The Bone-Grafting Decision Tree: A Systematic Methodology for Achieving New Bone

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Since the development of bone grafting as an adjunct to implant therapy, a variety of grafting techniques have been developed. At the same time, the choice of grafting materials has proliferated. The potential for combining a variety of materials with different techniques presents implant practitioners with options that may be bewildering and may result in various outcomes. When the appropriate surgical technique and graft material are selected for a given defect site, the original morphology of the site can be regained or even surpassed. However, selection of an inappropriate surgical technique or graft material, or both, may lead to resorption of the graft material or failure of it to integrate with the surrounding tissue. Alternatively, the disrupted or lost tissue may be replaced with fibrous tissue rather than functional bone.

This article presents a methodology for: (1) selecting the bone graft material that is most likely to be transformed into viable new bone, (2) selecting the optimal surgical technique for bone grafting, and (3) ensuring that bone regeneration results. These crucial recommendations are derived from an understanding of the biology of bone growth and repair, which is necessary for successful implant therapy.

Successful bone grafting requires that the clinician select the optimal bone grafting material and surgical technique from among a number of alternatives. This article reviews the biology of bone growth and repair, and presents a decision-making protocol in which the clinician first evaluates the bone quality at the surgical site to determine which graft material should be used. Bone quantity is then evaluated to determine the optimal surgical technique. Choices among graft stabilization techniques are also reviewed, and cases are presented to illustrate the use of this decision tree. (Implant Dent 2006;15:122–128)

Key Words: bone graft, autogenous bone, xenograft, allograft

Background

For any bone graft to be successful, 4 conditions must exist: (1) bone-forming cells (osteoblasts) must be present at the site, (2) the blood supply to the site must be sufficient to nourish the graft, (3) the graft must be stabilized during healing, and (4) the mucoperiosteal flap must be sutured without tension on the incision.[1]

Bone-Forming Cells (osteoblasts) Must be Present at the Site

Bone tissue is composed of cells, an insoluble extracellular matrix, and soluble molecules that serve as regulators for cell function. The bone cells may be 1 of 3 types: osteocytes, osteoblasts, or osteoclasts.[2-5] Osteocytes are the mature bone cells found within the lacunae of the dense cortical bone. A solid mass containing only microscopic channels, cortical bone does not contain a significant number of either osteoblasts, which are responsible for bone apposition, or osteoclasts, involved with remodeling and bone resorption. The periosteum that is tightly attached to the outer surface of cortical bone does contain the potential for both osteoblastic and osteoclastic activity, along with collagen fibers. An even larger supply of osteoblasts and osteoclasts is found within the spongy cancellous bone that lies beneath the cortical bone. Cancellous bone is composed of a lattice of large hydroxyapatite plates and rods, known as the trabeculae. Because cancellous bone has an 8 times higher surface-to-bone ratio than cortical bone, this provides higher access to bone-forming cells.[6,7]

Only osteoblasts can create new bone. For any graft to be successful, the graft matrix must be populated by osteoblasts or primitive mesenchymal cells that can be transformed into osteoblasts.[8,9] If osteoblasts are not present in the recipient bed, they must be harvested and brought to the site.[10,11] Alternatively, primitive mesenchymal cells may be brought in *via* the blood supply from the adjacent bone or periosteum to populate the extracellular matrix and be transformed into osteoblasts.[12-14] The absence of a sufficient population of osteoblasts will likely cause the graft to fail.

Sufficient Blood Supply to Nourish the Graft Must be Present

The optimal result of bone grafting is regeneration, as opposed to repair. Repair is the process in which the continuity of lost tissue is regained by new tissue that does not restore the

