

Implant Site Development and Extraction Site Grafting

*Bone Biology & Physiology,
Selection of Grafting Materials,
Selection of Barrier Membranes
and Surgical Technique*



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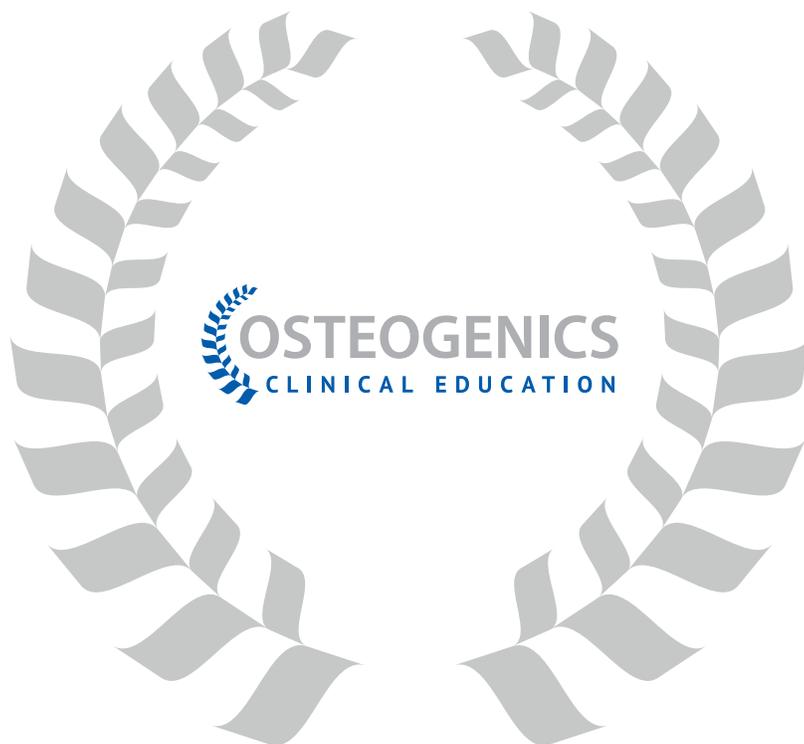


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The loss of bone following tooth extraction is a significant clinical problem in implant dentistry as well as conventional restorative dentistry. Clinical studies indicate that in the first few months following tooth extraction as much as 1-3 mm in alveolar ridge height and 3-5 mm in ridge width may be lost due to the resorptive nature of the healing process. Unfortunately, this bone loss is permanent and has severe consequences in terms of potential implant support. Moreover, in the esthetic zone, bone loss can severely impact the appearance of implant restorations due to subsequent loss of interdental papillae, facial soft tissue recession, or loss of soft tissue volume which is essential in providing camouflage of abutments and restorative components.

The literature has shown that early bone loss can be significantly reduced by advanced socket management techniques combined with atraumatic tooth extraction. The process of socket grafting is not technically difficult, but does require an understanding of wound healing and an appreciation of the biological properties of the products available for socket grafting. The use of a standardized clinical technique and material selection protocol is also important if predictable results are to be achieved.

With these goals in mind, this manual will guide the reader through a logical process of understanding the selection and use of particulate grafting materials as well as the various membranes available for socket grafting. The subtle differences in augmentation materials, and the effect that material properties have on clinical outcome will be discussed. Finally, a technique of socket grafting developed by the author will be presented. It is our intent to provide the reader with a scientific, standardized and proven approach to socket grafting which will yield predictable results.

Bone as an Organ System

Bone is a dynamic and highly ordered structure on the macroscopic, microscopic, cellular and molecular levels. Conceptually, bone is described within the framework of the following anatomical and functional components.

- 1. Organic matrix:**
 - 40% of the dry weight of bone
 - composed of 90% Type I collagen
 - non-collagenous proteins
 - ground substance/H₂O
 - proteoglycans, cytokines, & growth factors
- 2. Mineralized matrix:**
 - 60% of the dry weight of bone
 - hydroxylapatite crystals: Ca₁₀(PO₄)₆(OH)₂

- 3. Cells:**
 - osteoprogenitor cells
 - osteoblasts
 - osteocytes
 - osteoclasts
- 4. Vascular & Nutrient Distribution:**
 - bone receives 5 - 10% of cardiac output
 - arterial supply
 - microcirculation, extracellular fluid
 - lymphatics
 - venous return
- 5. Neurological:**
 - autonomic
 - neurosensory
- 6. Marrow:**
 - serves both hematopoietic and osteogenic functions
- 7. Periosteum:**
 - a source of osteoprogenitor cells, neurovascular distribution, blood supply
- 8. Endosteum:** "inner osteogenic layer"
 - a source of osteoprogenitor cells
- 9. Communication System:**
 - a network including Haversian and Volkmann's canals, canaliculi, lacunae and extracellular fluid.

Structural Classification

Compact Bone

This is a clinical term referring to the dense, solid bone found at the outer cortical layer of the maxilla or mandible or the cortical plate of the extraction socket. Composed primarily of mineralized matrix, it is designed for load bearing and protection with relatively few cells and blood vessels.

Trabecular bone

This is a clinical term referring to the less dense bone located between the cortical plates of the maxilla or mandible. Trabecular bone may also be referred to as spongy or cancellous bone. Clinically, trabecular bone may vary in density and may be composed of thick or relatively thin trabeculae.

Lamellar Bone

On the microscopic level, this term describes a highly organized, secondary structure of bone arranged in a typical layered fashion. Lamellar bone may be arranged in concentric Haversian systems such as seen in dense compact bone, or it may be found as circumferential or endosteal lamellae located immediately beneath the periosteum. This is the principal load-bearing bone of the body and is the predominant component of mature cortical and trabecular bone.

Woven (embryonic) Bone

In distinct contrast to the highly organized structure of lamellar bone, on the light microscopic level the term woven bone describes a highly cellular, less organized, poorly mineralized bone that is formed in response to growth or injury. For example, woven bone is the first type of bone observed in a healing extraction site, or found immediately adjacent to a dental implant in the first few weeks following implantation. Woven bone is initially very weak. However, it is eventually remodeled into highly organized, load bearing, lamellar bone with increased mineral density. Woven bone is not typically found in the adult skeleton except in response to fracture or injury.

Cellular Components

There are four major cell types that we are concerned with in the context of socket grafting, implantology and ridge augmentation.

Osteoprogenitor Cells

These cells may also be referred to as undifferentiated stem cells, pluripotential cells, stem cells, or bone marrow stromal cells. Osteoprogenitor cells, which are initially fibroblastic in appearance, differentiate into preosteoblastic and mature osteoblastic cells found lining the endosteal surfaces of bone.

The Osteoblast

The osteoblast is the "bone forming" cell responsible for deposition and calcification of the extracellular bone matrix. They are initially derived from mesenchymal pluripotential/stem cells in the bone marrow. Depending on the microenvironment and exposure to various growth factors, it may also differentiate into fat, cartilage or muscle (Owen & Ashton, 1986. Beresford, 1989). Mature osteoblasts are polarized and secretorily active, synthesizing collagen and other proteins such as growth factors. Once osteoblasts have done their work, they may be known as "resting surface cells" or if they are encircled in bone, are referred to as osteocytes.

The Osteocyte

The osteocyte is a mature, fully differentiated osteoblast which has been surrounded by mineralized bone matrix. While it is no longer active in terms of forming bone matrix, it does play a role in cell to cell communication via fluid flow in the lacunar-canalicular system. This communication is believed to be involved in the response of bone to load or injury and in regulating the response of bone to the mechanical environment (Skerry et al., 1989).

The Osteoclast

This "bone resorbing" cell is responsible for the resorptive aspect of bone modeling and remodeling. This large, motile, multinucleated cell elaborates enzymes such as collagenase, lysosomal enzymes, and acids at the "ruffled border" of the cell, which is the site for resorption of mineralized bone matrix and collagen degradation (Baron, 1989). The complex actions of this cell are under hormonal control (PTH, D3, calcitonin, glucocorticoids, prostaglandins, ILGF, TNF, TGFb, androgens, thyroid hormones, bisphosphonates) and are influenced by local factors as well (vascular/NO2, stress, strain).



Figure 1

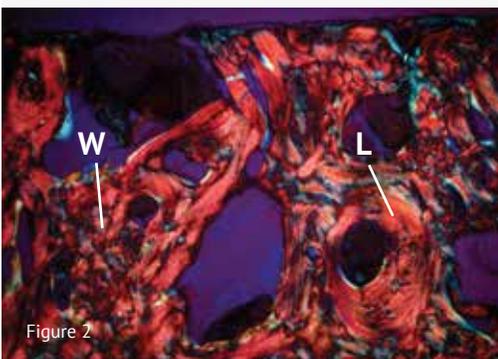


Figure 2

Histology from a bone core taken by the author from an extraction site grafted with tricalcium phosphate at 6 months (Fig.1). The application of polarized light on the same sample (Fig. 2) demonstrates the difference in organization between lamellar and woven bone. In this section, focal zones of lamellar bone are seen (L) as well as less organized, woven bone (W). (Histology by Dr. Michael D. Rohrer, University of Minnesota.)

Bone as a Dynamic Tissue

In the human body, bone plays an important structural role, providing the framework for and the protection of vital organs. Throughout the body, bone is important in facilitating locomotion and other complex functional movements such as mastication. In addition, bone plays an important role in metabolism, serving as a reservoir of lipids, calcium and phosphate. In the adult, bone is also important in the production of blood cells (erythrocytes, differentiated granulocytes, platelets) which are derived from pluripotential hematopoietic stem cells in the bone marrow.

Structurally, bone is a complex and constantly changing tissue which is capable of self-repair and adaptation to new loads. Two fundamental concepts, modeling and remodeling, are used to describe the dynamic nature of bone.

Modeling is the process whereby, in response to some stimulus or physical force, a bone may change in three-dimensional size or shape. An example is the change observed in alveolar bone following the loss of teeth. In this case, osteoclastic resorption becomes uncoupled from and outpaces osteoblastic deposition, resulting in a net loss in bone mass. Clinically, this phenomenon is manifest as alveolar ridge resorption.

In contrast to a visible three-dimensional change, the concept of remodeling refers to the internal turnover of bone. Remodeling is a coupled process where osteoclastic resorption and osteoblastic formation are more or less balanced. Similar to the constant regeneration and replacement of the epidermis, remodeling helps maintain the skeleton in a healthy state ready to carry load. Remodeling also plays a role in maintaining calcium homeostasis and in the repair of microtrauma to bone. A clinical example of remodeling is the development and long-term maintenance of healthy bone at the bone-implant interface in response to appropriate physiologic loading.

The rate of remodeling may vary from location to location and from one type of bone to another. Because remodeling is a surface-level phenomenon, and since trabecular bone has a much greater surface area than cortical bone, the rate of remodeling is six times greater in trabecular bone than in cortical bone. Thus, more rapid loss will typically be observed first in areas rich in trabecular bone, such as the vertebral bodies and dental alveolus, and later in cortical bone sites.

It is clear that bone formation and resorption is under cellular control, and that these processes are mediated by molecular messengers. The extracellular fluid within the canalicular system is the medium through which cell to cell communication occurs; presumably by exchange of biochemical mediators produced in response to stress, strain, inflammation or other environmental cues. These mediators interact with the bone cells via cell surface receptors, causing release of "second messenger" cell signaling molecules. In turn, DNA and protein synthesis is "turned on" within the cell, manifest as changes in cellular behavior or differentiation.

Alveolar Bone Loss

In addition to physiological remodeling, in implant dentistry we must be concerned with the ongoing response of bone to loading. It is well accepted that mechanical overload of implants can result in bone resorption, and that dynamic mechanical loading within physiological limits tends to result in maintenance of bone mass and functional trabecular orientation. In contrast, inadequate mechanical stimulation or the application of high static loads can result in reduced bone mass through resorptive modeling.

How do bone cells communicate with the outside environment? The concept of mechanotransduction; the translation of mechanical signals into biochemical response, provides some insight. Integrins, a group of specialized transmembrane receptor molecules found on

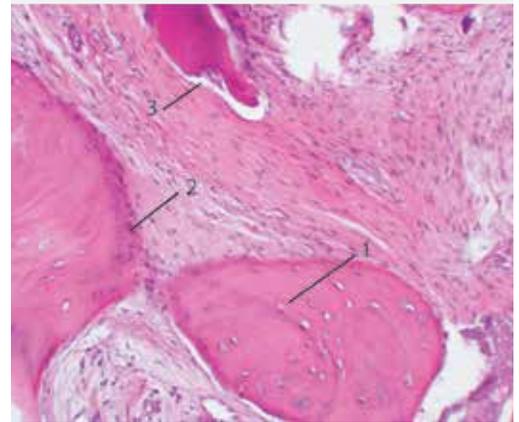


Figure 3. A sample bone core taken by the author from an extraction site grafted with demineralized bone at 4 months. Osteocytes (1) are seen encased in islands of newly formed mineralized bone. Osteoblasts and pre-osteoblasts (2) are observed on the leading edge of bone formation. An osteoclast is observed (3) in contact with and actively resorbing a fragment of residual allograft. (Histology by Dr. John M. Wright, Texas A&M Baylor College of Dentistry)

NOTES

the bone cell, enable the cell to sense and respond to changes in the local environment through simultaneous contact with the extracellular matrix and the actin cytoskeleton inside the cell membrane. Through the coupling of mechanical cues with a tightly regulated, complex intracellular and nuclear biochemical cascade, events such as proliferation, migration, and adhesion can be affected.

The loss of bone following tooth extraction provides a good example of the complex interaction between the environment and cellular behavior and response. A recent study found that disuse atrophy in bone is related to acquired resistance of bone cells to the effects of insulin like growth factor (IGF-1). In this investigation, cells which were protected from mechanical loading showed reduced expression of integrins and therefore a reduced ability to respond to the effects of the growth factor.

Similarly, loss of the natural dentition results in reduced physical loading of alveolar bone. Shortly thereafter, resorptive modeling of the alveolus occurs. Certainly, the process of post-extraction bone loss is complex and many factors are involved.

While it is interesting to speculate on the cellular and molecular mechanisms involved in alveolar bone loss, the central question remains: can anything be done clinically to eliminate or reduce this phenomenon?

Let's look at the available evidence. Over 20 years ago, it was shown that root-shaped cones made from hydroxylapatite, when placed into fresh extraction sites, resulted in a reduction in bone loss (Quinn and Kent). Later, hydroxylapatite particles were used in the same fashion by the same authors with some success in animal studies (Block and Kent, 1986). Unfortunately, the use of cones and particles was never widely accepted, and interest in these procedures declined due to premature exposure and loss of graft materials during the early healing phase.

With the advent of guided tissue regeneration (GTR) in periodontics, the concept of using barrier membranes to improve socket healing was explored. The use of guided tissue regeneration membranes placed over extraction sockets, even without underlying graft materials was shown to result in a reduction of ridge resorption (Nemcovsky 1996, Lekovic 1997, 1998).

Recently, immediate implant placement into extraction sites has been suggested as one method to reduce bone loss (Schropp 2003, Covani 2003, Boticelli 2004). It has further been suggested that if the gap between the implant and buccal socket wall is 2.0 mm or less, that no additional intervention in the form of adjunctive graft materials or membranes is required. However, a careful analysis of the data reveals that while osseointegration was indeed successful, a substantial reduction in bone width occurred, up to 56% in one report (Boticelli 2004).

Therefore, we can draw several conclusions from the available evidence in these socket grafting studies.

1. The use of a guided tissue regeneration membrane alone, with no underlying graft material, results in a reduction in bone loss.
2. The use of a particulate material alone with no membrane results in a reduction in bone loss, but particle loss reduces the predictability of the procedure.
3. Implants placed immediately into extraction sockets integrate predictably. However, if no graft material is placed into the gap between the facial aspect of the implant and the buccal plate, bone loss occurs similar to untreated extraction sites.
4. Particulate grafting materials differ in terms of their resorption profile and have the potential, if not used appropriately, to actually interfere with normal bone formation. ■





Mechanisms of Bone Formation and Graft Healing

Implantation of a graft material, whether natural or synthetic, results in a host response. There are effects at the tissue, cellular, and molecular level resulting from the interaction of the host tissue with the implanted material. These effects are chiefly dependent on the morphology, chemical composition, porosity and particle size of the material. In addition, materials which contain biomimetic or bioactive molecules may accelerate the normal wound healing kinetics by modulation of normal cellular processes. Even inert biomaterials - which may appear to do little more than take up space - may cause significant biologic effects through mechanical interaction with host tissue.

