndrome (AIDS). Since 1976, most tissue banks in the United States have been represented by the American Association of Tissue Banks (AATB), which evaluates members for compliance with a comprehensive set of standards. On December 14, 1993, the FDA mandated that every national tissue bank must comply with governmental regulations that essentially parallel the AATB comprehensive screening standards. These regulations include donor screening, repeated infectious disease testing, labeling requirements, long-term tracking of the graft, and inspections of facilities. Many local in-hospital bone banks at first had difficulty in fulfilling these obligations, but they are now required by law to comply.

Strict donor-screening and tissue-testing techniques have significantly lowered the risk of disease transmission. The AATB records indicate that, of the 3 million tissue transplants performed since the identification of the human immunodeficiency virus, only two donors' tissues have been linked with documented transmission of the AIDS virus.[7] Both cases involved transplantation of unprocessed, fresh-frozen allografts. Attempts at sterilization of allografts have compromised the tissue. Ethylene oxide and radiation alter some of the structural properties as well as the biochemical properties of the graft. In one well-documented instance of a donor with AIDS, grafts that were lyophilized and irradiated did not give rise to AIDS, while fresh-frozen grafts did. Thus, there is a suggestion that such processing of bone may destroy the AIDS virus.

Ceramics

Ceramics have been utilized solely as osteoconductive bone-graft matrices. Most calcium phosphate ceramics currently under investigation are synthetic and are composed of hydroxyapatite ($Ca_{10}[PO_4]_6[OH]_2$), tricalcium phosphate (TCP) ($Ca_3[PO_4]_2$), or combinations of the two. These biomaterials are produced commercially as porous implants, nonporous dense implants, and granular particles with pores. Most calcium phosphate ceramics are created with the use of a high-temperature process called sintering along with high-pressure compaction techniques.

The chemical composition of the ceramic profoundly affects its rate of bioresorption. Studies indicate that TCP, which is more porous than hydroxyapatite, undergoes biologic degradation 10 to 20 times faster than hydroxyapatite.[8] In clinical trials, TCP was totally resorbed in some circumstances but lasted a number of years in others.[9,10] Once in the body, TCP is partially converted to hydroxyapatite, which is degraded slowly. The resorbing cell for hydroxyapatite is the foreign-body giant cell (not the osteoclast), which stops after resorbing 2 to 10 µm of hydroxyapatite. Thus, large segments of hydroxyapatite will remain in place in the body for periods of up to 10 years.

In clinical applications, TCP is remodeled better than hydroxyapatite due to its porosity, but it is mechanically weaker because it is resorbed so quickly. Therefore, it is not ideal in compression, unlike hydroxyapatite. The combination of the two is used clinically to offer both advantages. Material factors such as the surface area affect biologic degradation; in general, the larger the surface area, the greater the bioresorption. Dense ceramic blocks with small surface areas biodegrade more slowly than porous implants. Thus, the shape and architecture of the ceramic have a profound effect on its resorption rate.

Ceramics are brittle and have very little tensile strength. Use of ceramics in applications requiring significant impact, torsional, bending, or shear stress seems impractical at present. However, the mechanical properties of porous calcium phosphate materials are comparable to those of cancellous bone once they have been incorporated and remodeled. Ceramics must be shielded from loading forces until bone ingrowth has occurred. Rigid stabilization of surrounding bone and non-weight-bearing are required during this period because the ceramics themselves tolerate minimal bending and torque loads before failing.

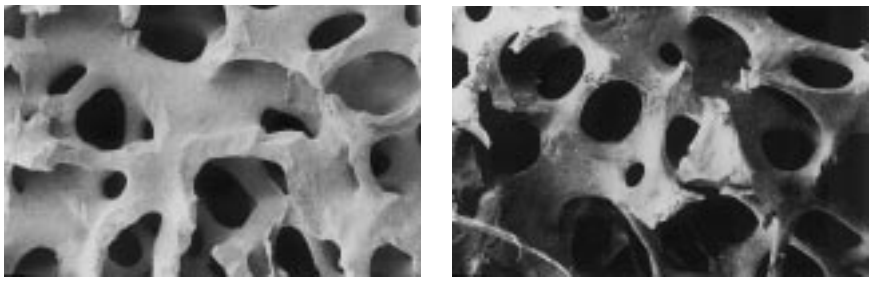
The optimal osteoconductive pore size for ceramics appears to be between 150 and 500 µm. Ceramics appear to have no early adverse effects such as inflammation, and foreign-body responses to ceramics are practically nonexistent when they are in a structural arrangement.[9-11] However, small granules of material have been shown to elicit a foreign body–giant cell reaction (at least in the rodent) and partial resorption. When ceramics are used, radiographs demonstrate continued presence of the ceramic for a prolonged period of time due to the failure of complete remodeling. A persistently dense radiographic appearance creates difficulty in determining the degree of bone ingrowth and incorporation into the implant.[12] Tricalcium phosphate, which is more biodegradable, loses more of its radiodensity and appears to be more incorporated into the bone.