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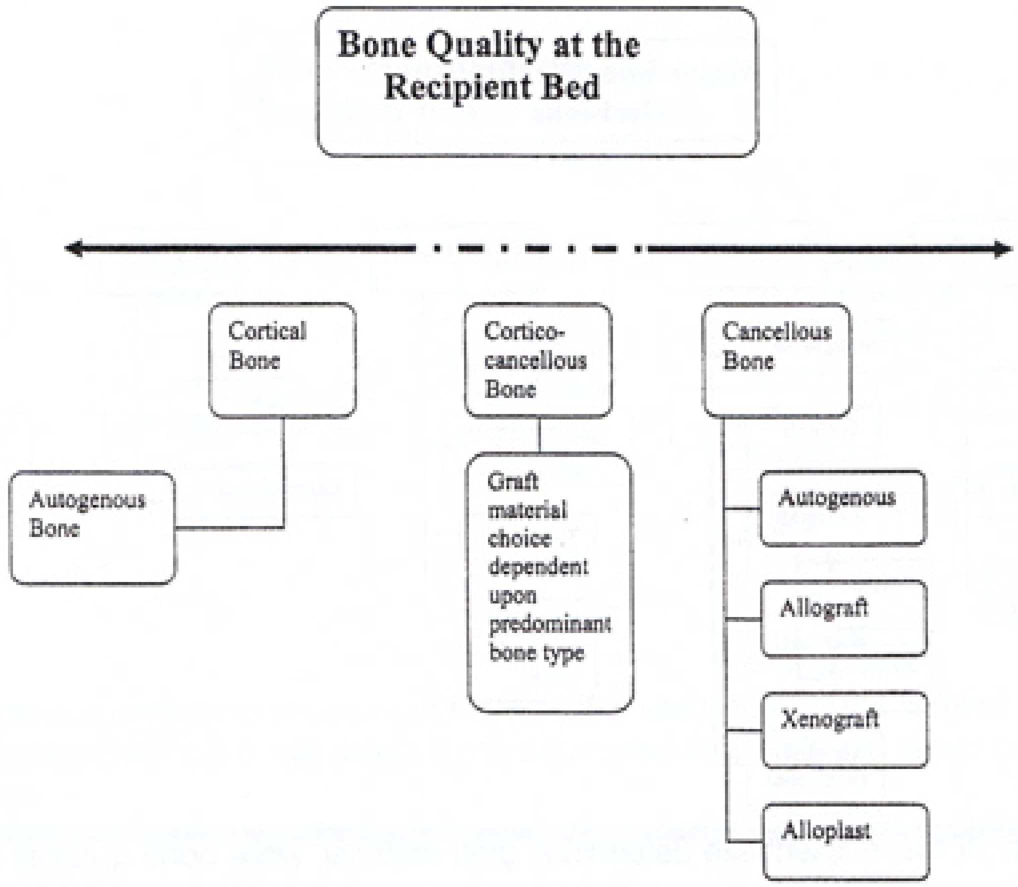

Fig. 2. A large cancellous compartment at the recipient site increases bone graft success and permits alternatives in graft material, while a recipient site of mostly cortical bone must be grafted with autogenous bone.

The function of alveolar bone is to stabilize teeth. When teeth are extracted or removed, the bone resorbs and, moreover, the proportion of cancellous bone shrinks, relative to the cortical bone at the site. As the cancellous compartment decreases, the reservoir for osteoblasts does likewise. Computerized tomography will reveal the ratio of cancellous bone-to-cortical bone at the recipient bed before surgery.

If the recipient bed is found to consist primarily of cortical bone, sufficient osteoblasts will not be present to ensure new bone formation. Bone that is rich in osteoblasts, either cancellous or corticocancellous autogenous bone, must then be harvested and used as a graft material. On the other hand, the presence of a large cancellous compartment at the graft site will allow the surgeon to use a scaffold matrix other than autogenous bone. The recipient site must be decorticated to allow the cancellous bone to provide the supply of osteoblasts. An exception is the sinus, where no decortication is performed, but the precursor cells for the osteoblasts are found in the circulating blood.

A common condition at graft sites is the presence of corticocancellous bone. In such cases, the surgeon must evaluate the ratio of cortical-to-cancellous bone present. If cortical bone is most predominant, autogenous bone will optimize bone graft success. If the bone is mostly cancellous, a combination of graft materials (*e.g.*, xenograft, allograft, and alloplast) or autogenous bone can be effective. The preference of the authors is to use resorbable and natural materials.

Blood flow to the graft is crucial. This process is important even when performing a small graft, such as a socket-preservation graft after an extraction. Often when a tooth is extracted for periodontal disease, the tooth may be removed without provoking any bleeding. If a graft material is placed within the socket, the surgeon might discover after 3–5 months that bone has not regenerated. Such failures can often be explained by the surgeon's not considering that blood flow is necessary to nourish the graft and populate it with bone-forming cells. Even when performing a simple socket-preservation technique after tooth removal, the surgeon must remove the thin dental lamina lining the socket to tap into the cancellous bone. Likewise, the graft material must be packed loosely into the site to allow spacing between the particles for angiogenesis and revascularization within the graft.

Bone Quantity

Once the best graft material option for a given site has been identified, the surgeon can move on to consider the best choice among several surgical techniques. The bone quantity at the recipient site (Fig. 3) determines which surgical technique can be considered. All surgical techniques for bone grafting fall into 2 main categories: onlay grafts and interpositional grafts (Fig. 4).

Onlay grafts involve the placement of graft material on top of the cortical bone. The graft material constitutes the topmost layer at the site and is covered by the periosteum. Either block or particulate onlay grafts may be used. Block grafts may be composed of either cortical or corticocancellous autogenous bone, or of a compressed xenographic or allographic material. Particulate onlay grafts may consist of cancellous or corticocancellous autogenous bone, allographic, xenographic, or alloplastic materials, or some combination thereof.