When selecting a bone graft material for a given clinical situation, several questions arise: What is the clinical outcome desired? Do we want vital bone for the future placement of implants, or do we want long-term, stable preservation of a pontic site? Will the implantation of a specific material result in the intended effect? What is the primary mechanism of action or biologic effect of the material? Will the material remain intact over the long term, or will it resorb and be gradually replaced by vital bone? How long will this resorption take? Should two or more materials be combined? How much material do I need to place in the defect? Is it possible that using this material could result in less bone formation or actually interfere with integration of dental implants?

While there are many good materials on the market today, it is clear that materials available for socket grafting (or any other grafting procedure) are not equal in terms of their biologic effect, host response and clinical outcome. In order to predict the clinical outcome from the use of a given graft material, it is helpful to understand the biologic effect and typical host response of that material.

The ideal graft material:

From a biological standpoint, the ideal bone graft material would be: (1) a bioresorbable, osteoconductive matrix providing a three-dimensional lattice with ideal dimensions for ingrowth of new blood vessels and osteoprogenitor cells; (2) osteoinductive, capable of recruiting and encouraging the migration of osteoprogenitor cells into the site, and then stimulating them towards osteoblastic differentiation; and (3) osteogenic, containing vital cellular elements capable of forming bone or differentiating into osteoblasts.

With the notable exception of autogenous bone, none of the products available for bone grafting possess all of these proper-

ties. Autogenous bone is typically either not available or available in limited quantities. Therefore, the dental surgeon must make informed choices depending on other factors, such as the type and morphology of the defect, the number of adjacent bony walls, the general health of the patient and the ultimate clinical use of the site, among other factors.

Classification of Materials Based on Mode of Action

Osteoconduction, osteoinduction, and osteogenesis are descriptive models of bone formation, healing and regeneration. These terms may also be used to describe and classify the biological properties and clinical effects of graft materials. A working knowledge of these concepts will allow the clinician to make rational choices in material selection based on the problem at hand (the type and size of the defect) and the clinical outcome desired.

Osteoconduction:

An osteoconductive material is analogous to a scaffold or framework onto which existing bone cells may grow. Osteoconductive materials may also stimulate the recruitment and migration of potentially osteogenic cells to the site of matrix formation (Davies and Hosseini 1999). Clinically, osteoconduction results in bone growth within a defect or on a surface which may otherwise repair with soft tissue. Osteoconductive properties are related to structural and material properties (porosity, pore size, shape, particle size, crystallinity) that influence cell attachment, migration, differentiation and vascularization. Examples of purely osteoconductive materials include hydroxylapatite (natural or synthetic), polymers, and bioactive glass.

Osteoinduction:

Osteoinduction refers to the property of a material to induce differentiation of undifferentiated pluripotential cells toward an osteoblastic phenotype. Clinically, implantation of an osteoinductive material stimulates bone formation, even in an ectopic site such as muscle. Osteoinductivity is dependent on the activity of bone morphogenetic proteins (BMP's) which are located within the organic matrix of bone. Demineralized freeze-dried human bone allograft is an example of an osteoinductive material, although the osteoinductive capacity can be quite variable. Growth factors, such as recombinant human growth factor (rh-BMP2), which has only recently become available for clinical use, would also be considered osteoinductive.

Osteogenesis:

Osteogenesis refers to the formation of new bone from living cells transplanted within the graft. Cells with osteogenic potential

include endosteal or cambial osteoblasts, perivascular cells, and undifferentiated stem cells from the bone and bone marrow. As the "Gold Standard" graft material, autogenous bone is the only material that is truly osteogenic. However it is also osteoconductive and osteoinductive, providing a scaffolding for the directed growth of new bone and bone morphogenetic proteins present in the bone matrix.

Related Concepts & Terms

Bioactivity: A characteristic of an implant material that facilitates a direct bond with living tissue, implying the lack of a fibrous capsule around the implant. An example of a bioactive surface is a hydroxylapatite coated dental implant.

Biomimetic: The ability of a synthetic material to emulate a naturally occurring environment in order to exploit the normal physiologic mechanisms of cell proliferation, migration and differentiation.

Cellular Differentiation: The process whereby a cell changes and takes on the function or characteristics of a different type of cell. For example, an undifferentiated mesenchymal stem cell may differentiate into an osteoblast under the right conditions.

Mitogen: A mitogen is a substance, typically a protein, which triggers signal transduction pathways leading to an increase in the rate of cell division. An example is the action of platelet derived growth factor (PDGF), found in preparations of platelet rich plasma and on fibroblasts, resulting in an apparent increased rate of soft tissue healing.

Morphogen: A morphogen is a substance, typically a protein, which governs the pattern of tissue development and the presence and positions of the various specialized cell types within a tissue such as bone. An example is bone morphogenetic protein, found in demineralized allograft, which acts on undifferentiated cells to form osteoblasts.

Osteotrophic: Refers to the ability of a material to attract bone cells and perhaps grow bone on its surface. Similar in concept to osteoconduction.

Classification of Grafting Materials Based on Source

Autograft (Autogenous)

Refers to a transplant of viable cortical or cancellous bone from one location to another within the same patient.

Allograft

Refers to a transplant within the same species, such as the use of demineralized freeze-dried human bone or freeze dried dermis in human subjects.

Xenograft

Refers to a cross-species transplantation of a tissue such as the use of anorganic bovine bone or porcine collagen in human subjects.

Alloplast

Refers to implantation of a synthetic material, such as hydroxylapatite or tricalcium phosphate, bioactive glass, or polymers.

Autogenous Bone

Autogenous bone is often referred to as the gold standard grafting material. In fact, if an ideal material could be manufactured, it would closely resemble autogenous bone. Autogenous bone has osteoconductive, osteoinductive, and osteogenic properties. It has no antigenic properties, and zero risk of disease transmission.

Depending on the location of the donor site, it may be cortical or cancellous. Cancellous bone contains a higher percentage of cells, and therefore has more osteogenic potential. Conversely, while there are fewer cells, cortical bone is believed to have higher levels of BMP's, and is useful when immediate structural support or three-dimensional augmentation is required. Autogenous bone may be prepared and used as granules, shavings or blocks depending on availability and the clinical requirements.

A major advantage of autogenous bone is the presence of viable osteogenic cells within the graft. However, only a small percentage of these cells actually survive transplantation. Those within 300 μm of a blood supply in the first 1 to 2 weeks will survive, while the others will die due to lack of nutrition. The remaining non-vital bone matrix serves as an osteoconductive scaffold and is gradually replaced by "creeping substitution", which is a process of osteoclastic resorption followed by osteoblastic deposition of new bone. Gradual revascularization occurs at a rate of about 1mm per day with cancellous grafts revascularizing in approximately 2 weeks, whereas cortical grafts may take 2 months or longer to revascularize (Zipfel, et al. 2003).

Although autogenous bone is the only grafting material that is truly osteogenic, it does have osteoinductive activity as well. As autogenous bone matrix is broken down during remodeling by osteoclasts, bone morphogenetic proteins are released resulting in the attraction, differentiation and proliferation of bone forming cells.

In defects of low regenerative potential, for example where multiple adjacent bony walls are missing or in larger defects, the addition of autogenous bone to allograft, xenograft or alloplastic materials is critical for predictable results. Fortunately, there are several techniques available for simple intraoral harvesting of autogenous bone.

The edentulous maxillary tuberosity may be harvested where a small amount of bone is required. A Rongeur forcep or trephine drill in a slow speed with a surgical handpiece can be used. After harvest, the bone is morselized into small fragments less than 1.0

mm in size and kept moist in sterile saline until ready for use.

A second technique involves the use of an osseous coagulum trap. This device attaches to the high speed dental vacuum, and employs a removable filter that collects bone through a sterile surgical suction tip. This method is particularly useful in dental implant procedures, where an average of 0.2 cc of autogenous bone can be harvested from a single implant osteotomy.

While a coagulum trap is a simple and reliable method of harvesting bone, extreme care must be taken to prevent contamination and preserve the viability of the bone. A second, dedicated suction line and suction tip is recommended to prevent saliva and other potential contaminants from entering the filter. To prevent dessication, immediately following harvest the bone should be rinsed with 50 to 100 ml of sterile saline, removed from the filter and placed in sterile normal saline until ready for use.

A third method of harvesting intraoral autogenous bone is the use of a bone "scraper." This device consists of a handle and a re-usable or disposable cutting blade which is designed to engage cortical bone and remove the bone in thin layers or "shavings" that can be used alone or mixed with other materials. A substantial amount of bone volume may be harvested with this instrument in a very short period of time and with minimal additional morbidity.

Examples:

Safescraper® Twist Cortical Bone Collector, Micross Minimally Invasive Cortical Bone Collector, Smartscraper Cortical Bone Collector, Osteogenics Biomedical, Inc.; Osteo-Harvester™, OsteoMed, Inc.; Maxillon® and Ebner® grafters, Maxillon Laboratories, Inc.; Osseous Coagulum Trap, Quality Aspirators.

Allografts

Demineralized Freeze-Dried Bone (DFDBA)

Available from licensed tissue banks, DFDBA is sourced from human cadavers screened for malignancy, HBV, HCV, HIV and associated lifestyle factors that place the recipient at risk for infectious disease.

Bone harvesting is done aseptically under operating room conditions. The tissue is then cut into blocks, strips or ground to a specific particle size range. The ideal particle size for most intraoral bone grafting procedures is 200-500µm. The bone is processed by steaming followed by an ethanol soak to remove cells and other adherent organic material. The mineral component is then removed by treatment with 0.6 N hydrochloric acid from 6 to 16 hours. The product is then freeze-dried (lyophilized), packaged and usually sterilized with ethylene oxide (ETO) or gamma irradiation.

DFDBA is believed to have osteoinductive activity due to the presence of bone morphogenetic proteins (BMP's). Demineralization with acid is believed to be required to expose and facilitate the release of BMP molecules contained in the mineralized organic bone matrix. After implantation, a cascade of events is set in motion which ultimately results in the differentiation of mesenchymal cells into osteoblasts (osteinduction). Histologically, new bone formation is observed on the surface of DFDBA particles as they are simultaneously resorbed. Six to 12 months is required for resorption and total replacement by vital bone. Some non-vital bone particles may be observed in sites grafted with DFDBA many years after implantation. The presence of a small amount of residual material is not believed to be clinically significant, however.

In over 40 years of use, and millions of applications in dentistry and orthopedics, there



Osseous Coagulum Trap



Safescraper® Twist Cortical Bone Collector,



Micross Minimally Invasive Cortical Bone Collector



Smartscraper Cortical Bone Collector

have been no confirmed cases of disease transmission using DFDBA. However, even with donor screening, aseptic processing and sterilization there remains a question about patient safety. The risk of any specific lot of DFDBA containing HIV has been calculated to be 1 in 2.8 billion. Patients should be educated regarding the use of human transplant materials, advised of the low risk of disease transmission, and counseled to assure psychological acceptance of the use of human material prior to surgery. It should be noted that there have been cases of disease transmission from allograft tissues, but to date these have involved the use of fresh or fresh-frozen bone.

Recently, the osteoinductive capacity of commercially available DFDBA preparations has been questioned. Although osteoinduction was first demonstrated by Urist in the 1960's, recent evidence suggests that this phenomenon is not universal among products from the various bone banks around the country. It has been shown that the processing techniques and certain sterilization methods, such as irradiation or ethylene oxide, may affect BMP viability. Donor age has also been shown to be a variable which may affect the amount of active BMP's within a given lot of DFDBA. Sophisticated testing for the presence of BMP's, such as enzyme-linked immunosorbent assay, is currently being done by tissue banks in an effort to supply material with true osteoinductive potential.

The advantages of DFDBA include predictable bone formation in most applications, reasonable cost, ready availability, and lack of additional morbidity to harvest the graft. The disadvantages include the small risk of disease transmission and variability of inductive potential.

Examples: Dembone®, Pacific Coast Tissue Bank; OraGraft® DFDBA; LifeNet Health; Dynagraft® assayed DFDBA in a gelatin matrix, Sybron Implant Solutions, DBX Demineralized Bone Matrix, Dentsply Tulsa Dental.

Mineralized Freeze-Dried Human Bone Allograft (MFDBA)



For socket grafting prior to the placement of dental implants, the use of mineralized freeze-dried human bone is a reasonable choice. Mineralized freeze dried allograft is both an osteoconductive and osteoinductive material. It is available as cortical or cancellous granules of various sizes, as well as in block form.

There is a difference in performance between demineralized and mineralized bone matrix, primarily related to resorption time. When compared to demineralized bone, it may take 6 months or longer for mineralized cortical particles to be resorbed and replaced by vital bone. While the presence of residual mineralized bone particles can give the clinical (and radiographic) impression of a successful result, on a microscopic level the presence of residual graft material in this case can actually interfere with vital bone formation.

However, a slowly resorbing material can be an advantage in certain clinical situations. When we consider larger defects, or those missing two or more adjacent walls, a material with a slower turnover time can potentially result in more volume in the regenerated site. Because of the physical presence of the slower resorbing mineralized particles over an extended time frame, there is simply more space for ingrowth of new blood vessels and bone to occur.

However, the potential advantages of the increased turnover time may be a disadvantage in terms of bioavailability and activity of BMP's. In theory, the mineralized component must be resorbed in order to expose the BMP's and make them biologically active. Whether or not this is clinically relevant is not known at this time.

Examples: enCore® Mineralized Allograft, Osteogenics Biomedical, Inc.; OraGraft® Mineralized Freeze-dried Bone Allograft, LifeNet Health; Puros® Mineralized Bone Graft, Zimmer Dental.

Combining DFDBA and MFDBA

If rapid osteoinduction is desired while still retaining the spacemaking benefits and increased mineral density associated with mineralized allograft, a rational approach may be to combine the mineralized allograft with DFDBA or autogenous bone. With such a combination, one may take advantage of the presumed osteoinductivity and more rapid turnover time of the demineralized or autogenous graft combined with the prolonged turnover time and higher density achieved with the mineralized allograft tissue.

Although allograft bone is a valuable material in the hands of the implant surgeon, it should be appreciated that the performance of these materials can vary widely based on processing techniques, donor characteristics, particle size and structure (cortical vs. cancellous), and perhaps most importantly, the defect type and architecture. It is vital for clinicians to employ sound clinical judgement, and to recognize the limitations of allografts in the management of complex defects.

Examples: enCore® Combination Allograft, Osteogenics Biomedical, Inc.; Regenaform® Paste, Exactech Dental Biologics; DynaBlast™ Paste, Keystone Dental.

Alloplasts

As a group, alloplasts are broadly defined as synthetic implantable biomaterials. They are widely available in different forms in terms of density, porosity and crystallinity, all of which are engineered into the product. Biocompatibility and tissue response to alloplast materials is excellent, and there is no risk of disease transmission associated with their use. Their mechanism of action is via osteoconduction.

Alloplasts may be used alone as osteoconductive scaffolds, or more commonly as volume expanders in combination with freeze-dried or autogenous bone as a "composite" graft. This composite graft approach may result clinically in improved bone density, and more complete bone fill of large, complex bone defects.

With regard to resorption, alloplasts typically degrade by solution mediated resorption. Six to 24 months is required for resorption, depending on the material used, graft volume, physical environment, number of adjacent bony walls, patient age, and local vascularity.

Alloplasts represent a low cost, safe and convenient material for a variety of applications in reconstructive implant dentistry.

Dense Hydroxylapatite (HA)

Dense HA is characterized by its high-density, high crystallinity and low resorbability. The material exhibits bioactivity, or the capacity to directly bond to bone without a soft tissue interface. Therefore, particles placed adjacent to bone bond directly to bone and may become surrounded by bone. Soft tissue compatibility is excellent, as well. Particles placed more than a few millimeters away from bone are enmeshed in a dense, stable fibrous connective tissue matrix. The low resorbability results in excellent long term ridge maintenance and soft tissue support, however its use is limited to sites where implants are not planned in the future.