The replamineform ceramics are porous hydroxyapatite materials derived from the calcium carbonate skeletal structure of sea coral. They are produced from a marine coral specimen using a hydrothermal exchange method that replaces the original carbonate of the coral with calcium phosphate replicas.[13] In contrast to the random pore structure created in totally synthetic porous materials, the pore structure of the coralline calcium phosphate implants is highly organized and is similar to that of human cancellous bone (Fig. 1). The pore size of these materials is determined by the genus of the coral used. Coralline hydroxyapatite derived from the genus *Gonipora* has large pores measuring from 500 to 600 µm in diameter, with interconnections measuring 220 to 260 µm.[9,12] The coral genus *Porites* has a microstructure that appears similar to that of interstitial cortical bone, with its smaller pore diameter of 200 to 250 µm, its parallel channels interconnected by 190-µm fenestrations, and its porosity of 66%.[9,12] Coralline hydroxyapatites are available commercially as Pro Osteon Implant 500 and Pro Osteon Implant 200 (Interpore Orthopaedics, Irvine, Calif), with average pore sizes of 500 and 200 µm, respectively.

Experimental animal studies have consistently demonstrated the superior performance of autologous bone grafts when compared with ceramic implants alone.[8,9,11] However, some studies have yielded promising results when certain specific conditions were met. Coralline hydroxyapatite performed quite favorably as a defect filler in proximal tibial defects in dogs when compared with corticocancellous autogenous bone.[14]

Clinically, the first successful results were reported in dentistry and reconstructive craniofacial surgery. In orthopaedics, Bucholz et al[15] demonstrated a similar efficacy between calcium phosphate ceramics and autogenous grafts for certain applications, particularly to fill defects under tibial plateau fractures where the material was under compression. In studies comparing the use of coralline hydroxyapatite and cancellous bone in the tibia (including the tibial plateau), they reported no difference in functional outcome, and on histologic analysis, the hydroxyapatite implants revealed bone ingrowth with both cortical and cancellous bone in appropriate locations. Bucholz et al[9] also studied TCP and found it comparable to autogenous bone for filling defects secondary to trauma, benign tumors, and cysts. Studies performed by other individuals, including Altermatt et al,[10] have indicated that granular hydroxyapatite and TCP, particularly when used in bone defects, can be quite efficacious.

An advantageous property of ceramics when used as a filler to restore volume in cavities is that the osteoconductive hydroxyapatite bonds well to bone. Ceramics alone do not have osteoinductive properties. However, there is some suggestion that hydroxyapatite has significant chemical affinity for local growth factors that act in the regeneration process. Ohgushi et al[16] found that ceramics can be filled with bone marrow prior to use, at least in animal studies, and that bone marrow grows well within ceramics and results in a composite. This has not been attempted in humans, however. It can be concluded that ceramics can serve as a bone graft expander and/or filler, particularly in compressive applications. Because a ceramic material is brittle and has no initial hoop strength or shear strength, the bone must be protected while the ceramic is incorporated. It does not stimulate new bone formation and so is not as attractive for "jump-starting" the healing process in the treatment of nonunions.



A B

Fig. 1 The porous structure and composition of coralline hydroxyapatite **(A)** and human cancellous bone **(B)** are very similar. (Courtesy of Interpore Orthopaedics, Inc, Irvine, Calif.)

Demineralized Bone Matrix

Demineralized bone matrix (DBM) is formed by means of acid extraction of bone, which leaves noncollagenous proteins, bone growth factors, and collagen in continuity in a composite. Demineralized bone matrix is prepared by bone banks, and a chemically processed form is produced commercially under the name Grafton Allogenic Bone Matrix (Osteotech, Shrewsbury, NJ). Currently, DBM is available freeze-dried and is processed from cortical or corticocancellous bone as a powder, as crushed granules, and as

chips. Grafton is also available as a gel; it is packaged in a syringe, from which it can be applied directly intraoperatively. All four forms are easy to mold intraoperatively.

Demineralized bone matrix has been utilized to promote bone regeneration, mainly within well-supported, stable skeletal defects. The results in clinical trials have been excellent.[17] The enhanced osteoinductive capability of DBM is afforded most notably by BMP, although the amount of BMP within demineralized grafts is far lower than in recombinant BMP studies. The FDA requires sterilization of the DBM prepared by bone banks,[7] which may decrease the viability of the available BMP. Grafton is processed from human bone by means of a patented technique that incorporates a permeation treatment that does not expose tissue to ethylene oxide or gamma radiation, which may protect more of the BMP.