Interpositional grafts involve the placement of graft material within a 3, 4, or 5-walled cancellous compartment. These grafts include such techniques as the sinus-lift graft, in which the graft is placed within a defect bordered by the medial wall of the sinus, the alveolus, and posterior and anterior region of the sinus. Thus, the recipient site contains and stabilizes the graft material, and circulating blood flow provides cells, soluble regulators, and nourishment. Another interpositional graft is the split-cortical graft to the maxilla, in which the cortices are split vertically, exposing the cancellous compartment. Bone graft material is then placed within the fissure. A similar technique is the sandwich graft, used in the mandible. In this approach, a section of the cortical bone is removed, graft material is placed within the cancellous compartment, and then the plug of cortical bone is repositioned on top of the graft material and stabilized with bone screws. Another example of an interpositional technique is the socket graft.

Stabilizing the Graft

Once the surgical technique and graft material have been chosen, the surgeon must consider the question of how the graft will be stabilized. In a 5-wall defect, the osseous walls stabilize the graft. No matter which surgical techstructure and function of the original tissue. On the other hand, regeneration is the biologic process by which the structure and function of the original tissues are regained. One important factor that influences the course of regeneration *versus* repair is the blood supply available to the graft and surrounding tissues.[15,16]

In tissues that lack an adequate blood supply, cells will not remain viable, and regenerative healing will not occur. Furthermore, without an adequate vascular supply, a fibrin clot may not form.[17,18] The fibrin clot serves as the initial matrix where the mesenchymal cells can migrate, divide, and develop into osteoblasts.[12,19] It also serves as an anchorage for the osteoblasts that will continue the bone-forming process.

The Graft Must be Stabilized During Healing

The graft environment also influences whether regeneration or repair will occur. Mechanical stresses on the healing graft may lead to excessive distortion and disruption of the initial fibrin clot.[20,21] Regeneration then decreases, and a lower type of repair tissue, such as fibrous tissue, forms. For example, grafting an osseous defect with loss of buccal bone, if the graft is not stabilized to prevent movement, it is likely that fibrous tissue will fill the defect instead of bone. The surgeon can control this factor by ensuring the stability of the matrix during the healing process. Using fixation devices such as guided bone regeneration (GBR) membranes, titanium mesh, bone screws, or bone tacks, depending upon the surgery being performed, complete this process.

The Flap Must be Sutured Without Tension on the Incision

Primary closure over the graft ensures tissue continuity over the graft, which in turn increases the blood supply to the graft. It also protects the graft from external forces, as well as the salivary enzymes and other elements in the oral environment. To avoid the risk of the incision opening, tension must not be placed on the incision line when achieving primary closure.[22,23]

The periosteum is not elastic and will not stretch over incision sites when grafts are added. One way to achieve primary closure without placing the incision under tension is by using a scalpel to cut and spread the periosteum only. Care must be taken to avoid any intrusion upon the underlying connective tissue and blood vessels. Thus, the periosteum can be spread and extended. This technique has consequences that must be considered in any bone grafting procedure. For one thing, any incision into the periosteum reduces its effectiveness in contributing to bone healing and also allows for fibrovascular invasion into the graft. To prevent this result, the surgeon should use a GBR membrane between the graft and periosteum.[24] However, the use of such membranes also reduces the effectiveness of the periosteum in bone healing.

Choosing the right membrane is critical to the outcome of regenerative therapy. Because bone is the slowest growing tissue, the GBR membrane must be cell occlusive, keeping faster growing tissues like epithelium, fibrous tissue, or gingival connective tissue out of the defect space and allowing osseous tissue to form. The decision to use a resorbable or non-resorbable membrane is based on the size and location of the defect, how long does the membrane need to form as a barrier, and how much bone regeneration is required. A rule of thumb is 1 mm of bone regeneration per month per barrier function time. For example, a 2–3-month barrier function time is required for small defects of 2–3 mm, and larger defects may require 6–13 months.