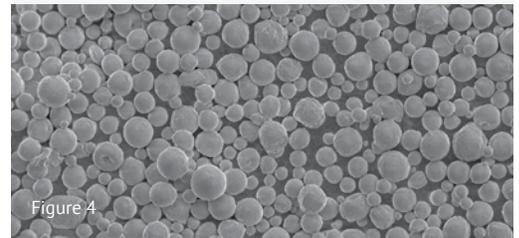


Figure 4



Figure 5

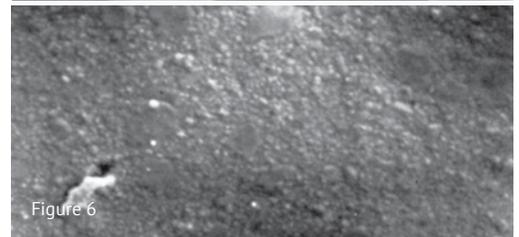


Figure 6

Scanning electron microscopic study of dense, non-resorbable hydroxylapatite. Figure 4 is an image of HA powder, with a particle size of 30 μm . This powder may be compacted and sintered at high temperature into dense, non-porous structures such as beads or random shaped particles (Figure 5). At 1500 X, the particle surface appears non-porous and very dense (Figure 6). (Osteograft® D300. Images courtesy of Dentsply Tulsa Dental)

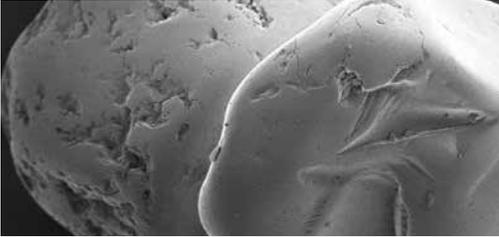


Figure 7. SEM of low density hydroxylapatite. The surface porosity, lower packing density and lower sintering temperatures facilitate solution mediated resorption of these particles. Osteograft® LD. Image courtesy of Dentsply Tulsa Dental.



Figure 8. SEM of synthetic, microcrystalline HA (200X). This is a pure, rapidly resorbable form of calcium and phosphate. OsteoGen®. Image courtesy of Implants, LTD.

For grafting of extraction sites where long term ridge preservation is desired, and the future use of implants has been ruled out, HA is an inexpensive and predictable bone filler. It is an excellent choice for augmentation of pre-existing ridge defects, for example under a fixed bridge pontic.

Examples: OsteoGraf® D-300 μ , D-700 μ , Dentsply Tulsa Dental.

Low-Density HA

In contrast to dense HA, low-density hydroxylapatite is a readily resorbable material designed to undergo solution mediated resorption upon implantation. While chemically similar to dense HA, and sharing the same biocompatibility profile, the behavior of this material is quite different.

Low density HA is available as granules, and is most useful as volume expanders when combined with autogenous bone, or as a calcium source when combined with demineralized bone allograft.

Example: OsteoGraf® LD-300, LD-700, Dentsply Tulsa Dental.

Microcrystalline Non-Ceramic HA

Manufactured using a low temperature precipitation process, micro-crystalline, non-ceramic hydroxylapatite is a readily resorbable source of bioactive calcium phosphate. By avoiding high temperature processes, these materials do not become ceramics and maintain chemistry very similar to biologic apatites. The crystals are not resorbed by cell mediated processes, rather they are dissolved into solution, providing a ready source of calcium and phosphate as well as a structural lattice which can support early bone formation.

Example: OsteoGen® non-ceramic, microcrystalline HA powder, Implants Ltd.

Beta-Tricalcium Phosphate

Beta tricalcium phosphate (β -TCP) is a synthetic ceramic bone graft material which has been used in a variety of orthopedic and dental applications for over 30 years. Similar in many respects to resorbable HA, β -TCP has value as a bone graft volume expander and as an osteoconductive mineral source. β -TCP is available in a variety of particle sizes, ranging from particles of less than 100 microns in diameter for use in periodontal defects, to particles several millimeters in diameter for use in large traumatic defects. It is also available combined with type I collagen to form flexible sheets and malleable blocks. Structurally, β -TCP can be manufactured to resemble natural bone; a highly porous (20-92%) mineralized matrix with random, interconnected pores. The pore size varies somewhat with the size of the particles, typically ranging from 5-500 μ m in diameter in the products available for oral and maxillofacial applications.

The mechanism of action is similar to other resorbable alloplasts: osteoconduction and resorption, with gradual replacement by host bone. Osteoconduction is facilitated by the interconnected pores and relatively large surface area. Upon implantation, proteins are absorbed onto the surface of the particle, followed by cellular invasion and initial vascularization of the porous matrix. Eventually, dissolution of the particle occurs, followed by cell-mediated resorption of the smaller, sub-micron particles. Deposition of bone occurs at a rate determined in part by the resorption rate, which is related to particle size and the porosity of the product. Resorption and replacement with host bone is variable, but generally occurs within 9 to 12 months.

Porous beta tricalcium phosphate may be used as a vehicle for the delivery of drugs

or biologic agents. Recently, an enhanced version of β -TCP containing recombinant platelet derived growth factor (rhPDGF-BB) has been introduced. Conceptually, this product combines the benefits of an osteoconductive scaffold with a mitogenic growth factor, allowing for precisely tailored dosage and localized delivery of a compound with proven wound healing and periodontal regenerative benefits. Whether or not this results in more rapid or more complete bone formation in large defects is currently under investigation.

Examples: Bioresorb® β -TCP, Oraltronics GmbH; CeraSorb® M Dental, Curasan AG; Vitoss® porous β -TCP ceramic, Orthovita Corp. GEM-21S® porous β -TCP/rhPDGF-BB, Osteohealth Inc.

Biphasic Calcium Phosphates

Hydroxylapatite and beta tricalcium phosphate may be combined in various ratios into a single product, known as biphasic calcium phosphate (BCP). The rationale for this combination product is to take advantage of the differential resorption rates of the two materials, achieving a balance between long term stability and support (HA) and more rapid dissolution and bone ingrowth (TCP). One such product, comprised of 20% beta-TCP (β -TCP) and 80% HA, is intended to mimic the structure of natural cancellous bone. The open structure of the BCP with interconnected macropores ($>100\mu\text{m}$) promotes vascular infiltration, nutritional transport and cell colonization, while a 3-dimensional, microporous architecture ($<10\mu\text{m}$) creates a favorable environment for adsorption of macromolecules and cell attachment.

In terms of using BCP for socket grafting, there is very little reliable clinical data describing resorption rates or stability. Therefore, the use of this material as a primary grafting material cannot be recommended at this time.

Example: OsSatura® BCP. Isotis Orthobiologics/Gensci Regenerative Technologies; Straumann Bone Ceramic.

Calcium Phosphosilicate (CPS) (aka Bioactive Glass)

Calcium Phosphosilicate (CPS) is a family of amorphous synthetic materials composed of calcium phosphate, sodium, silicon and oxygen, referred to as 45S5. Upon implantation, this unique biomaterial releases soluble Si, Ca and P ions into solution, forming a hydroxycarbonate surface layer through a biochemical transformation.⁸⁶

The mechanism of action of CPS occurs primarily through osteoconduction although there is a documented in vitro stimulation of osteoblasts and periodontal ligament fibroblasts.⁸⁷⁻⁹⁰ This effect has been called “osteostimulative”, which is distinct from osteoinduction and is defined as “an active stimulation of osteoblast proliferation and differentiation in vitro as evidenced by increased DNA synthesis, osteocalcin and alkaline phosphatase”.⁹² Turnover and resorption rate of CPS based products is variable because of the different physical forms of the material available.

A new formulation of CPS has recently been introduced in putty form with a bimodal particle size distribution. The putty consists of polyethylene glycol/glycerine binder and two different size particles, a 32-125 μm particle which is more rapidly resorbed providing the initial burst of Ca and P ions via solution mediated resorption, and a 90-710 μm particle that is more resistant to resorption and provides a longer term scaffolding for bone formation. A recent systematic review indicates that the material is substantially replaced by host bone in 5-6 months.⁹¹

Calcium Phosphosilicate materials have been used extensively in periodontal regeneration with good results, and the available evidence and long term documentation is

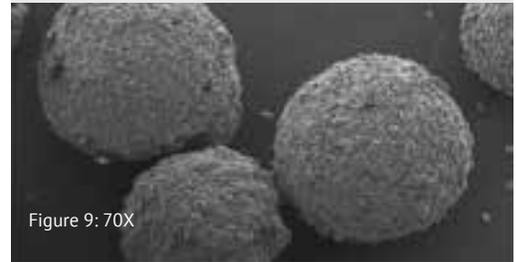


Figure 9: 70X

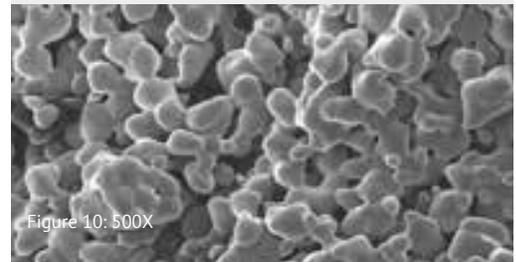


Figure 10: 500X



Figure 11: 1010X

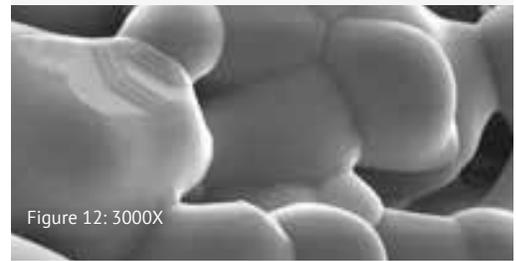


Figure 12: 3000X

Figures 9-12. Scanning electron microscopic study of beta tricalcium phosphate granules. The round form of the granule can be seen in the micrograph. The primary particles - which are large enough not to be susceptible to phagocytosis - form a framework that is penetrated by an interconnected system of micropores. As a result of capillary forces acting through this canal system, blood components and body fluid can reach the interior of the granule. This not only serves cell nutrition, but also the hydrolytic dissolution of the material from inside out. Furthermore, it promotes penetration of the material with blood vessels and cells. (Cerasorb® granules. Images courtesy of Curasan, Inc.)

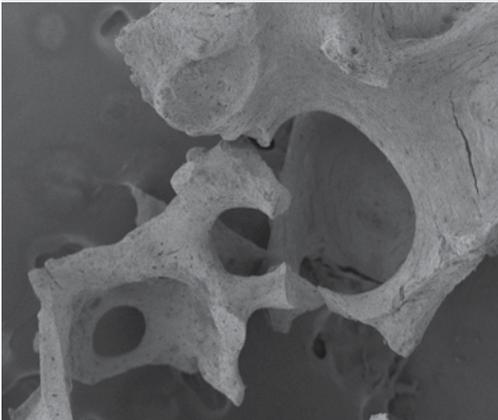


Figure 13. Scanning electron micrograph of porcine xenograft particle (200X) demonstrates typical osseous architecture and interconnecting pore structure. (Zcore™ Porcine Xenograft Particulate. Osteogenics Biomedical, Inc.)

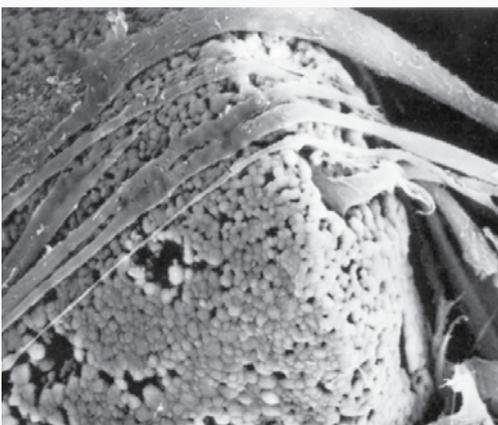


Figure 14. SEM of thermally processed, microporous anorganic bovine bone (Osteograft® N300). Ingrowth of fibroblasts into the HA pores is shown. Image courtesy of Dentsply Tulsa Dental.

good for the use of CPS in socket preservation where a synthetic material with a 5-6 month turnover time is desired.⁹²

Examples: NovaBone® Dental Putty. Manufactured by NovaBone Products, LLC, Alachua, FL. Distributed by Osteogenics Biomedical, Inc. Lubbock, TX. Biogran®, Manufactured by Orthovita. Distributed by 3i Biomet.

Polymers

Bioplant HTR® is a synthetic, macroporous polymethyl methacrylate (PMMA) bead with a calcium hydroxide coating. The particle is manufactured with a 350 µm central pore which is said to facilitate bone ingrowth.

The mechanism of action is via osteoconduction. Bone ingrowth is believed to occur on the particle surface and within the pore of the particle.

The turnover rate and resorbability of this material is not clearly understood. The material may in fact be partially resorbable, with dissolution of the calcium hydroxide coating and long-term retention of the PMMA component.

Example: Bioplant HTR®, Sybron Kerr.

Calcium Sulfate

Medical grade calcium sulfate (Plaster of Paris) is a biologically inert, resorbable osteoconductive material with a long history of use in orthopedics as a void filler.

Because calcium sulfate is rapidly resorbed (4 to 8 weeks), it is not used for socket grafting or implant site development as a stand-alone material. Rather, it is used as a "binder" type of material, usually mixed with various alloplasts, allografts or autografts to improve handling and to prevent particle migration.

Examples: Calcigen™ Oral, Implant Innovations, Inc.; Dentogen & Nanogen, Orthogen Corp.

Xenografts (Anorganic bone matrix)

Xenografts are naturally derived hydroxylapatite (carbonate apatite) sourced from cattle (bovine), horses (equine) or pigs (porcine). To prepare xenografts, bulk bone material is harvested from disease-free animals and transported to a processing facility. The bone is then washed, pulverized, and soaked in solvents to remove organic material. The particles are then sieved to achieve the appropriate particle size range and treated to remove the remaining organic and cellular components, leaving behind the mineralized bone matrix.

There are two processes currently used to prepare anorganic bovine bone. One process uses a low temperature, chemical extraction process to remove the organic and cellular components. The other uses high temperature (>1500°C) to remove residual organic components. In each case, the end result is a microporous structure composed of natural hydroxylapatite and free of cells and soft tissues.

Xenogenic bone is an osteoconductive material. The structure, chemistry, and pore architecture, which is similar to human bone mineral, is generally believed to result in enhanced bioactivity compared to synthetic hydroxylapatite.

Resorption of xenograft particles, if it occurs at all, occurs predominantly through

osteoclastic activity. Studies have shown residual graft particles present in grafted sites for up to 24 months (Artzi 2004). Particles placed adjacent to soft tissue and remote from host bone may simply become encapsulated with soft tissue and are virtually resistant to resorption. For this reason, xenografts are sometimes used for buccal plate augmentation, with the expectation that the enhanced contour will last over time.

While there have been no reported cases of disease transmission using bovine bone in millions of applications, there is some concern regarding the transmission of bovine spongiform encephalopathy (BSE). Although there are reports of BSE infected cattle in the U.S., Europe, and Canada, the risk of BSE transmission is believed to be extremely low due to the harsh processing and sterilization required in the production of these materials. Increasingly, cattle used for the production of medical products are either sourced from countries where BSE is not present, or from closed, disease-free herds. However, patients should be counseled regarding the use of bovine products prior to surgery to assure psychological acceptance in light of the BSE risk. Similarly, patients should be counseled regarding the use of porcine or equine bone, since there may be psychological, cultural, or religious objections to implantation of any of these biomaterials.

Recently, as an alternative to bovine xenografts, porcine xenografts have been introduced. Derived from porcine cancellous bone, the product is an osteoconductive, porous material with a 3-D structure very similar to human cancellous bone. The resorption kinetics and characteristics are similar to bovine bone. Studies are underway to develop comparative data in terms of resorption in extraction sockets compared to bovine xenograft.

A bovine bone product has been introduced that utilizes the concept of biomimetics, reported to enhance cell attraction and morphogenesis. This product consists of thermally deorganified bovine bone that has been treated with a synthetic bioengineered peptide. This peptide sequence, 15 amino acids in length, represents the cell binding domain of human type I collagen. At least one study involving periodontal defects demonstrated enhanced bone fill compared to controls treated with traditional techniques.

Generally, xenografts are used either in combination with autogenous bone (50:50 ratio) for bone augmentation procedures, or used alone when volume augmentation (such as buccal plate augmentation) or long term extraction site volume preservation is desired. These materials turn over very slowly compared to allografts, and if a resorption time of 3-4 months is desired, they should be combined with autogenous bone or other rapidly resorbing biomaterials.