Although DBM offers no structural strength, it has proved useful in facilitating the development of bone that is comparable in mechanical strength to autograft. It has been most successfully used in conjunction with internal fixation (Fig. 2) and as an adjunct to other grafting materials. Its applications include augmentation of autogenous and traditional allograft bone grafts in repairing cysts, fractures, nonunions, and stable fusions.

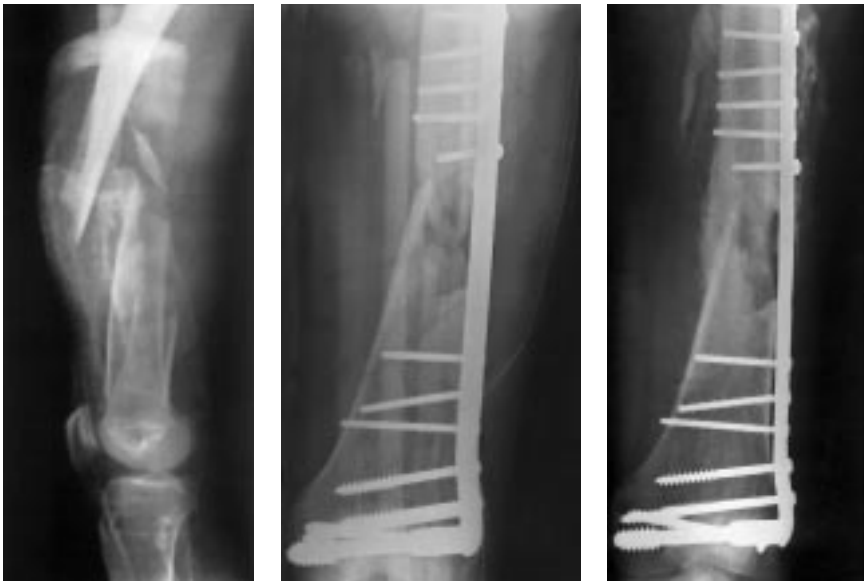


Fig. 2 Radiographs of a grade II comminuted left femoral fracture treated with a supracondylar plate and a three-part composite graft consisting of demineralized allograft bone gel (Grafton), demineralized allograft chips, and autogenous bone marrow. **A,** Preoperative view. **B,** Radiograph obtained immediately postoperatively shows fixation and three-part composite graft in place. **C,** Good bone formation bridging two segments at 8 months. (Courtesy of Paul G. Kleinman, MD, East Meadow, NY.)

Bone Marrow

Bone marrow contains osteoprogenitor cells on the order of 1 per 50,000 nucleated cells, and certain techniques have increased that number fivefold. Burwell[18] and Salama and Weissman[19] have utilized bone marrow, either by itself or in combination with an inorganic matrix for clinical application. It can grow into ceramics and can be used to bring osteoprogenitor cells back to a deficient grafting bed. A number of studies by Connelly and Healey have demonstrated that bone marrow can successfully treat nonunions when provided in adequate amounts.

Bone marrow should be harvested in aliquots of approximately 2.5 to 3 ml per site (cancellous bone from the proximal humerus or, preferably, the ilium). The marrow is then diluted with blood, after which it should be used immediately to maintain its viability. It has had only limited reported clinical use; however, it does offer the ability to augment all the other synthetic grafts and allografts that are currently more widely used, as well as to reestablish a more normal fracture milieu after extensive irrigation. There is essentially no morbidity from obtaining bone marrow, but it would be desirable if the osteoprogenitor cells could be easily increased in number and concentration.

Composite Grafts

The desire to incorporate the favorable properties of different materials into a single graft compound has led to the proliferation of various composite grafts. Composite grafts can be defined as any combination of materials that includes both an osteoconductive matrix and an osteogenic or osteoinductive material. For example, composites of TCP and BMP are currently being used in craniofacial reconstruction.[20] The ceramic maintains soft-tissue position and provides an osteoconductive matrix, and the proteins stimulate osteoinduction.

Collagraft (Zimmer, Warsaw, Ind; and Collagen Corporation, Palo Alto,

Calif) is a commercially prepared composite consisting of suspended deantigenated bovine fibrillar collagen and porous calcium phosphate ceramic, of which 65% is hydroxyapatite and 35% is TCP. The collagen is purified from bovine dermis and is 95% type I and 5% type III. Calcium phosphate consists of granules with 70% porosity and a pore diameter ranging from 500 to 1,000 μm. The mixture is nonosteoinductive; the addition of autogenous bone marrow provides osteoprogenitor cells and a limited amount of growth factors, such as platelet-derived growth factor and transforming growth factor-beta within the bone marrow clot.

In a prospective, randomized multicenter trial, Cornell et al[21] compared a composite graft consisting of Collagraft plus autogenous marrow with a cancellous iliac bone graft in acute long-bone fractures and found no significant differences in functional result or radiographic appearance. The use of Collagraft significantly shortened operative time and avoided the complications and morbidity of autograft harvesting. This study, however, did not include a control group treated without grafting, and additional trials against such controls are needed.