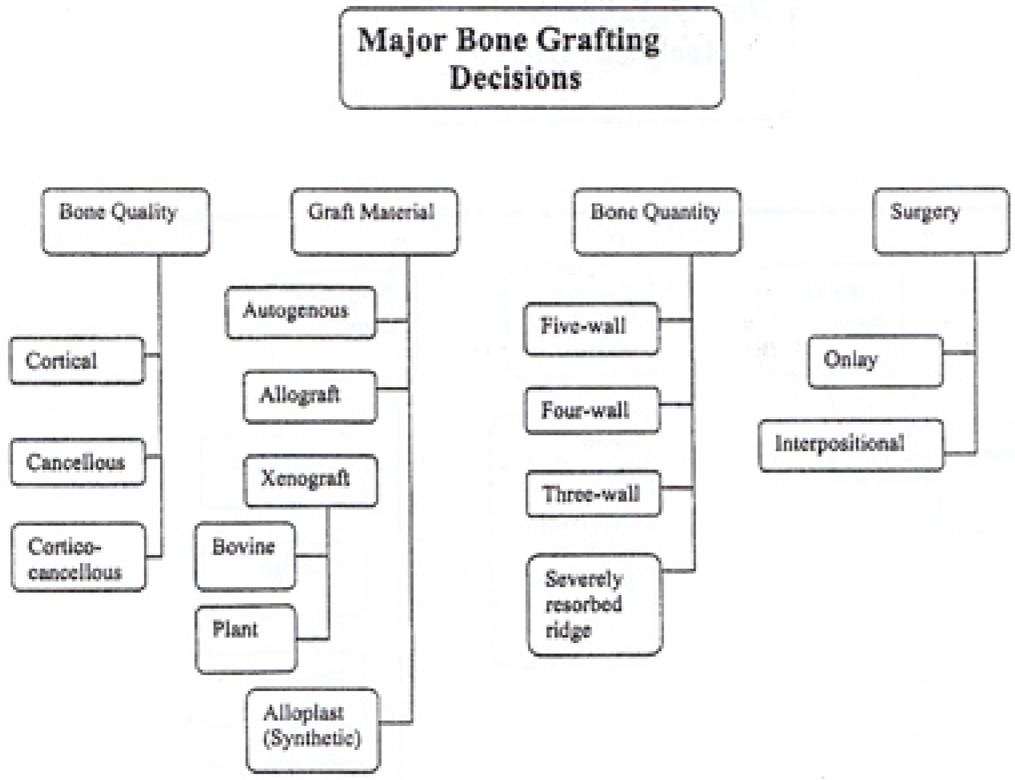

Fig. 1. Bone quality of the recipient site determines graft material, while bone quantity influences the surgical procedure.

The Decision Process

Successful bone grafting requires addressing a number of questions. If the questions are answered correctly, the graft will likely succeed. Fig. 1 presents an overview of the key questions that must be addressed, which are:

- What is the quality of the recipient bone at the graft site?
- What type of material should be grafted?
- How much recipient bone is present?
- How should it be grafted?

Bone Quality

The first section of the decision tree involves evaluating the bone quality. For this we turn to Fig. 2. The surgeon must evaluate what kind of bone is available at the site. Is it predominantly cortical, corticocancellous, or cancellous? It has been estimated that cells within the cancellous bone are responsible for at least 60% of a patient's bone healing capacity. The periosteum in a young, healthy patient may contribute an additional 30% of bone healing, with the osteocytes within the cortical compartment responsible for approximately 10% of bone healing. However, as the patient ages, the effectiveness of the periosteum to regenerate bone is decreased.