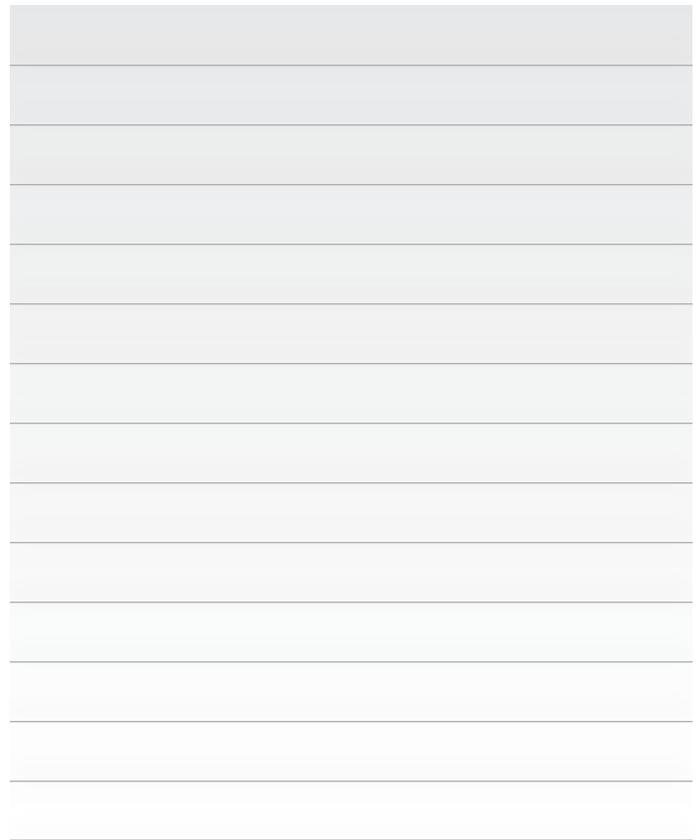
Examples: ZCore® Porcine Xenograft (anorganic cancellous granules), Osteogenics Biomedical, Inc. OsteoGraf® N-300, N-700, (thermally deorganified bovine bone), PepGen P15® enhanced bovine bone, PepGen Flow and Putty, Dentsply International; BioOss® (chemically deorganified bovine bone), Geistlich Phar-

ma AG, Equimatrix® (equine natural bone matrix) Osteohealth, a division of Luitpold Pharmaceuticals, Inc.

Coral and Algae Derived HA

Coralline HA is a naturally derived graft material prepared from sea coral. After harvest, it is deorganified with a thermal (steam) process leaving the macroporous organic skeleton of calcium carbonate. The material is then exposed to a phosphate bath resulting in a chemical exchange of carbonate for phosphate. The result is a highly porous particle composed of a very dense hydroxylapatite with high carbonate content. The natural porosity of the material facilitates cell attraction and ingrowth while the structural density prevents rapid resorption of the particle.

Coralline HA promotes bone formation via osteoconduction. For significant bone ingrowth to occur the particle must be very close to host bone. There is very little turnover of the particle matrix, so the material can be used for long term ridge preservation. The material is more expensive than dense HA particles. Like dense HA, coralline HA is contraindicated for placement into sites which may receive dental implants. As there are currently no dental products composed of coralline HA believed to be on the US market (2016), this information is included for historical interest. ■





SECTION 3 | Guided Tissue Regeneration (GTR) Membranes

In the healing of any bone defect, there is competition between the local soft tissue cells and adjacent bone cells to migrate into and repopulate the wound. In the normal healing of an oral wound, soft tissue cells divide and migrate at a much faster rate than bone cells, so large defects tend to fill with soft tissue. In contrast, isolation of bone defects by the use of a guided tissue regeneration membrane allows migration of bone-derived cells to repopulate the wound exclusively. There may be additional benefits to the use of a membrane as well, such as protection of the wound from mechanical disruption and salivary contamination.

Guided tissue regeneration membranes appear deceptively simple, but in order to function well they must meet certain biomaterial requirements. GTR membranes should be biocompatible and easy to manipulate. They should be flexible and compliant in order to avoid perforation of overlying soft tissues, yet stiff enough to resist collapse into the underlying defect. They must be of sufficient density to resist passage of unwanted cells and bacteria, yet allow the passage of oxygen and small molecules. They should be bioinert, and not evoke inflammation upon implantation. They should be user friendly, and manufactured from materials that are easy to cut, trim and fit precisely over the defect. The membrane should be dense enough to resist infection if exposed to the oral cavity. If the membrane is resorbable, the resorption process should not interfere mechanically or biochemically with osteogenesis. If non-resorbable, the membrane should be easily removed with minimal disruption of the wound complex.

Experimental GTR membranes made of Millipore filter (0.2 μm pore size) were first used successfully by Boyne in 1962. Later, porous e-PTFE (expanded polytetrafluoroethylene) membranes were introduced and studied extensively in the field of periodontics. Expanded PTFE is bioinert and soft tissue compatible, and has been considered the gold standard material for guided tissue regeneration.

The concept of using GTR barriers for extraction site grafting was introduced in the early 1990's both as a method to protect the underlying wound (or implant) and prevent migration of graft material. At that time, there were several products available for use; a highly porous expanded PTFE membrane (GoreTex[®]) a highly porous resorbable polymer membrane (Guidor[®]), a porous polylactide mesh (Vicryl[®]), gelatin sponge (GelFoam[®]) and collagen sponge (CollaPlug[®]). Due to the porous nature of these materials, primary closure was required over the extraction site to achieve predictable bone regeneration and particle containment. In the case of highly porous e-PTFE, failure to achieve primary closure or flap dehiscence with early membrane exposure resulted in bacterial contamination of the surface. With a nominal membrane pore size in the range of 30 to 100 μm and the diameter of pathogenic bacteria generally less than 10 μm , migration of organisms

through the membrane, and ultimately failure of bone regeneration, was a common complication. Similarly, with the resorbable materials, premature exposure resulted in complications such as rapid degradation, graft particle exposure, particle migration, and failure of bone regeneration.

In the context of extraction site grafting, the requirement for primary closure over the GTR membrane creates several challenges. The flap manipulation required to achieve primary closure over the typical extraction site is difficult, time consuming and results in additional surgical trauma and morbidity. Mobilizing the flap to create tension-free primary closure over the membrane also results in disruption of the soft tissue architecture which can negatively affect the esthetic outcome in the final restoration. An additional disadvantage of the requirement for primary closure is the necessity of a second surgical procedure for removal of the membrane.

To address the problems created with the requirement for primary closure, a second generation PTFE membrane was developed by the author in 1993: high-density PTFE (d-PTFE). Since bacterial migration into the highly porous, expanded PTFE was problematic, the pore size and membrane structure of the new material was modified to prevent bacterial contamination while still providing a biocompatible surface for the attachment of cells. Animal studies confirmed the efficacy of d-PTFE as a guided tissue regeneration material, and FDA clearance was granted in 1994.

In clinical use, it was found that the d-PTFE could be used in an "open regeneration" technique over extraction sites, achieving an acceptable biologic seal over the socket and graft complex, while leaving the soft tissues in their native position. This would bring closure to the ongoing argument for primary closure, and allow the use of a predictable, non-resorbable membrane for routine socket grafting.

There are many advantages of using d-PTFE in socket grafting applications. Since primary closure is not used, a second surgery is not required for membrane removal. Membrane removal is accomplished by grasping the exposed membrane with forceps and gently lifting it from the wound. Because the nominal pore size is less than 0.3 μm , bacterial contamination of the exposed membrane is limited to the surface only, preventing complications and graft failure. The procedure is rapidly and easily accomplished using basic surgical techniques and minimal flap reflection or dissection. Soft tissue architecture is maintained, including the interdental papilla and the full width of keratinized mucosa. With the open technique, an increase in keratinized mucosa width is possible, rather than a loss.

Non-Resorbable Membranes

High-Density PTFE (d-PTFE)

Dense PTFE is entirely synthetic, and is manufactured by extrusion of PTFE paste under heat and pressure. The raw material is then compressed to achieve an appropriate density, porosity and film thickness. A nominal pore size of less than 0.3 microns is achieved. The film may then be textured or further machined to improve strength or handling characteristics. It is then die-cut, packaged and sterilized by steam autoclave.

Dense PTFE is non-resorbable and chemically stable. In addition to its long history in the field of guided tissue regeneration, PTFE has been used for over 30 years in cardiovascular applications such as suture, vascular grafts and heart valves. PTFE is bioinert and does not cause inflammation. If manufactured with a small pore size, bacteria are prevented from entering the structure of the barrier while still allowing diffusion of oxygen and small molecules across the membrane.

Upon implantation, dense PTFE is immediately coated with plasma proteins, facilitating cellular adhesion to the smooth, biocompatible surface. This cellular adhesion is observed to form a hermetic seal, providing resistance to migration of bacteria and epithelial cells around and under the membrane when it is exposed in the mouth. Plasma protein adsorption also facilitates diffusion of soluble organic molecules across the membrane. Removal of dense PTFE is simplified due to the lack of tissue ingrowth into the surface structure.

A textured, high-density PTFE is available. Texturing the membrane results in an increase in surface area and increases the pull-out strength of the material through three dimensional attachment of soft tissue. The increased stability in the wound results in less flap retraction and reduces the risk of membrane movement and loosening.

The primary advantage of high-density PTFE is the ability to remain exposed in the mouth while protecting the underlying defect and bone graft. The membrane is soft, flexible and easy to handle. Primary closure is not required and the membrane may be removed without additional surgery if exposed. If primary closure technique is used, the membrane may be easily removed through a small incision in a flapless technique.

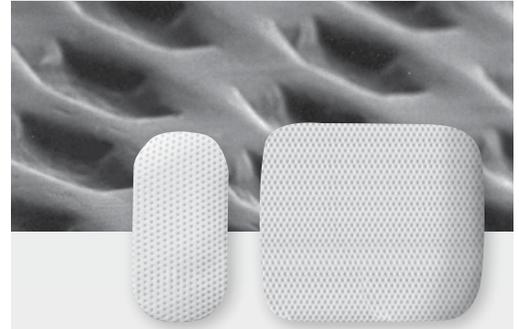
Dense PTFE is also available with titanium reinforcement, which increases the stiffness of the material for use in defects where spacemaking is required. The embedded titanium framework allows the membrane to be shaped to fit a variety of defects without rebounding and provides additional stability in large, non-spacemaking osseous defects.

Examples: Cytoplast™ GBR-200, Cytoplast™ TXT-200 (textured), Cytoplast™ Ti-250 Titanium-Reinforced Membrane, Osteogenics Biomedical, Inc.

Expanded PTFE (e-PTFE)

This is a highly porous membrane, chemically identical to high density PTFE. The pore size is controlled during the manufacturing process by slowly stretching the material under intense heat.

Expanded PTFE has a long history of success in GTR procedures, particularly in periodontics. However, the highly porous structure of e-PTFE allows ingrowth of bacteria when the membrane is exposed in the mouth. Exposure results in high rates of infection and frequently requires early removal of the device. In addition, the highly porous structure also allows soft tissue ingrowth which complicates removal, often requiring sharp dissection and extensive surgery. Expanded PTFE must be completely buried and primary closure must be maintained to ensure predictability.



Cytoplast™ TXT-200 Singles (left) and Cytoplast™ TXT-200 (right)

Cytoplast™ TXT-200 high-density PTFE guided tissue regeneration membrane was designed specifically for extraction site grafting and augmentation procedures where exposure to the oral cavity is common. The microtextured surface increases the surface area for improved soft tissue attachment compared to smooth, dense PTFE, yet remains resistant to bacterial invasion due to the nanoscale porosity. The result of this unique approach to membrane design is that the membrane can be left exposed in the mouth without complications.

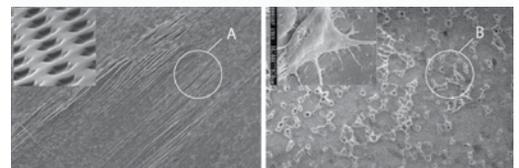


Figure 15

Figure 16

SEM views of Cytoplast™ TXT-200 textured high-density polytetrafluoroethylene membrane. The hex shaped dimples increase the surface area available for soft tissue attachment (inset SEM at 100X). Although the membrane grossly appears to be non-porous, the ultrastructural surface features are quite interesting. Parallel grooves and fibrils, 1 to 3 microns in diameter (A), play a role in cell migration and attachment (SEM 1,500 X). At high power, nanoscale pores (B) can be visualized (SEM 20,000 X). Pores less than .3 microns prevent the migration of bacteria and undesirable cells into the membrane, yet allow diffusion of small organic molecules and oxygen, and are important in facilitating cellular adhesion and spreading (inset SEM at 6,000 X).

While expanded PTFE is useful and quite predictable in deep, buried sites for guided tissue regeneration, there is currently no role for this material in extraction site grafting where exposure is likely.

Examples: GoreTex® Regenerative Membrane (discontinued), GoreTex® Regenerative Membrane Titanium-Reinforced (discontinued), W. L. Gore and Associates.

Resorbable Barrier Membranes

Bioresorbable GTR membranes, initially developed to avoid the complications associated with e-PTFE, are currently manufactured from polylactide/polyglycolide, type I bovine collagen and porcine collagen. While not ideally constructed for the coverage of extraction sites or in areas where exposure is likely, they are ideally suited for reconstructive procedures such as coverage of corticocancellous block grafts, particulate onlay grafts, and coverage of apical defects and sinus lift access windows.

Poly lactide/Polyglycolide Copolymer (PLA/PGA)

Medical devices such as sutures, bone pins, screws and plates can be manufactured from biocompatible, resorbable polymers. The ratio of PLA to PGA and the polymer molecular weight are among the variables that determine the physical characteristics and resorption profile of the final product. Plasticizers may be added to improve handling qualities. PLA/PGA polymers degrade by hydrolysis, and are eliminated via the Krebs Cycle as CO₂ and water.

It should be remembered that all resorbable polymer GTR barriers require primary closure to achieve predictable results. Premature exposure may result in early degradation, exposure of the underlying graft and ultimately failure of the procedure.

Examples: Gore Resolut® (discontinued), Gore Resolut® Adapt® (discontinued), Gore Resolut® Adapt® LT (discontinued), W.L. Gore and Associates; EpiGuide®, Curasan AG; Inion® GTR™, Inion, Ltd.

Collagen

Introduced as a resorbable GTR barrier in 1995, collagen has been shown to provide adequate defect isolation and has been favorably compared to e-PTFE in periodontal studies. Collagen for biomedical use is typically derived from bovine or porcine skin or tendon. Following harvest, the raw material is purified to remove non-collagenous proteins and processed by freeze drying and cross-linking to increase the resorption time. The primary indication for the use of collagen membranes is for isolation of deep, buried bone defects such as periapical surgical defects, coverage of block grafts and coverage of sinus lift access windows.

Although the manufacturing process is designed to remove antigens, individual patients may react unfavorably to the use of animal collagen. Some patients may object to the use of animal materials on a psychological basis. Resorption time may be unpredictable and can vary from patient to patient and from one site to another.

The use of human acellular dermis has been advocated as a GTR barrier and would be considered a collagen allograft. Fascia lata and pericardium have also been used as a source of dense, collagen-rich connective tissue which can be used as a GTR barrier.

Recently, manufacturers of collagen barriers have increased the density and degree of crosslinking in an effort to create materials that can withstand exposure. Whether this has any advantage over using dense PTFE is not known at this time.

Examples: Vitala® Porcine Derived Collagen, Osteogenics Biomedical, Inc.; Cytoplast™ RTM Collagen, Osteogenics Biomedical, Inc.; Biomend®, Zimmer Dental; BioGide, Geistlich Pharma AG; Alloderm® acellular dermis, Lifecell, Inc. ■

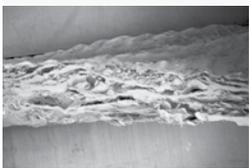


Figure 17

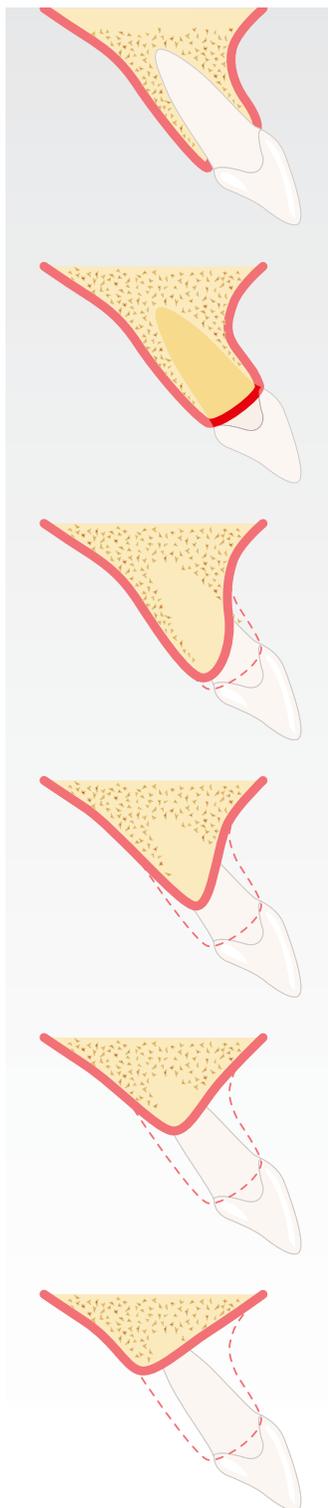


Figure 18

Scanning electron microscopic views of Cytoplast™ RTM collagen membrane. Lyophilization results in a multilayered, selectively porous yet cell occlusive structure. The collagen is crosslinked to provide a barrier function for approximately 4 months (SEM at 100 X).