Collagraft is currently available only as a paste or in soft strips and therefore provides no structural strength. In addition, it has a tendency to flow if there is continued bleeding at the site of the fracture. The material must be carefully maintained in the location of use until the clot has formed. Biopsy specimens from patients in whom Collagraft was used have demonstrated some slight inflammation at the site of the granules, but there were no infections in over 139 patients treated with the material, compared with five infections in 128 patients treated with autogenous bone graft.[21] This appears to be a material that can be used as a bone-graft expander or as a graft substitute for stabilized fractures that are protected by internal fixation but require grafting due to extensive comminution or segmental bone loss. Pharmaceuticals, such as antibiotics and antineoplastic agents, can also be combined with Collagraft to create a delivery system that would treat bone disorders locally. Its use is contraindicated in intra-articular fractures because of potential migration of granules into the joint.

Summary

A number of grafting materials are available as alternatives to autogenous bone graft for a wide range of clinical applications (Table 3). Allografts can provide structure and osteoconduction; however, they offer limited osteoinduction and no osteoprogenitor cells. Their indications are similar to those of autologous bone, including repair of nonunions, promotion of arthrodesis, and segmental replacement of long bones. However, if the grafting bed is unfavorable (e.g., after infection or if there is poor soft-tissue coverage), the allograft bone must be augmented with either autograft or another graft substitute that provides growth factors and osteoprogenitor cells. Allograft alone would be contraindicated in treating a 4-cm humeral defect that developed from an infected nonunion. Concerns regarding allografts include fracture, osteointegration, transmission of disease, and infection.

Ceramics, available in powders, granules, and blocks, are excellent in compression and confer critical structural support. However, they are brittle and have little strength in bending, shear, and tension until incorporated into the existing adjacent bone. Because ceramics are exclusively osteoconductive, they are contraindicated for use by themselves. They must be combined with autograft or have access to a rich bone marrow, but they are effective graft fillers or expanders when patching defects after tumor resection or in a depressed tibial plateau fracture.

Demineralized bone matrix is a limited source of BMP and can be used as an adjunct in the regeneration process. Despite its osteoconductive

Table 3
Clinical Applications of Bioalternative Grafts*

Reconstruct diaphyseal defect (6 cm)
1. Vascularized cortical autograft
2. Nonvascularized cortical autograft
3. Frozen cortical allograft†
4. Freeze-dried allograft
Augmentation of autologous bone graft
1. Bone marrow mixed with either ceramics or allograft
2. Ceramics or morcellated allograft
3. Demineralized bone matrix or bone marrow
Expander to fill defects or cavities
1. Autograft or ceramics mixed with bone marrow
2. Ceramics or morcellated allograft alone
3. Demineralized bone matrix or bone marrow
Reconstruct short defects (2-4 cm) or perform arthrodesis of the cervical spine
1. Autograft
2. Frozen cortical allograft‡
3. Freeze-dried allograft
4. Ceramics
Nonunion
1. Autograft
2. Demineralized bone matrix
3. Bone marrow
4. Morcellated allograft

* Options are listed in order of efficacy, with the first being considered the most efficacious.
† Much, much preferable to the following option.
‡ Much preferable to the following option.

potential, DBM provides no immediate torque or compressive strength; thus, its use as the sole material would be contraindicated when grafting large cortical segmental defects. Its clinical applications include augmentation of autogenous and allograft bone for repairing fractures, packing cysts, and promoting arthrodesis, and it can be used in both posterolateral lumbar fusions and hip fusions with instrumentation.

Bone marrow is best used as an adjunct to existing allograft or biosynthetic ceramics to provide osteoprogenitor cells to compromised grafting beds. Because it provides no structural strength and is available only in small amounts, it should never be used alone in attempts to fill gaps or span segmental defects. It is strictly an adjunct to other grafts and works well to jump-start the healing of nonunions.

Composite grafts consisting of ceramics, collagen, and bone marrow have been used successfully, but since they are in a form without structure, they must be protected until they have been osteointegrated. They have a role in augmenting limited autogenous bone graft.

Bone morphogenic protein is not currently available clinically in a highly purified or recombinant form. The closest alternative is DBM, which is readily available from bone banks. Recombinant BMP is still in clinical trials, but it is anticipated that it will be more easily accessible to the orthopaedic surgeon in the near future.

When the grafting site is compromised and all three components of osteoconduction, osteoinduction, and osteoprogenitor cells are required, autogenous bone graft is probably superior. However, a composite of particulate ceramic, bone marrow, and DBM that incorporates all three regenerative components may be just as effective. Clinical trials are needed to further define relative efficacy.

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