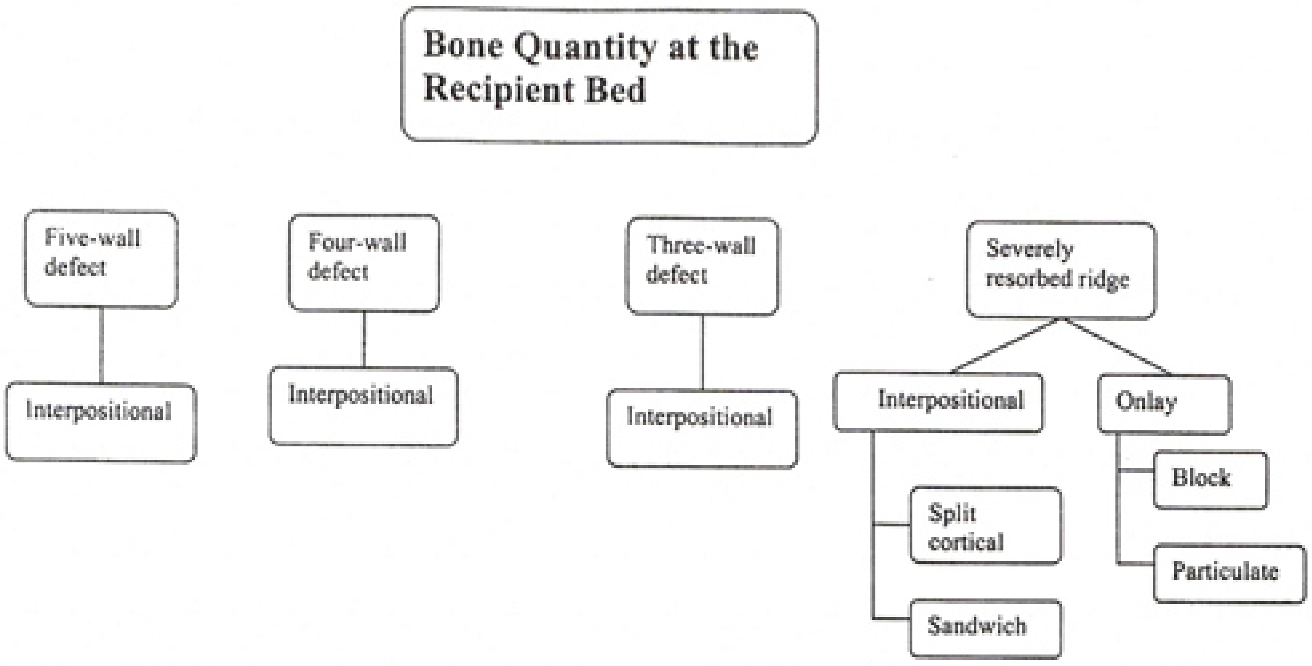

Fig. 3. The bone quantity and structure of the recipient site influence the surgical procedure and graft success; grafting a 5-wall defect is more successful than a 3-wall defect or a severely resorbed ridge.

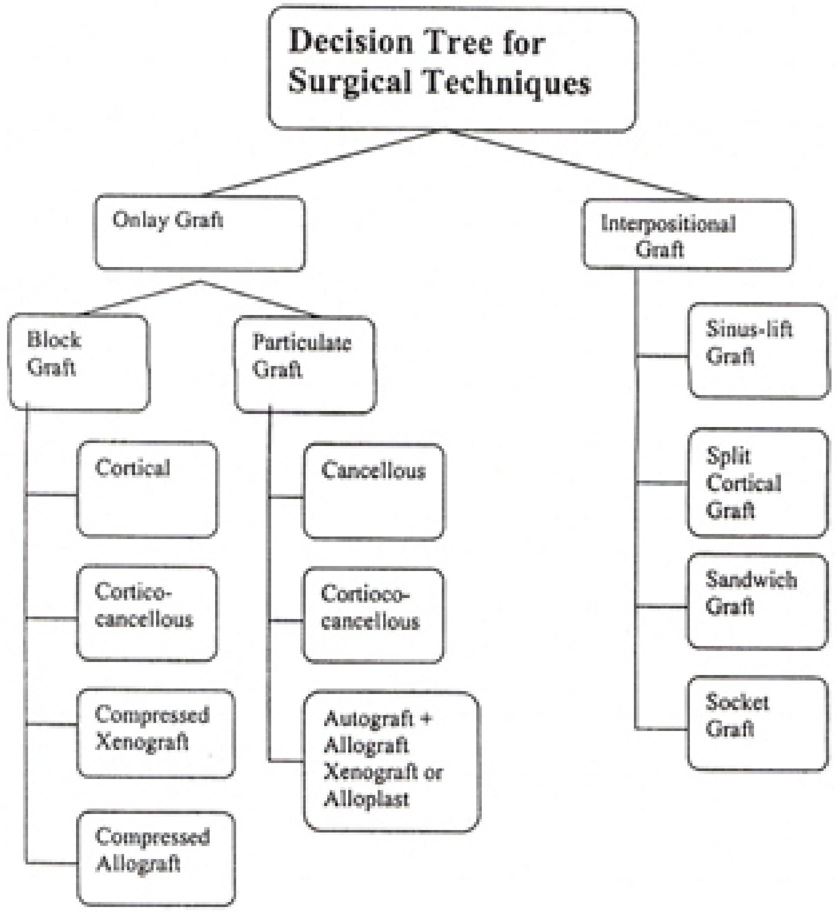

Fig. 4. The surgical technique (*i.e.*, onlay graft or interpositional graft) and graft material are influenced by first assessing bone quality and quantity.