SECTION 4 | Extraction Site Reconstruction (ESR)



Progressive Atrophy

Extraction site grafting is an excellent place to begin to work with GTR membranes and grafting materials. Mastery of this technique will provide a predictable method of conserving alveolar bone for prosthetic support, esthetics and future placement of dental implants.

Extraction Site Healing and Alveolar Ridge Resorption

Extraction sites heal in a highly predictable fashion, with little intervention required for clinically acceptable wound healing to occur. The initial step involves the formation of a blood clot in the socket. At the apical aspect of the socket, the clot is rapidly replaced by a highly vascular granulation tissue, accompanied by ingrowth of blood vessels from the periodontal plexus. By about 14 days, this granulation tissue is replaced by an organized connective tissue matrix which is eventually mineralized to form bone. Socket healing progresses in an apical to coronal direction, so that by 21 days approximately 2/3 of the socket is filled with the connective tissue required to form bone (osteoid). Bone formation begins in the apex, progressing coronally to partially fill the socket with immature bone by 6 weeks.

At the coronal aspect however, within hours of extraction migrating epithelium invades the clot, resulting in incomplete bone regeneration in the upper 1/3 to 1/4 of the socket. As a result, the extraction site heals in a concave fashion. Impaction of debris and bacteria into the healing socket further prevents the formation of bone.

Incomplete repair at the coronal aspect of the socket, coupled with surgical micro-trauma to the facial or lingual cortex results in extensive modeling of the residual alveolar crest. As much as 40-50% of alveolar width and 20-30% of height is irreversibly lost in the first year following extraction. Progressive atrophy following tooth loss ultimately results in the thin, knife-edge ridge or total loss of the alveolus down to basal bone. The rate of ridge resorption is related to a host of local and systemic factors, and may be highly variable.

The complications of alveolar bone loss are well known. There is loss of prosthetic stability in the case of traditional removable prosthetics. In a fixed prosthetic reconstruction, the loss of ridge height may result in compromised esthetics, requiring overcontoured or long pontics. In cases where dental implants are planned, the loss of bone may require the placement of shorter or smaller diameter implants or will require secondary bone grafting to provide adequate bone support. In the esthetic zone, even slight changes in soft tissue architecture affect the ability of the implant team to deliver an inconspicuous implant restoration.

Theory of Guided Bone Regeneration in Extraction Sites

As discussed previously, the use of cell-occlusive barriers has been shown to result in complete bone regeneration in otherwise non-healing defects. For example, the author has shown that the typical healing of critical sized defects (4.0 mm) in the rat mandible occurs by fibrous bridging of the defect without bone formation (Bartee & Carr, 1995). This type of fibrous healing is believed to be due to the migration of soft tissue cells into the bone defect and the exclusion of bone forming cells. However, with the placement of a dense PTFE barrier over the defect, predictable bone formation occurs, even in the absence of a graft material.

In human clinical studies, other investigators have shown that extraction site defects heal with greater internal bone fill and less ridge resorption when membranes are placed over intact sockets, even without the use of a graft material. These studies indicate that physical isolation of the extraction socket (or defect) alone is enough to change the wound healing dynamics in the favor of bone formation over fibrous healing.

A second theoretical mechanism of action is believed to occur through environmental isolation of the healing wound. In response to injury, growth factors are elaborated by the platelets and other immunocompetent cells which are believed to attract and stimulate the migration of potential bone forming cells. As these cells enter the socket, important molecular events involved in cell attachment, migration and differentiation begin to unfold. By isolating and concentrating these molecular messengers (cytokines, polypeptide growth factors), the local environment favors bone regeneration over fibrous repair.

The introduction of particulate grafting materials further enhances the regeneration process by osteoconduction and osteoinduction, particularly when there are missing or damaged socket walls. In addition to aiding in the distribution of bone forming cells throughout the defect (osteoconduction), interaction of host cells with graft materials appears to induce changes in cellular behavior consistent with bone formation. Cellular activities such as migration, division, differentiation and protein synthesis are all influenced by the physicochemical properties of the various bone grafting materials.

Graft Material Selection

When treatment planning involves grafting of extraction sites, the clinician has a wide variety of commercially available graft materials from which to choose. Because they vary greatly in terms of their composition, degradation rates and biological capacity, it is impossible to recommend a single material that is ideal for every clinical situation. Indeed, selection of particulate graft materials is part of an overall treatment planning process which begins with consideration given to the final prosthetic plan.

If we consider a potential extraction site, the ultimate prosthetic treatment of that site will fall under one of three major categories; a traditional fixed or bonded prosthesis, a traditional removable prosthesis, or a fixed implant-supported prosthesis. For each potential prosthetic option, the ideal graft material would differ based largely on the resorption profile of the material.

For example, if a traditional fixed bridge will be used and the extraction site to be grafted is a pontic site, a dense, non-resorbable synthetic alloplast could be appropriate based on the assumption that the clinical outcome desired is long term stability of the alveolar ridge. Of secondary concern in this type of case is actual bone regeneration, assuming that there is no possibility of placing an implant into that site in the future.

In distinct contrast, if an implant is going to be placed, then the graft material would ideally be rapidly resorbed and be replaced by vital bone. Because the implant will be placed either immediately into the socket or within a few weeks of extraction, the outcome desired is maximum vital bone density within the socket with minimal external resorption of the socket. Therefore, a material with a more rapid resorption rate, whether natural or synthetic, is appropriate in this clinical situation.

In a third example, if the patient is considering an implant, but is not yet committed to this treatment plan, a slowly resorbing mate-

rial, densely packed into the socket, is a logical choice to provide both long term ridge stability while simultaneously preserving the option of implant placement at a later time.

In addition to the resorption rate of the graft material, the morphology of the extraction site will impact material selection as well. Of particular importance are the number of intact bony walls and the volume of the defect. Intact sockets heal almost spontaneously with new bone, and there may be little need for any modification in technique other than the use of a barrier membrane and an osteoconductive material.

Conversely, if there is a buccal wall defect extending more than 1/3 the width of the site, the biological capacity of the augmentation materials will need to be that much higher in order to predictably regenerate the buccal contour of this site. If it is in the esthetic zone, the requirements are even higher. This type of site may ultimately require block bone augmentation, so grafting the socket with allograft bone particles at the time of extraction, while it may not result in an ideal contour, may reduce the complexity of the block graft done at a later time.

The clinical history of the site is important. If the tooth is to be extracted as a result of trauma, and there is associated hard and soft tissue damage, for example buccal plate fracture, the clinician should expect a reduced blood supply and less predictable healing with the potential for greater hard and soft tissue recession. Similarly, sites with bone loss due to endodontic failure, exhibiting external root resorption or vertical root fracture tend to heal in an unpredictable fashion. A graft material with a greater biological capacity should be selected in these cases and adjunctive soft tissue thickening procedures should be considered in the esthetic zone.

The general health of the patient should be evaluated as well. Any systemic condition that would predispose the patient to poor or delayed wound healing (advanced age, uncontrolled diabetes, smoking) will lead to compromised results. The healing capacity of the patient is the most important determinant of bone graft success or failure.

Recommendation of Graft Material Based on the Prosthetic Plan

Long-term ridge preservation for traditional fixed or removable prosthetics

For long term ridge preservation, where there is no possibility of placing implants in the future, dense non-resorbable hydroxylapatite (Dense HA) is a good option. This recommendation is based on several factors including well documented hard and soft tissue biocompatibility, ease of use, low cost and long term clinical experience.

Particles of dense HA placed into contact with bone will form a biochemical bond and rigid attachment. Particles more than a few millimeters from bone will be surrounded with a fibrous connective tissue matrix which may mineralize and incorporate the HA particle. Other particles will remain biologically inert within the dense connective tissue matrix. The dense HA particle undergoes

no clinically significant resorption and is not compressible, so it is a reliable long-term ridge preservation material. Once encapsulated, the particles remain clinically stable with little tendency to migrate or exfoliate. Due to the fibro-osseous integration, transmission of force is mediated from within the graft matrix to the surrounding bone during functional movements of the jaws, resulting in maintenance of alveolar bone mass. Dense HA is therefore the material of choice to use in extraction sites that will be restored with a traditional fixed or removable prosthesis.

It should be strongly emphasized, however, that dense HA is not indicated in sites which may receive dental implants, for several reasons. First, the density of the material makes osteotomy preparation difficult, if not impossible, in a well-healed site. Second, sites grafted with dense HA particles are relatively avascular and devoid of vital bone, and therefore have a diminished capacity to bond to dental implants. For this reason, an implant placed into a ridge grafted with dense HA will not form a predictable osseous interface.

Ridge preservation for implants: Implant Site Development

The preservation of hard and soft tissues after extraction is recognized as a key component in achieving esthetic implant supported restorations. Preservation of bone volume and soft tissue thickness provides for a more natural emergence profile of the restoration and camouflage of the underlying implant and restorative components. Coupled with proper implant site preservation/development, the use of zirconia abutments gives restorative team members the ability to create implant-supported restorations which rival natural dentition in terms of their beauty. Whether the clinician extracting the tooth is also placing the implant, or if the implants will be done in a team approach, it is vital that consideration be given to

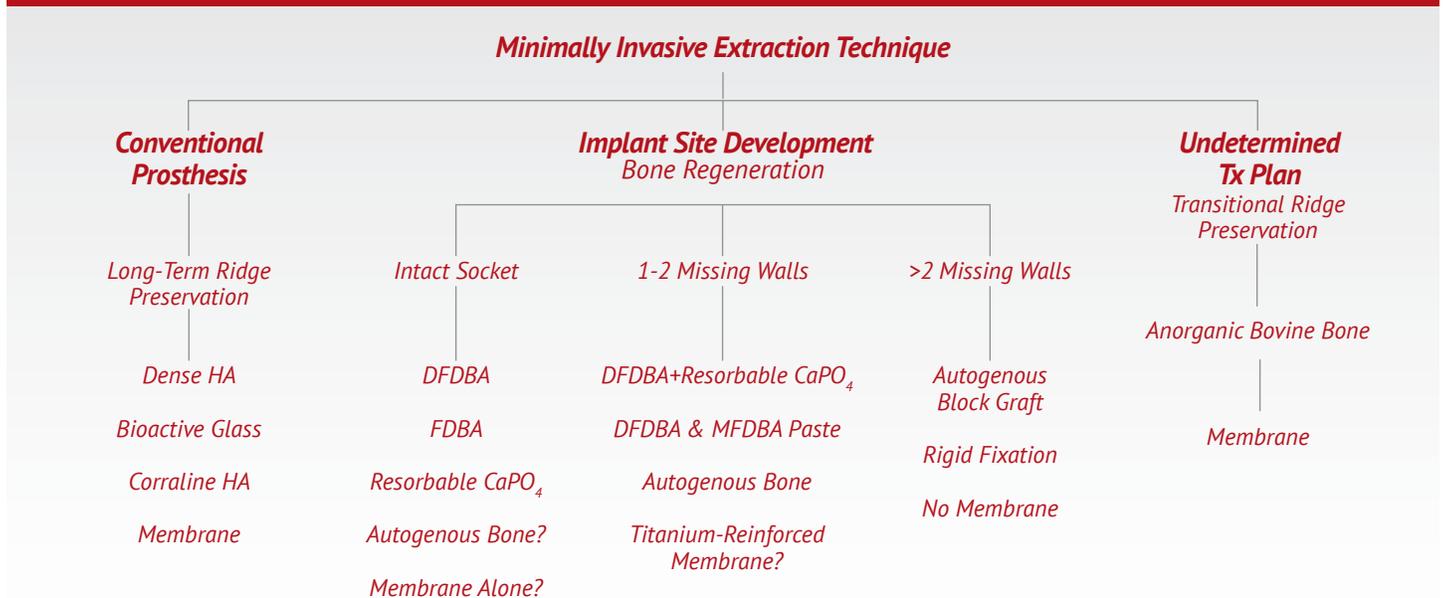
minimally traumatic surgery and a strategy for ridge preservation be employed simultaneous with tooth extraction.

One approach to implant site preservation where implants will be placed in the near term is to use a composite grafting technique. The rationale for using a composite technique (more than one type of graft material) is to achieve a synergistic effect by taking advantage of the differential resorption patterns of the available materials as well as the various modes of action.

For example, larger defects (larger than a single molar site) or those with missing walls would ideally receive an osteoinductive component, such as demineralized freeze-dried human bone (DFDBA) plus a mineralized component. Because larger, compromised sites present more of a regenerative challenge than intact sockets, appositional bone growth from the adjacent walls will occur slowly, resulting in volume contraction. To achieve more rapid bone regeneration, an osteoinductive component (DFDBA) is added. Because the bone mineral has been removed during processing, DFDBA typically resorbs at a much faster rate than mineralized bone allograft. While this can be an advantage in terms of more rapid turnover of the graft particles and faster bone formation, there tends to be more loss of graft volume compared to mineralized allograft. Because in a large defect an extended time frame for healing can be expected, a mineralized component with an extended resorption profile, such as mineralized human bone, anorganic bovine bone, or calcium phosphate should be combined with the DFDBA.

A commonly used composite graft is a 50:50 mixture of DFDBA and MFDBA. Autogenous bone chips or shavings, if readily available, are added to provide cellular activity for an osteogenic effect. This mixture will result in predictable bone regeneration in 3 or 4 walled defects when used in combination with a barrier membrane.

Decision Making for Extraction Site Grafting



The Cytoplast™ Ridge Preservation Technique



Figure 1. Minimally invasive, atraumatic extraction technique should be used. The use of periostomes or surgical sectioning is encouraged to minimize mechanical trauma to the thin cortical bone. All soft tissue remnants should be removed with a sharp curettage. Special care should be taken to remove residual soft tissues at the apical extent of the socket of endodontically treated teeth. Bleeding from the socket walls should be noted and if necessary, decortication of the socket wall can be done with a #2 round burr to increase early vascularization and access to osteoprogenitor cells.



Figure 2 and 3. A subperiosteal pocket is created with a small periosteal elevator or curette, extending 3-5 mm beyond the socket margins (or defect margins) on the palatal and the facial aspect of the socket. In the esthetic zone, rather than incising and elevating the interdental papilla, it is left intact and undermined in a similar fashion. The d-PTFE membrane will be tucked into this subperiosteal pocket.



Figure 4 - 6. Particulate augmentation material is placed into the socket with a syringe or curette. Ensure that the material is evenly distributed throughout the socket, but not condensed or packed too tightly. This will only reduce the available space between particles, which is critical for vascular ingrowth and subsequent bone formation.



Figure 7 - 9. The d-PTFE membrane is trimmed to extend 3-5 mm beyond the socket walls and then tucked subperiosteally under the palatal flap, the facial flap and underneath the interdental papilla with a curette. The membrane should rest on bone 360° around the socket margins, if possible. Note that minimal flap reflection is necessary to stabilize the membrane. Prior to suturing, ensure that there are no folds or wrinkles in the membrane and that it lies passively over the socket. Remove any stray bone graft particles which may be present between the membrane and the flap. To prevent bacterial leakage under the membrane, take care to avoid puncturing the membrane, and do not overlap two adjacent membranes.





Figure 10. The membrane is further stabilized with a criss-cross PTFE suture. It is not recommended to suture through the membrane. Alternatively, interrupted sutures may be placed. The PTFE sutures, which cause minimal inflammatory response, are left in place for 10 to 14 days.