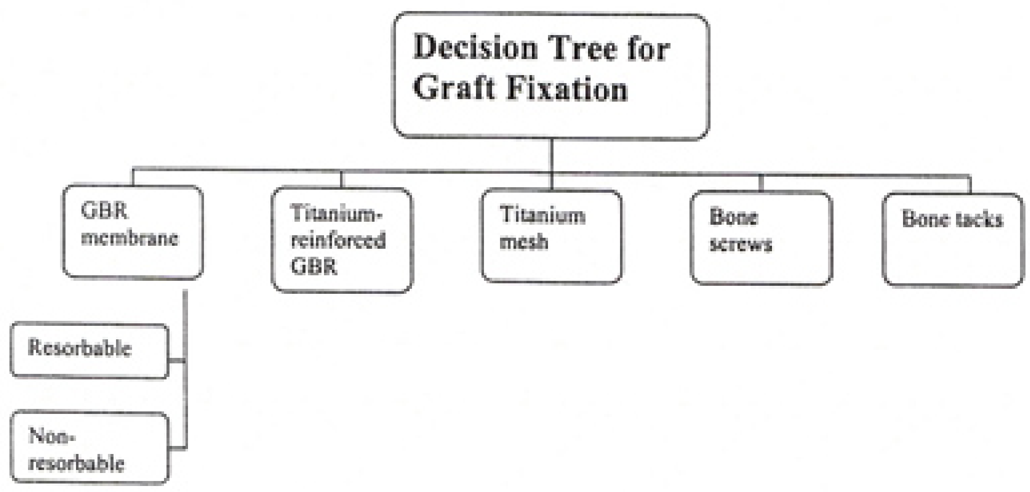

Fig. 5. Stabilization of the graft is extremely important for success. Assessment of recipient site bone quality, quantity, and graft material determines the method.

nique and graft material are used, if the graft is not stabilized, a lower form of repair (rather than bone regeneration) is likely to occur. The basic options for graft stabilization are: a GBR membrane, a titanium-reinforced GBR membrane, titanium mesh, bone screws, or bone tacks (Fig. 5).

In smaller defects, a GBR membrane can be used to stabilize the graft material. As the site to be grafted increases in size, a GBR membrane may not be sufficient to protect the graft from micromovement that would destabilize the matrix and disturb the blood clot. In this situation, a firmer stabilization material will be required, such as a combination of titanium mesh and a GBR membrane. This is especially true when the graft material is of a particulate composition.

If the donor bone is of a cortical or corticocancellous type, bone screws typically are used to stabilize the bone before it is covered with the periosteum and the mucoperiosteum is sutured. Whether particulate or corticocancellous, if the graft is not stabilized, then a lower form of healing will occur, and the bone graft will not be successful. The following case descriptions illustrate the use of the bone-grafting decision trees.

Case No. 1

Extraction of the maxillary dentition resulted in 4 and 5-walled defects, primarily of the cancellous compartment (Fig. 6). A decision was made to graft the ridge with a mixture of xenograft (PepGen P-15™; Dentsply Friadent Ceramed, Lakewood, CO) and freeze-dried demineralized bone allograft. The sockets were debrided and irrigated, and a minor alveoloplasty prepared the edentulous ridge for the interpositional graft. A GBR membrane was placed over the extraction sites, and the mucoperiosteal flap was repositioned and sutured.

Case No. 2

The bone quality of this edentulous maxilla (Fig. 7) was composed mostly of cancellous bone bordered by cortical bone. The presence of the cancellous bone made it possible to use a combination of xenograft material (PepGen P-15 228) and freeze-dried