Figure 11 and 12. The membrane is removed, non-surgically, in 21 - 28 days. With intact sockets, the membrane may be removed as early as 3 weeks. Studies have shown that by 21-28 days there is a dense, vascular connective tissue matrix in the socket and early osteogenesis is observed in the apical 2/3 of the socket. Sockets with missing walls may benefit from a longer time frame. Topical anesthetic is applied, and then the membrane is grasped with a tissue forcep and simply removed with a gentle tug.



Figure 13. Immediately following membrane removal, a dense, highly vascular, osteoid matrix is observed filling the socket. Adjacent gingival epithelium migrates across the osteoid matrix upon removal of the membrane.



Figure 14. The socket at 6 weeks. Thick, keratinized gingiva is beginning to form over the grafted socket. The natural soft tissue architecture is preserved, including the interdental papillae. New bone is beginning to form in the socket.

Extraction Site Reconstruction: Patient Management

General Instructions

Good oral hygiene is important to keep postoperative complications to a minimum. However, patients should avoid direct contact, such as heavy brushing or other manipulation of the surgical site for the first 2 weeks. If the exposed membrane becomes heavily contaminated with plaque, it may be cleaned with a Q-tip. Peroxide or chlorhexidine should be used as long as the membrane is in place, but may be applied locally rather than used as a rinse. Postoperative visits should be planned for observation at 1 week, suture removal at 2 weeks and the membrane is removed at 3 to 4 weeks.

In the opinion of the author, the use of prophylactic antibiotics enhances the predictability of socket grafting procedures. Antibiotic prophylaxis should be administered prior to surgery and continued for 5 days following the graft procedure. While the use of antibiotics is not without risk, it is a generally accepted practice when performing implant or grafting procedures.

Preventing Complications

The most common complication with socket grafting, or any procedure involving guided tissue regeneration membranes, is sloughing of the interdental papilla or flap retraction. This may be prevented with careful dissection, meticulous tissue handling and precise suturing. In the esthetic zone, it is recommended to perform the extraction and membrane placement without severing the papilla, but instead by carefully elevating the intact papilla from the interdental bone and tucking the membrane under it. If dehiscence and membrane exposure occurs, keep the exposed area clean and prevent disruption of the membrane for at least 3 weeks. At that time, remove the membrane as per usual protocol. The exposed area will granulate in and repair with new epithelium in 2 to 3 weeks.

The most common reason for flap retraction is vascular compromise of the soft tissue. This may occur due to overtightening of sutures or stretching of the flap beyond the capability of the small arteries and capillaries to supply blood to the flap margins. A tension-free closure should be the goal. Periosteal releasing incisions can be made at the base of the flap to aid in achieving a tension-free primary closure. If used, vertical relief incisions

should be made at least 8 to 10 mm away from the membrane, or the width of one to two teeth away from the defect margins.

Tissue-borne removable temporary partial dentures are another major cause of wound healing complications in graft cases. Caution should be used when a removable temporary prosthesis is used over a recently grafted site. Ensure that adequate relief is provided on the tissue surface of the prosthesis to prevent pressure on the flap. There should be no pressure whatsoever on the grafted site from the prosthesis. Even soft liners or tissue conditioners should not be in direct contact with the grafted site during the first 3 weeks. The pontic form should be ovate, to provide proper lateral support to the adjacent interdental papilla, rather than placing vertical pressure on this delicate tissue. The occlusion should be carefully adjusted to prevent micromotion during function, which could result in complications with soft tissue healing or with graft failure.

With the use of prophylactic antibiotics, antiseptic rinses and precise technique, postoperative infection is rare. The presence of purulent drainage, bad taste or foul odor in the postoperative period indicates infection of the graft. A simple method to evaluate the health of the tissue under the membrane is to gently touch the exposed membrane with a dental mirror handle. The membrane and underlying tissue should be firm, with no exudate or fluid movement noted when gentle pressure is applied. If infection is suspected under the membrane, it should immediately be removed. Failure of the graft may or may not occur depending on the time of membrane removal.

Although relatively rare, there are two primary causes of postoperative infection associated with socket grafting.

The most common cause of postoperative infection is due to the presence of graft particles between the flap and GTR membrane, between the flap and underlying bone, or between the flap and adjacent teeth. The presence of graft materials in these sites can create a pathway for capillary fluid motion and bacterial ingress into the graft site, resulting in a biomaterial-centered infection which will not respond to antibiotic therapy. Prior to, and after closure, carefully use suction and vigorous postoperative irrigation with sterile saline to ensure that all intervening graft particles have been removed.

A second major cause of infection associated with GTR procedures involves the overlapping of GTR membranes where the overlapped area becomes exposed to the oral cavity. This creates a potential space for capillary flow of bacteria beneath the membrane and into the graft material resulting in infection beneath the membrane. In cases of multiple extraction sites where two or more membranes will be used, ensure a minimum distance (gap) of 0.5 mm between adjacent membranes. It is important to plan to place this gap between membranes over sound, interdental bone rather than graft material.

Management of Temporary Restorations and Soft Tissue Healing

Maximum benefit of extraction site reconstruction is realized if careful attention is paid to the construction of temporary bridges or removable partial dentures. To a great extent, the soft tissue contours will follow the contour of the pontic form in these restorations.

An ovate pontic form will facilitate anatomic and esthetic healing of the soft tissues. Excessive pressure from an overlying temporary, however, will result in flap necrosis and resorption of these delicate soft tissues.

Similarly, excessive pressure from denture bases or flanges will result in flap necrosis, particularly if there is an underlying membrane. Careful observation at postoperative appointments, with appropriate adjustment of the prosthesis, is required for the best results. Any areas of ulceration or tissue blanching should receive immediate attention. ■

NOTES



Extraction, Immediate Implant Placement and Guided Bone Regeneration Using a Flapless Approach



Fig 1



Fig 2



Fig 3



Fig 4



Fig 5



Fig 6



Fig 7



Fig 8

This is a 60 year-old female who presented with a crown-root fracture of a non-vital maxillary right central incisor. The crown was temporarily stabilized with composite resin bonded to the adjacent teeth (Fig 1).

Extraction of the tooth and immediate implant placement was planned. To minimize soft and hard tissue recession, a flapless, minimally invasive extraction technique was employed (Fig 2).

The tooth root was extracted using only an intrasulcular incision. A #15 blade was used to sever the periodontal ligament and create space for root luxation and elevation (Fig 3).

Next, a subperiosteal pocket was created on the buccal and palatal aspect of the socket using a micro periosteal elevator (Fig 4).

Following luxation and initial elevation of the root with the micro elevator, the tooth was removed with forceps (Fig 5).

The interdental papillae were carefully undermined and elevated. This can be done with a small periosteal elevator or curette (Fig 6).

All remaining soft tissue was removed from the interior and margins of the socket with a sharp curette (Fig 7).

The implant osteotomy was done in the standard fashion, with the implant being placed against the palatal wall of the socket (Fig 8).



Fig 9



Fig 10



Fig 11



Fig 12



Fig 13



Fig 14



Fig 15



Fig 16

The gap between the facial aspect of the implant and the buccal wall was filled with a combination of autogenous bone chips harvested from the implant osteotomy combined with allograft bone (Fig 9).

A textured, high-density PTFE barrier membrane (Cytoplast™ TXT-200) is placed. The membrane is trimmed, then placed into the superiosteal pocket on the palatal aspect (Fig 10).

The membrane is then tucked under the facial flap (Fig 11).

Next, the membrane is tucked under the interdental papillae, taking care to keep the edge of the material a minimum of 1.0 mm away from adjacent tooth roots (Fig 12).

A single 3-0 suture (Cytoplast™ PTFE Suture; CS0518) is placed to further stabilize the membrane. The membrane is intentionally left exposed, as primary closure is not required in this technique (Fig 13).

Figure 14 shows the surgical site at 3 weeks. The exposed membrane is easily removed by grasping with a tissue forceps. Topical anesthesia may be used, but local anesthesia is not necessary.

The site at 6 weeks after implant placement (three weeks after membrane removal), reveals keratinized mucosa forming across the former extraction site (Fig 15).

Figure 16 shows the clinical view following placement of the implant abutment and acrylic provisional restoration.

Summary

The flapless technique described provides a minimally invasive approach to extraction with socket grafting or immediate implant placement. Because the interdental papilla remains intact, there is less disruption of blood supply. As a result, there is a greater potential for maintenance of soft tissue volume. In addition, the use of a dense PTFE membrane improves the predictability of immediate implant placement, excluding the requirement for primary closure and resultant disruption of soft tissue architecture.

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Use of Titanium-Reinforced dense PTFE Membrane for Immediate Socket Reconstruction



Fig 1



Fig 2

This mandibular right lateral incisor was vertically fractured, exhibiting long-standing chronic inflammation (Fig 1).

Upon extraction of the tooth, both the buccal and lingual plate were missing due to bone resorption (Fig 2).

The socket was grafted with a combination of demineralized human freeze-dried bone and mineralized freeze-dried bone in a 50:50 ratio (Fig 3).



Fig 3



Fig 4

A Cytoplast™ Ti-250 Anterior Narrow dense PTFE membrane was pre-curved over an instrument handle. It was then trimmed to cover the defect margins, taking care to avoid contact with the adjacent tooth roots (Fig 4).

The membrane is tucked in place under the mucoperiosteal flaps (Fig 5).

The wound was closed with a 3-0 PTFE suture (Cytoplast™ PTFE Suture; CS0518), intentionally leaving the membrane exposed and the soft tissues in their normal position. In this technique, primary closure is not necessary, allowing preservation of the keratinized tissue width (Fig 6).



Fig 5



Fig 6

Figure 7 shows the appearance of the titanium-reinforced membrane, intentionally left exposed, at 30 days. Topical anesthesia is applied for membrane removal; the membrane is grasped with forceps and gently removed from the wound.

Immediately after removal of the membrane, a dense, well-vascularized connective tissue matrix is observed within the socket. There is no loss of graft material. The oral epithelium has been prevented from migrating into the defect (Fig 8).



Fig 7



Fig 8



Fig 9



Fig 10



Fig 11



Fig 12

Figure 9 shows the clinical appearance 12 weeks after extraction.

A flap was elevated for implant placement. The missing buccal and lingual plate have been restored to full contour (Fig 10).

A 3.5 mm one-piece implant is placed into dense bone, and is stable enough for immediate temporization (Fig 11).

Figure 12 shows the immediate post-op clinical view. An immediate, non-functional temporary restoration was fabricated on the implant.

Summary

The use of a titanium-reinforced dense PTFE membrane provides several advantages in the management of complex defects where one or two walls are missing. The additional support results in greater bone volume compared to membrane materials that may collapse into the defect. Because an open technique can be used, there is no reduction in keratinized tissue width, and there is maintenance of normal soft tissue architecture. Because bacteria cannot penetrate the dense membrane structure, concerns about membrane exposure are eliminated. ■



APPENDIX A | Cytoplast™ Regentex™ d-PTFE Guided Tissue Regeneration Membranes



Figure 1: Cells attach in a pavement-like fashion to smooth surface. High-density membrane prevents bacterial migration into membrane.



GBR-200

Cytoplast™ GBR-200 is intended for basic guided bone regeneration procedures such as extraction site reconstruction. High density construction allows use where primary closure is not possible or membrane exposure is likely to occur. The smooth and dense surface resists bacterial contamination (Figure 1). Because PTFE is inert, non-reactive and non-resorbable, there is a predictable barrier to soft tissue and bacterial entry into the wound while the membrane is in place.

- 200 microns thick
- 12 mm x 24 mm or 25 mm x 30 mm sizes
- High-density PTFE
- Smooth surface
- Soft and supple
- High tensile strength
- May be easily cut with scissors to fit a variety of defects

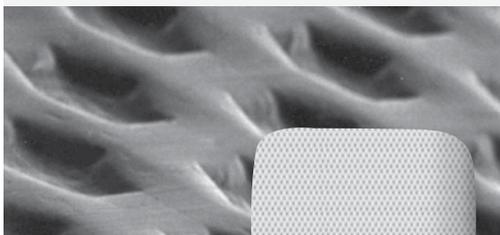
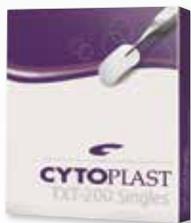


Figure 2: Textured surface increases the surface area of smooth PTFE membranes. High-density design prevents contamination of membrane structure with bacteria. Thin area under dimple facilitates diffusion of oxygen and small molecules through the membrane.



TXT-200

Cytoplast™ TXT-200 is intended for more demanding GTR procedures where some tissue integration with the membrane is desirable. To achieve integration without porosity, the surface is dimpled with a patented Regentex™ hex shaped pattern, which provides an increased surface area over smooth membranes (Figure 2). This unique design allows some tissue ingrowth while remaining non-porous to bacteria and soft tissue cells. The increased area available for soft tissue integration may reduce the chance of membrane exposure and displacement.

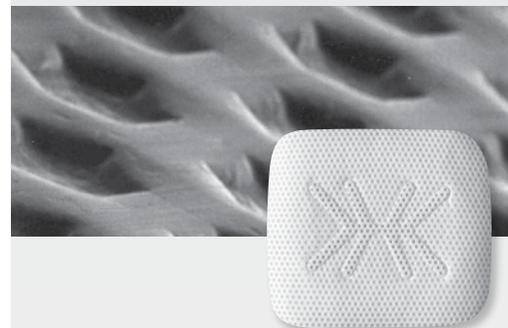
- 200 microns thick
- 12 mm x 24 mm or 25 mm x 30 mm sizes
- High-density PTFE
- Micro-machined Regentex™ surface increases surface area.
- Increased surface area may increase membrane stability and reduce micro-movement or flap retraction.
- Designed for periodontal applications and treatment of larger defects.
- Designed to achieve high integration with tissue in areas of compromised soft tissue such as thin flaps.

Ti-150 & Ti-250

This innovative, hybrid design consists of a thin layer of expanded PTFE (e-PTFE) laminated to a TXT-200 membrane, a high density membrane with the Regentex™ textured surface. In between these two layers lies titanium framework. The titanium framework is a grade of titanium that has little to no memory. Once formed, the titanium-reinforced membrane will remain in that shape until mechanically altered.

The titanium framework provides additional stiffness in the center portion of the membrane while allowing the edges to remain soft and supple. This feature greatly increases membrane rigidity to aid in spacemaking for the repair of larger defects and defects missing adequate bony architecture.

- Ti-150 is 150 microns thick, Ti-250 is 250 microns thick
- Available in twelve different shapes and sizes
- Dense PTFE backing
- May be easily cut with scissors to custom-fit various defects
- Titanium framework has little or no memory
- Designed for periodontal applications, large defects, and defects missing adequate bony architecture
- Regentex™ surface combined with e-PTFE backing provides high integration with tissue in areas of compromised soft tissue such as thin flaps
- Easier removal than with more porous titanium mesh and e-PTFE membranes



Ultra thin layer of e-PTFE to increase surface area for tissue integration.

Laser cut, commercially pure titanium strut for increased rigidity in central portion of membrane has little or no memory.

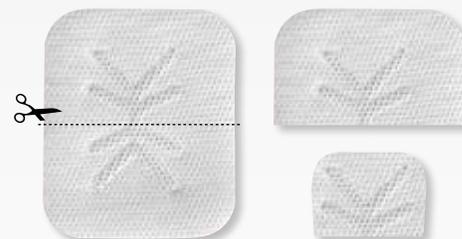
Regentex™, textured, high density PTFE backing prevents migration of bacteria into wound if exposed. Edges remain soft and supple to prevent flap complications.