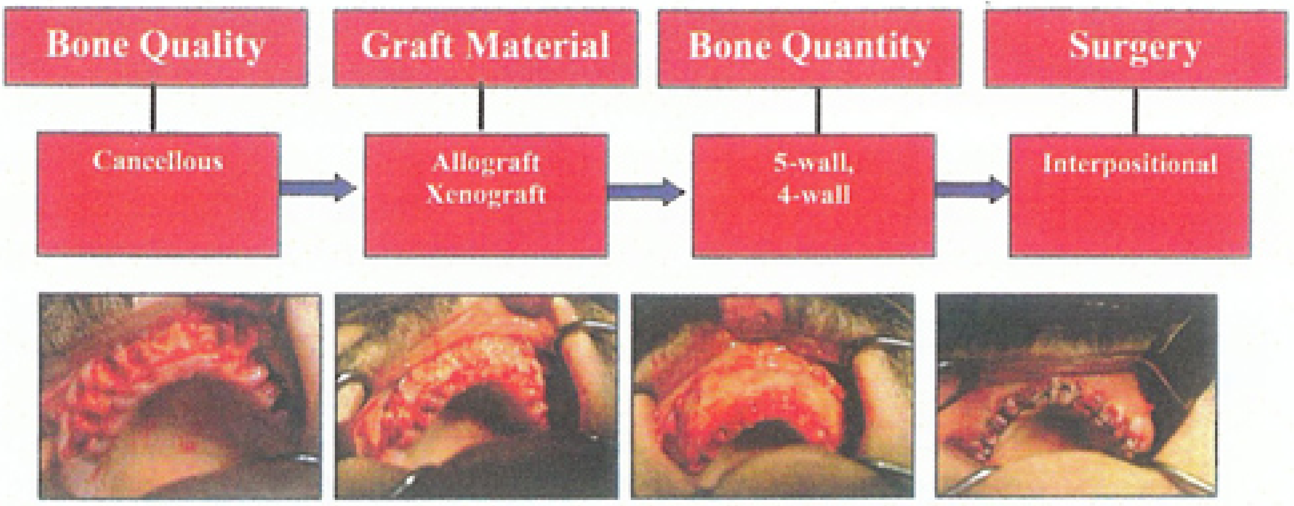

Fig. 6. The recipient site of 5 and 4-wall defects is composed mostly of cancellous bone that has a bearing on the choice of an interpositional surgical technique, and allograft and/or xenograft material.

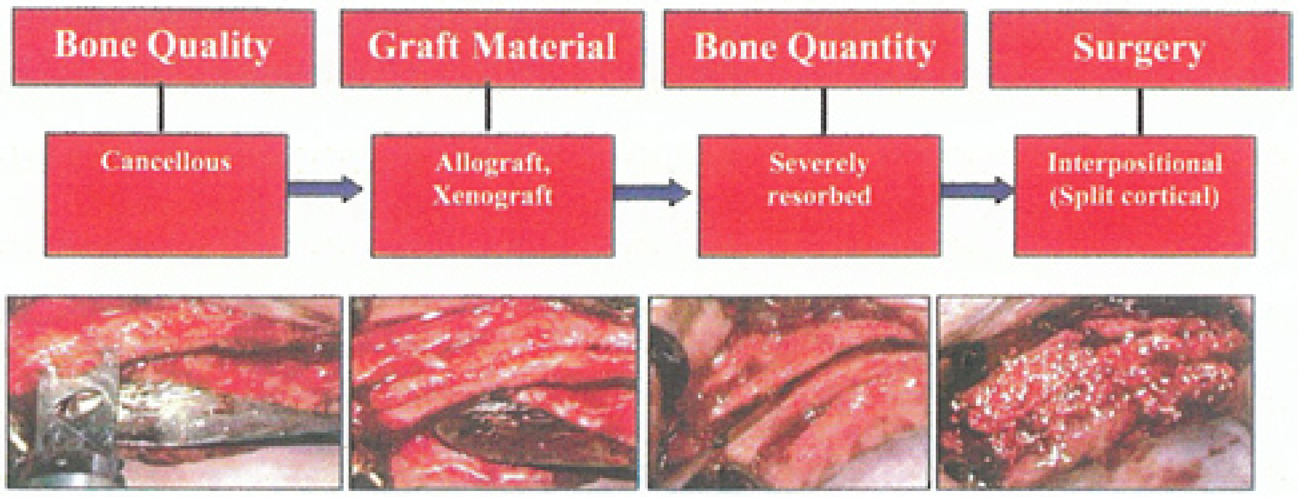

Fig. 7. The large cancellous compartment permitted splitting and spreading of labial and buccal cortical bone, and the placing of graft material within this compartment.

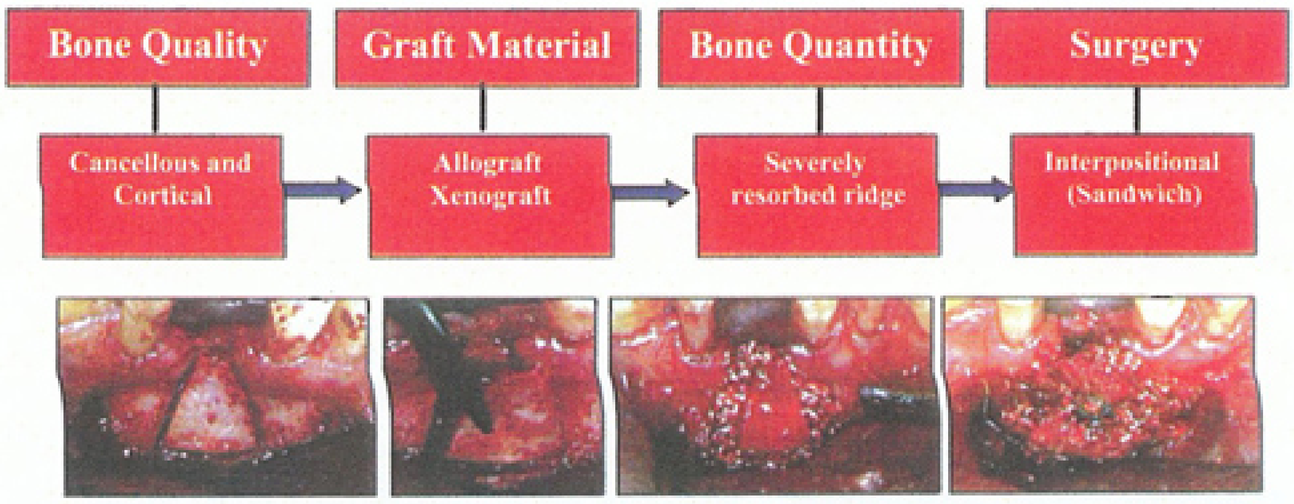

Fig. 8. Removing the cortical bone exposes an adequate cancellous compartment that is grafted with an allograft and/or xenograft. A transosseous screw stabilizes the repositioned cortical bone.