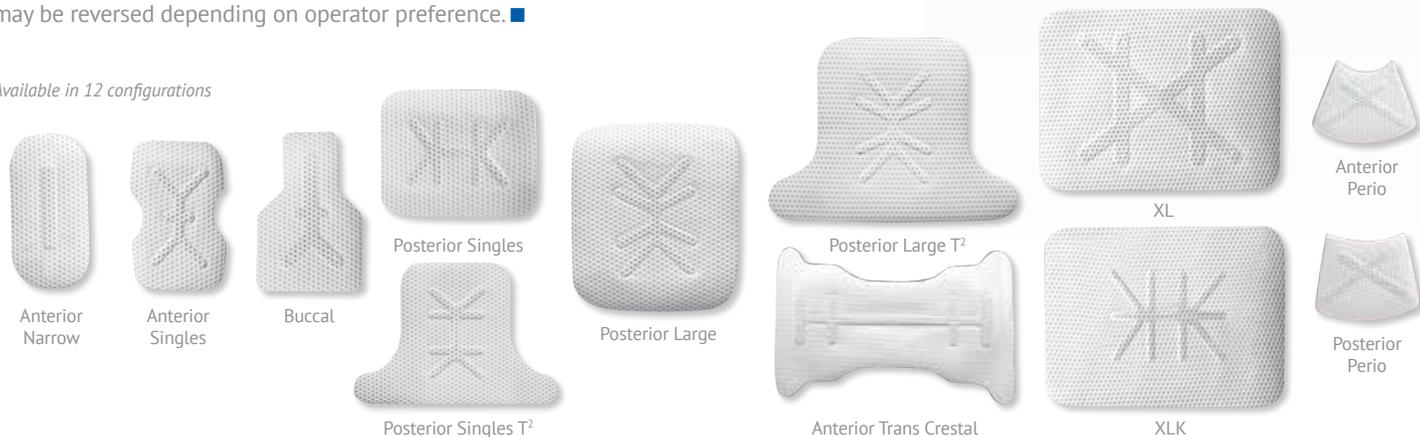
Cutting and Trimming Instructions for Titanium-Reinforced Membranes

Because the membrane is a laminated product, care must be taken in trimming the membrane to fit smaller defects. The material, including the titanium strut, may be easily cut with surgical scissors. However, with the introduction in 2008 of four new shapes and sizes, aggressive trimming of the membrane is no longer necessary. Although the product is designed to withstand trimming, over-trimming of larger membranes may result in delamination of the membrane.

If trimming the Posterior Large, the recommended procedure is to cut the membrane in the central strut area (see right), resulting in two symmetrical pieces. Then trim around the outside edges as necessary. It is important to maintain a zone of 2-3 mm of intact membrane from the titanium framework in order to prevent delamination and to maintain a soft and supple edge. The textured side should face the soft tissue, although this may be reversed depending on operator preference. ■



Available in 12 configurations





APPENDIX B | References

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APPENDIX C | Selection of Abstracts

Membrane References

Urban IA, Monje A, Wang HL.

Vertical Ridge Augmentation and Soft Tissue Reconstruction of the Anterior Atrophic Maxillae: A Case Series. *Int J Periodontics Restorative Dent*. 2015 Sep-Oct;35(5):613-23.

Severe vertical ridge deficiency in the anterior maxilla represents one of the most challenging clinical scenarios in the bone regeneration arena. As such, a combination of vertical bone augmentation using various biomaterials and soft tissue manipulation is needed to obtain successful outcomes. The present case series describes a novel approach to overcome vertical deficiencies in the anterior atrophied maxillae by using a mixture of autologous and anorganic bovine bone. Soft tissue manipulation including, but not limited to, free soft tissue graft was used to overcome the drawbacks of vertical bone augmentation (eg, loss of vestibular depth and keratinized mucosa). By combining soft and hard tissue grafts, optimum esthetic and long-term implant prosthesis stability can be achieved and sustained.

Ronda M, Rebaudi A, Torelli L, Stacchi C.

Expanded vs. dense polytetrafluoroethylene membranes in vertical ridge augmentation around dental implants: a prospective randomized controlled clinical trial. *Clin. Oral Impl. Res*. 2014 Jul; 25 (7): 859-66

Objective: This prospective randomized controlled trial was designed to test the performance of titanium-reinforced dense polytetrafluoroethylene (d-PTFE) membrane vs. titanium-reinforced expanded polytetrafluoroethylene (e-PTFE) membrane in achieving vertical bone regeneration, both associated with a composite grafting material.

Materials & Methods: The study enrolled 23 patients requiring bone augmentation with guided bone regeneration (GBR) procedures for placing implants in atrophic posterior mandibles (available bone height <7 mm). Implants were inserted and left to protrude from the bone level to achieve the programmed amount of vertical regeneration. Defects were filled with a composite bone graft (50% autologous bone and 50% mineralized bone allograft) and randomly covered with either an e-PTFE membrane (control) or a d-PTFE membrane (test). Membrane removal was performed after 6 months, and changes in bone height were recorded.

Results: Seventy-eight implants were inserted in 26 mandibular sites contextually to vertical ridge augmentation procedures. The healing period was uneventful in all sites, and the vertical defects were satisfactorily filled with a newly formed hard tissue. Mean defect fill after 6 months was 5.49 mm (SD \pm 1.58) at test sites and

4.91 mm (SD \pm 1.78) at control sites. The normalized data (percentage changes against baseline) did not show any statistically significant difference between test and control groups ($P = NS$).

Conclusions: Based on the data from this study, both d-PTFE and e-PTFE membranes showed identical clinical results in the treatment of vertical bone defects around implants, using the GBR technique. The membrane removal procedure was easier to perform in the d-PTFE group than in the e-PTFE group.

Urban IA, Lozada JL, Jovanovic SA, Nagursky H, Nagy K.

Vertical ridge augmentation with titanium-reinforced, dense-PTFE membranes and a combination of particulated autogenous bone and anorganic bovine bone-derived mineral: a prospective case series in 19 patients. *Int J Oral Maxillofac Implants*. 2014 Jan-Feb;29(1):185-93.

Objective: This prospective case series evaluated the use of a new titanium-reinforced nonresorbable membrane (high-density polytetrafluoroethylene), in combination with a mixture of anorganic bovine bone-derived mineral (ABBM) and autogenous particulated bone, for vertical augmentation of deficient alveolar ridges.

Materials & Methods: A mixture of ABBM and autogenous particulated bone was used for vertical ridge augmentation and covered with a new titanium-reinforced nonresorbable membrane. Ridge measurements were obtained before and after the procedure, complications were recorded, and biopsy specimens were taken for histologic examination.

Results: Twenty vertical ridge augmentation procedures were carried out in 19 patients. All treated defect sites exhibited excellent bone formation, with an average bone gain of 5.45 mm (standard deviation 1.93 mm). The healing period was uneventful, and no complications were observed. Eight specimens were examined histologically; on average, autogenous or regenerated bone represented 36.6% of the specimens, ABBM 16.6%, and marrow space 46.8%. No inflammatory responses or foreign-body reactions were noted in the specimens.

Conclusions: The treatment of vertically deficient alveolar ridges with guided bone regeneration using a mixture of autogenous bone and ABBM and a new titanium-reinforced nonresorbable membrane can be considered successful.

Belleggia F.

Clinical Evaluation of Guided Bone Regeneration Procedures Using a dense-Polytetrafluoroethylene Membrane. A Preliminary Report. Presented at the XX International SIO Congress in Milan, Italy. January 27 - 28, 2012.

Objective: To analyze the clinical outcome of guided bone regeneration (GBR) with a newly developed dense-polytetrafluoroethylene (d-PTFE) membrane.

Materials & Methods: Twenty consecutive GBR procedures were performed in 18 consenting patients, 8 males and 10 females, mean age 49.5 years (range 21-75), from January 2010 till October 2011, utilizing a d-PTFE membrane (Cytoplast) with or without titanium reinforcement, and a graft of particulated autogenous bone or deproteinized bovine bone mineral (Bio-Oss) or nanocrystalline [sic] hydroxyapatite embedded in a silica gel matrix (Nanobone) alone or mixed together. Twenty implants (10 Camlog, 9 Straumann, 1 Alpha-Bio) were placed at the time of GBR in 16 procedures. A staged approach, with 6 implant placement (5 Camlog, 1 Straumann) at the time of membrane removal, was performed in 4 procedures.

Results: All GBR procedures but one healed uneventfully. Only 1 late exposure of the membrane happened in a single simultaneous implant placement procedure after 11 weeks. The membrane was removed 1 week after the exposure and no sign of inflammation or infection was observed beneath the membrane within the regenerated bone. The other 19 membranes were removed after a 29.7 week healing period (range 19-44). All 26 implants were osseointegrated and completely surrounded by regenerated bone. Graft material did not affect the clinical outcome, while the limited number of treated cases did not allow statistical analysis within the groups.

Conclusions: This preliminary report of an ongoing study indicates that d-PTFE membranes may be used with high predictability (95% procedure's success, 100% implant survival and success) in GBR procedures. The only one late exposure did not cause wound infection.

Levin B.

Immediate temporization of immediate implants in the esthetic zone: Evaluating survival and bone maintenance. *Compendium* 2011;32:52-62.

This study followed 30 consecutively placed implants in the esthetic zone, inserted at the time of tooth extraction, and immediately temporized and augmented with bone grafting and resorbable guided bone regeneration. Implant survival, adverse events, and esthetic outcomes were evaluated. In this study, the esthetic zone is defined as the dentition spanning maxillary or mandibular first bicuspid. All implants osseointegrated and were ready for definitive restorative therapy by 12 weeks. No adverse events, such as infection, persistent inflammation, or abutment screw loosening, occurred. Radiographic bone levels were documented. This study also emphasizes clinical technique and rationale.

Yamashita M, Horita S, Takei N, Sasada Y, Shibato W, Ishikawa Y, Takao K, Maki K, Funakoshi E. Minimally Invasive Alveolar Ridge Preservation/Augmentation Procedure (Open Barrier Membrane Technique). 2010, AAP 96th Annual Meeting.

Introduction: Conventionally, expanded polytetrafluoroethylene (e-PTFE) has been widely used for guided bone regeneration (GBR). However, several disadvantages of the membranes have been recognized. A major complication with e-PTFE membranes is wound dehiscence and membrane exposure, which causes infection and results in severely compromised bone regeneration. In 2005, Funakoshi introduced the "Open Barrier Membrane Technique" as a novel minimally invasive GBR technique using non-expanded, high-density PTFE (d-PTFE) membrane, which is impenetrable to bacteria because of its surface characteristics (less than 0.2µm nominal pore size). Because primary coverage is not necessary, there is no need for periosteal releasing incisions that can cause swelling and pain. The aim of this retrospective study was to evaluate the clinical regeneration of alveolar ridge preservation/augmentation using d-PTFE membranes in addition to bone graft materials.

Materials & Methods: A total of 129 extraction sockets and alveolar ridges were evaluated post extraction in 111 subjects (49 males and 62 females; average age: 58 years; age range: 31 to 83 years). The extraction sites and deficient alveolar ridges were treated with the open barrier membrane technique for the placement of implants during 2002-2009. After reflection of the mucoperiosteal flaps, autogenous bone or bone substitute combined with an enamel matrix derivative and/or platelet rich plasma was placed into the extraction socket or onto the deficient ridge where a d-PTFE membrane was then placed over the site. Intentional primary closure was not attempted, i.e., the membrane was left exposed. Implants were placed 4 to 6 months after membrane removal.

Results & Discussion: None of the patients reported any unusual pain, swelling or discomfort during the treatment. Neither infection nor inflammation was present, although the membranes were exposed partially and plaque adhered on the surfaces of the membranes in almost all cases. After membrane removal, immature bone covered by a smooth red non-epithelialized soft tissue was observed. The tissue re-epithelialized completely within 1 month. Keratinized gingiva was preserved at all sites, and furthermore, some cases showed enhancement. All sites had successfully placed implants, and osseointegration was clinically obtained. Both socket- and ridge-type sites showed excellent bone gain as 100.9% and 95.8%, respectively, with no significant differences between the types ($P=0.12$). Minimal bone loss (0.8 mm total) was found at implant placement. A total of 60 sites (47%) were overfilled. These results indicated that this technique using d-PTFE membranes predictably provided stable regenerated bone volume. To achieve complete alveolar ridge reconstruction, three dimensional overfill is often required. This technique facilitates the overfilling because primary coverage is not required. Interestingly, the volume of bone loss corresponded approximately to the volume of overfill (0.9 mm total).

Conclusions: Non-expanded dense PTFE membranes predictably provided sufficient regenerated ridge suitable for implant placement. The open barrier membrane technique can be a new standard for alveolar ridge preservation and augmentation.

Zafropoulos GG, Kasaj A, Hoffmann O
 Immediate implant placement in fresh mandibular molar extraction socket: 8 year results. A case report. *J Oral Implantol* 2010;36(2):145-151.

Recently, the successful implant placement in fresh extraction sockets has been reported. In this case report, we present the results of an immediate implant placement in a fresh extraction socket of a mandibular molar with simultaneous bone regeneration using a non-resorbable membrane and no other graft materials. The clinical and radiographic findings that were measured eight years after the implant placement demonstrated a stable peri-implant situation and confirmed a satisfactory treatment result.

Zafropoulos GG, Deli G, Bartee BK, Hoffman O
 Single-tooth implant placement and loading in fresh and regenerated extraction sockets. Five-year results: A case series using two different implant designs. *J Periodontol* 2010;81:604-15.

Background: Implant-supported restorations are a commonly used treatment modality. However, insufficient data are available that compare treatment outcomes of implant restorations using different protocols. Similarly, data comparing the treatment outcomes of different implant designs are limited.

Methods: This retrospective, non-randomized study evaluates 241 single implants in 241 patients (127 males and 114 females; mean age: 49.3 years; range: 45 to 75 years). Tapered-type (TAP; n = 118) and cylindrical screw-type (CYL; n = 123) implants were used. Implants were grouped into the treatment categories of immediate placement, delayed placement, immediate non-occlusal loading, and delayed loading. Clinical parameters, including clinical attachment level (CAL), plaque index (PI), and bleeding on probing (BOP), were recorded at examinations at baseline (BSL) and 1 (E1), 3 (E3), and 5 years (E5) after loading with the final restoration.

Results: Eleven implants were lost (five CYL and six TAP). CAL and PI outcomes were similar for both implant types. No significant influence of implant position was found. A CAL loss of 1.5 mm was observed during the first 3 years. The type of implant and timing of placement showed no significant influence on the survival rate, whereas the failure rate was lower for immediate non-occlusal loaded implants.

Conclusion: The type of implant, position, and timing of placement and loading did not influence the survival rate of this treatment method.

Barboza EP, Stutz B, Ferreira VF; Carvalho W
 Guided bone regeneration using nonexpanded polytetrafluoroethylene membranes in preparation for dental implant placements – A report of 420 cases. *Implant Dent* 2010;19:2-7.
 The biologic principle of guided bone regeneration has been successfully used to prevent bone loss in extraction sites. This study comprises 420 cases of alveolar ridge maintenance in preparation for dental implant placements. Nonexpanded polytetrafluoroeth-

ylene membranes were positioned over all extraction sites and left intentionally exposed. Lyophilized mineralized bone allografts were used to prevent membrane collapse when buccal bone walls were lost. Membranes were removed at week 4. At the time of implant placements, all sites presented soft tissue compatibility with keratinized gingiva. The mucogingival junction position seemed to be preserved. Exposed nonexpanded polytetrafluoroethylene membranes associated, or not, with bone graft provide tissue formation suitable for implant placement.

Lee JY, Kim YK, Yun PY, Oh JS, Kim SG
 Guided bone regeneration using two types of non-resorbable barrier membranes. *J Korean Assoc Oral Maxillofac Surg* 2010;36:275-9.

Introduction: Guided bone regeneration (GBR) is a common procedure for the treatment of bone defects and bone augmentation. The nonresorbable barriers are well-documented barriers for GBR because of their stability and malleability. However, few GBR studies have focused on the different types of non-resorbable barriers. Therefore, this study examined the clinical results of different non-resorbable barriers for GBR; expanded polytetrafluoroethylene (e-PTFE) (TR-Gore Tex, Flagstaff, AZ, USA), and high-density polytetrafluoroethylene (d-PTFE) (Cytoplast membrane, Oraltronic, Bremen, Germany).

Materials and Methods: The analysis was performed on patients treated with GBR and implant placement from January 2007 to October 2007 in the department of the Seoul National University Bundang Hospital. The patients were divided into two groups based on the type of non-resorbable barrier used, and the amount of bone regeneration, marginal bone resorption after prosthetics, implant survival rate and surgical complication in both groups were evaluated.

Results: The implants in both groups showed high survival rates, and the implant-supported prostheses functioned stably during the follow-up period. During the second surgery of the implant, all horizontal defects were filled with new bone, and there was no significant difference in the amount of vertical bone defect.

Conclusion: In bone defect areas, GBR with non-resorbable barriers can produce favorable results with adequate postoperative management. There was no significant difference in bone regeneration between e-PTFE and d-PTFE

Park S-Y, Kye S-B, Yang S-M, Shin S-Y
 The effect of non-resorbable membrane on buccal bone healing at an immediate implant site: an experimental study in dogs. *Clin. Oral Impl. Res.* 22, 2011; 289-294. doi: 10.1111/j.1600-0501.2010.01995.x

Objective: For successful implant treatment in the esthetic area, stable hard tissue and soft tissue are very important. At the buccal side without buccal bone defects, prophylactic guided bone regeneration (GBR) with bone substitute was frequently used for achieving thick buccal bone. The aim of this study was to evaluate the effect of GBR using a non-resorbable membrane in an imme-

diate implant site without bone defects.