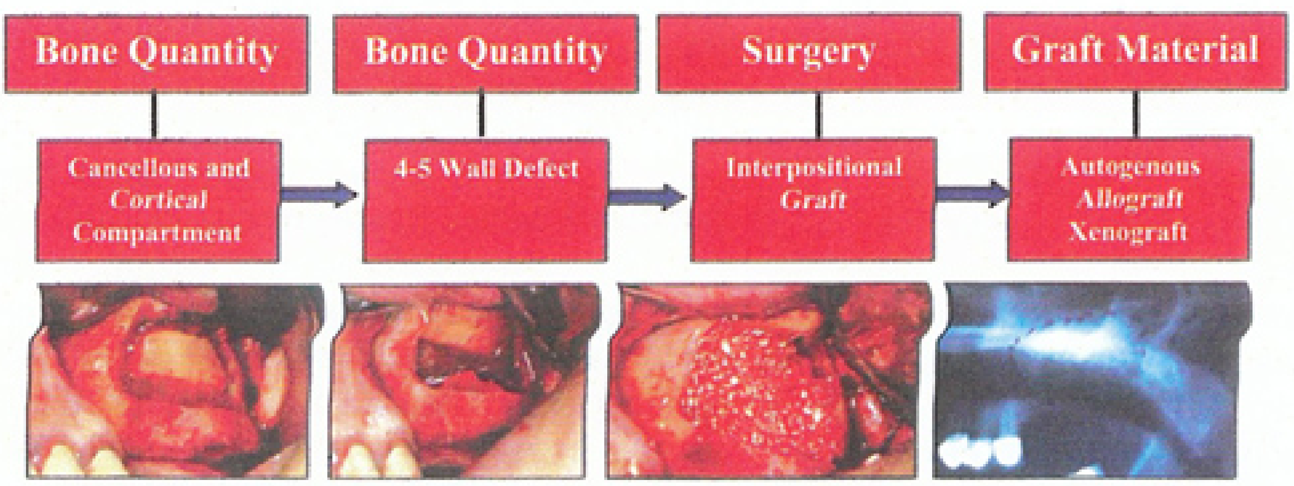

Fig. 9. The sinus-lift surgery prepares a 4–5-wall defect that can be grafted with autogenous bone, an allograft, xenograft, or mixture of graft material.

demineralized bone as graft materials. Because the ridge was severely resorbed, a decision was made to perform a split-cortical interpositional graft. A surgical sagittal saw bisected the cancellous compartment and extended all the way to the sinus floor. Chisels spread the labial-buccal bone from the stable palatal bone. After placement of the graft material, a GBR membrane was placed. A split-thickness dissection of the labial mucosa left the periosteum on bone and permitted a nontension closure of the incision.

Case No. 3

The mandibular edentulous area (Fig. 8) had a small but adequate cancellous compartment bordered by dense cortical bone. A decision was made to augment the site using a combination of xenograft (PepGen P-15 228) and freeze-dried demineralized bone allograft. Trauma had reduced the site to a single wall of bone, and a decision was made to perform an interpositional (sandwich) graft. A wide-based flap exposed the site for preparation of vertical, inferior horizontal, and crestal sagittal bone cuts into the cancellous bone. The cortical shelf was removed, and the graft material was placed within the cancellous compartment. The cortical shelf was then replaced, and secured with a bone screw and GBR membrane.

Case No. 4

A quadrilateral osteotomy (Fig. 9) prepared the buccal wall for inward reflection. Careful elevation of the antral membrane exposed the superior aspect of the reflected buccal wall, medial wall of the sinus, alveolar bone, and posterior and anterior components of the sinus cavity. Thin cortical bone and a narrow cancellous compartment bordered the osseous defect. An interpositional graft composed of PepGen P-15 228 mixed with platelet-rich plasma reconstituted the buccal wall. The x-ray shows the grafted sinus (Fig. 9). For this interpositional graft, circulating primitive mesenchymal cells and preosteoblasts populated the PepGen P-15 228 matrix to form bone sufficient for the placement of implants.