Material and methods: Immediate implants were placed into the mandibles of four mongrel dogs. In the experimental group (TM group), a non-resorbable membrane was placed and fixed onto the buccal bone plate around the implant. In the control group, the implants were placed without membrane coverage. After 12 weeks, the dogs were sacrificed and histological specimens were prepared. The vertical distances from the smooth-rough surface interface (SRI) to the gingiva, the first bone contact, and the bone crest were measured on the buccal and lingual sides. The horizontal thicknesses of the gingiva and bone at 0, 1, 2, and 3 mm below the SRI were measured.

Results: In the TM group, first-bone contact on the buccal side was more coronally positioned approximately 0.8 mm than the control group ($P = 0.041$). The buccal bone thickness of the TM group was well preserved and there was no difference between the buccal and lingual sides. Comparing the control group, implants of the TM group had 1 mm thicker buccal bone ($P = 0.0051$ at bone 1 mm level, $P = 0.002$ at bone 2 mm level). In the control group, buccal bone loss was observed and buccal bone was about 1 mm thinner than the lingual bone ($P < 0.05$).

Conclusion: GBR with a non-resorbable membrane and no bone graft substitute could help to preserve buccal bone thickness on the immediate implant site without defects.

Zafropoulos GG, Hoffmann O, Kasaj A, Willershausen B, Deli G, Tatakis DN
Mandibular molar root resection versus implant therapy: A retrospective nonrandomized study. *J Oral Implantol* 2009;35:52-62.

Success rates for both periodontal and implant therapy are often dependent on site and tooth type. For periodontally involved mandibular molars, the decision to hemisect or to extract and place an implant is often complicated. The purpose of the present study was to evaluate the outcomes of the aforementioned treatment modalities for mandibular molars in a private practice setting. A retrospective chart review was performed. In one group of patients ($n = 32$), 56 mandibular first or first and second molars were treated by hemisection (Group H). A second group ($n = 28$) received 36 implants in the mandible to replace periodontally involved first or first and second molars (Group I). All patients had been in maintenance for at least 4 years after treatment. The occurrence and timing of posttreatment complications were evaluated. Data were analyzed by parametric and nonparametric statistics, as indicated. The majority of hemisected teeth (68% of Group H) and implants (89% of Group I) remained free of complications for the entire observation period. Group H had a greater incidence of overall complications ($P = .027$) and nonsalvageable complications ($P = .013$) than Group I. For both groups, the percent CAL loss per year was greater for the teeth/implants that experienced complications than in those that remained complication free ($p < 0.015$). Within the limitations of this study, the results indicated that, in periodontitis patients, hemisected mandibular molars were more prone to complications than implants.

Fotek PD, Neiva RF, Wang HL
Comparison of dermal matrix and polytetrafluoroethylene membrane for socket bone augmentation: A clinical and histologic study.
J Periodontol 2009;80:776-785.

Background: Remodeling and resorption of the alveolar crest, specifically at the buccal aspect, characterize the healing extraction socket. These result in narrowing and shortening of the alveolar ridge, which compromise esthetics and complicate restoration. Alveolar ridge augmentation has been proposed to facilitate future site restoration by minimizing ridge resorption. Therefore, the purpose of this study was to compare extraction socket healing and alveolar ridge alteration after socket augmentation using bone allograft covered with an acellular dermal matrix (ADM) or polytetrafluoroethylene (PTFE) membrane.

Methods: Twenty non-smoking healthy subjects were selected. Each subject required maxillary premolar, canine, or central incisor tooth extraction. The extraction sites were debrided and grafted with a mineralized bone allograft that was covered with an ADM or PTFE membrane. Postoperative appointments were scheduled at 2, 4, and 8 weeks. After 16 weeks of healing, final measurements were performed, and trephine core biopsies were obtained for histomorphometric analysis. Implants were placed immediately after biopsy harvesting.

Results: Eighteen subjects completed the study. All sites healed without adverse events and allowed for implant placement. PTFE membranes exfoliated prematurely, with an average retention time of 16.6 days, whereas the ADM membranes appeared to be incorporated into the tissues. Buccal plate thickness loss was 0.44 and 0.3 mm, with a vertical loss of 1.1 and 0.25 mm, for ADM and PTFE, respectively. Bone quality assessment indicated D3 to be the most prevalent (61%). Histomorphometric analysis revealed 41.81% versus 47.36% bone, 58.19% versus 52.64% marrow/fibrous tissue, and 13.93% versus 14.73% particulate graft remaining for ADM and PTFE, respectively. No statistical difference was found between the two treatment groups for any of the parameters.

Conclusion: All sites evaluated showed minimal ridge alterations, with no statistical difference between the two treatment modalities with respect to bone composition and horizontal and vertical bone loss, indicating that both membranes are suitable for alveolar ridge augmentation.

Hoffman O, Bartee BK, Beaumont C, Kasaj A, Deli G, Zafropoulos GG
Alveolar bone preservation in extraction sockets using non-resorbable dPTFE membranes: A retrospective non-randomized study. *J Periodontol* 2008;79:1355-1369.

Background: The aim of this study was to investigate the clinical regeneration of extraction sockets using high-density polytetrafluoroethylene (dPTFE) membranes without the use of a graft material.

Methods: A total of 276 extraction sockets were evaluated in 276 subjects (151 males and 125 females; mean age, 50.2 years; age

range: 24 to 73 years). After extraction, flaps were elevated and a dPTFE membrane was placed over the extraction site. The flaps were repositioned and sutured into place. Primary closure was not obtained over the membranes. The cemento-enamel junctions of the adjacent teeth were used as reference points. Measurements were taken postextraction and 12 months after surgery in the same areas with the help of a stent and were defined as the distance from the reference points to the bone level. Hard tissue biopsies were taken from 10 representative cases during implant placement 12 months after socket preservation. The bone core samples were submitted for histologic evaluation. A stringent plaque-control regimen was enforced in all subjects during the 12-month observation period.

Results: A significant regeneration of the volume of sockets could be noted by histologic evaluation, indicating that the newly formed tissue in extraction sites was mainly bone. No influence of gender, smoking, age, or clinical bone level before treatment was found on the percentage of bone gain.

Conclusion: The use of dPTFE membranes predictably led to the preservation of soft and hard tissue in extraction sites.

Barber HD, Lignelli J, Smith BM, Bartee BK

Using a dense PTFE membrane without primary closure to achieve bone and tissue regeneration. *J Oral Maxillofac Surg* 2007;65:748-752.

The most common types of barrier membranes used for bone or tissue regeneration are made of expanded-polytetrafluoroethylene (e-PTFE) or resorbable materials, such as collagen. Both the e-PTFE and resorbable membranes require primary soft tissue coverage. This article explores the use of a dense-polytetrafluoroethylene (d-PTFE) membrane, which does not require primary soft tissue coverage. The advantages of d-PTFE in contrast to the other more commonly used types of barrier membranes and the clinical significance of these advantages for implant surgical and restorative treatment are discussed.

Walters SP, Greenwell H, Hill M, Drisko C, Pickman K, Scheetz JP
Comparison of porous and non-porous teflon membranes plus a xenograft in the treatment of vertical osseous defects: A clinical reentry study. *J Periodontol* 2003;74:1161-1168.

Background: The primary aim of this 9-month randomized, controlled, blinded, clinical reentry study was to compare the regenerative effects of a nonporous polytetrafluoroethylene (NP) periodontal membrane to a porous expanded polytetrafluoroethylene (P) periodontal membrane in the treatment of vertical osseous defects.

Methods: Twenty-four patients, 11 males and 13 females, age 24 to 74 (mean 50.5 ± 13.1) provided one site with an intraosseous defect ≥4 mm and were divided equally and randomly into two groups. Following debridement both groups were grafted with a bovine-derived xenograft coated with a synthetic cell-binding peptide; then the test group received an NP membrane and the control group received a P membrane. All defects were reentered

after 9 months. Measurements were performed by a masked examiner.

Results: There were no statistically significant differences ($P > 0.05$) between NP and P groups for any open or closed probing measurement at any time. Similar open initial defect depth for the NP group and P groups (4.8 versus 5.0 mm) demonstrated identical 9-month defect fill of 2.8 mm (57%) for both groups. A difference in crestal resorption for the NP compared to the P group (0.4 versus 0.8 mm) accounted for the difference in mean percent defect resolution, which was 67% for NP compared to 72% for the P group. Overall, nine (75%) of the NP group defects and eight (67%) of the P group defects showed more than 50% defect fill.

Conclusion: Treatment of vertical osseous defects with nonporous or porous polytetrafluoroethylene membranes in combination with a xenograft resulted in statistically significant improvement in open and closed probing measurements, with no significant difference between treatment groups.

Bartee BK

Extraction site reconstruction for alveolar ridge preservation Part 1: Rationale and material selection. *J Oral Implantol* 2001;27:187-193.

Alveolar ridge resorption has long been considered an unavoidable consequence of tooth extraction. While the extent and pattern of resorption is variable among individuals, there is a progressive loss of ridge contour as a result of physiologic bone remodeling. Over the long term, prosthodontic complications, loss of function, and inadequate bone for the placement of dental implants may result. Guided bone regeneration techniques and the use of bone replacement materials have both been shown to enhance socket healing and modify the resorption process. This review describes the process of alveolar bone loss, materials for extraction site grafting, and proposed mechanisms for ridge preservation.

Bartee BK

Extraction site reconstruction for alveolar ridge preservation Part 2: Membrane-assisted surgical technique. *J Oral Implantol* 2001;27:194-197.

Alveolar ridge resorption has long been considered an unavoidable consequence of tooth extraction. Guided bone regeneration techniques and the use of bone replacement materials have both been shown to enhance socket healing and to potentially modify the resorption process. This article will describe a surgical technique using textured, high-density polytetrafluoroethylene (PTFE) membrane and particulate bone replacement materials for graft containment and prevention of soft tissue ingrowth into healing extraction sites. The technique described does not require primary closure, facilitating the preservation of keratinized mucosa and gingival architecture.

Lamb JW III, Greenwell H, Drisko C, Henderson RD, Scheetz JP,

Rebitski G

A comparison of porous and non-porous teflon membranes plus demineralized freeze-dried bone allograft in the treatment of class II buccal/lingual furcation defects: A clinical reentry study. *J Periodontol* 2001;72:1580-1587.

Background: The aim of this 9-month reentry study was to compare the regenerative healing using porous (P) and non-porous (NP) teflon barrier membranes plus demineralized freeze dried bone allografts (DFDBA) in Class II buccal/lingual furcation defects.

Methods: Twenty-four patients, 13 males and 11 females, ages 38 to 75 (mean 54 +/- 10), were included in this study. Each patient had adult periodontitis and one Class II furcation defect measuring $>$ or $=$ 3 mm open horizontal probing depth. Twelve patients were randomly selected to receive the NP treatment and 12 received the P membrane. All defects received a DFDBA graft. Measurements were performed by a masked examiner.

Results: No statistically significant differences ($P > 0.05$) were found between NP and P groups at any time with respect to any open or closed measure. Improvement in mean open horizontal probing depth was significant for both the NP (2.33 +/- 0.78 mm) and P (2.75 +/- 0.75 mm) groups. Mean clinical attachment level gains at 9 months were significant for both NP (1.50 +/- 1.62 mm) and P (2.50 +/- 2.11 mm) groups. Seventeen of 24 defects had an intrabony component and $>$ or $=$ 50% fill was obtained in 100% of these defects.

Conclusions: The results of this 9-month reentry study comparing the use of porous and non-porous barrier membranes with a DFDBA graft indicate that there were no statistically significant differences between groups. Both groups showed a statistically significant improvement following the treatment of Class II furcation defects in humans.

Bartee BK

Evaluation of a new polytetrafluoroethylene guided tissue regeneration membrane in healing extraction sites. *Compend Contin Educ Dent* 1998;19:1256-1264.

The biological principles underlying guided tissue regeneration (GTR) are apparently well understood, and many of the molecular events involved in bone regeneration are being investigated. Much controversy exists, however, as to which membrane biomaterial is ideal for use in these procedures. Adding to the confusion, new applications of GTR membranes continue to evolve, such as extraction site reconstruction, implant site development, ridge augmentation, and the use of membranes in conjunction with the placement of dental implants. These innovative techniques place demands on the membrane that were unforeseen when the first generation of devices was developed. The present study suggests that the ideal design characteristics of a barrier membrane, such as pore size and polymer type, may depend on the intended use of the membrane, and are not fixed criteria that should be applied to all membrane devices. This article describes the clinical results in a series of case

studies using a high-density, microporous polytetrafluoroethylene membrane (Cytoplast Regentex GBR-200a). To evaluate the clinical efficacy of this membrane and technique, clinical and histological evaluations of the regenerated tissue are presented.

Bartee BK

The use of high-density polytetrafluoroethylene membrane to treat osseous defects: Clinical reports. *Implant Dent* 1995;4:21-26.

Alveolar bone resorption can result from tooth loss, periodontal disease, or trauma. Guided tissue regeneration is used in an attempt to exclude tissues devoid of osteogenic potential from a bone defect or cavity and promote new bone growth to replace missing osseous structure. Many types of barrier membranes have been used, but none have been found to be ideal for every clinical situation. Macroporous membranes, such as expanded polytetrafluoroethylene, require primary closure and a second surgical procedure for their removal. Macroporous membranes can incorporate bacteria and may become infected if exposed in the oral cavity. Membranes manufactured of resorbable polymers require primary closure of the augmentation site and exhibit variable patterns of resorption, introducing a degree of unpredictability into the procedure. The use of high-density polytetrafluoroethylene membrane to promote deposition of bone for ridge augmentation in the oral cavity is described. Two clinical reports are presented.

Basic Science: Dense PTFE Membrane

Crump TB, Rivera-Hidalgo F, Harrison JW, Williams FE, Guo IY
Influence of three membrane types on healing of bone defects. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 1996;82(4):365-74. Department of Periodontics, Baylor College of Dentistry, Dallas, Tx., USA.

Objectives: To determine and compare osseous regeneration associated with three guided tissue regeneration membrane types (expanded polytetrafluoroethylene, dense polytetrafluoroethylene, and an absorbable polylactic acid/citric acid ester base) and removal forces required for expanded and dense polytetrafluoroethylene membranes.

Study Design: Bilateral osseous defects were created in 30 adult rat calvaria; one defect was covered with a test membrane and the other received no membrane (control). After 2 or 4 weeks, forces required for membrane removal from the tissues were electronically determined, and the calvaria removed and decalcified. Sections through the defects were stained and evaluated electronically and microscopically. Data were analyzed statistically.

Results: Microscopic evaluation with Mann-Whitney U test revealed that dense polytetrafluoroethylene was associated with significantly greater bone formation than expanded polytetrafluoroethylene ($p = 0.02$) at 2 weeks and absorbable polylactic acid/citric acid ester base ($p = 0.004$) at 4 weeks. Electronic evaluation of the linear degree of fill with one way ANOVA and Tukey's test

found no significant difference ($p > 0.05$) among the experimental or the control groups. In addition, the Mann-Whitney U test indicated that removal forces required for dense polytetrafluoroethylene were significantly less than for expanded polytetrafluoroethylene ($p = 0.003$).

Conclusions: The use of dense polytetrafluoroethylene as a membrane barrier deserves further investigation as it allows osseous regeneration, it is easier to remove from healing soft tissues, and it is inexpensive. A study with larger sample sizes should be conducted.

Bartee BK, Carr JA

Evaluation of a high-density polytetrafluoroethylene (n-PTFE) membrane as a barrier material to facilitate guided bone regeneration in the rat mandible. *J Oral Implantol* 1995;21:88-95.

The purpose of this investigation was to evaluate the use of high-density polytetrafluoroethylene (n-PTFE) membranes to facilitate guided tissue regeneration (GTR) in the rat. The concept of guided tissue regeneration is based on the hypothesis that if the non-osteogenic connective tissue cells are mechanically blocked from entering a bone defect, selective re-population of the defect by osteoblasts will occur. Bilateral through-and-through defects of critical size were created in the mandibular angle of 12 rats. The experimental side was covered on both the medial and lateral aspects of the mandible with high-density n-PTFE membrane, with the opposite side serving as a control. Histological analysis revealed osteogenic tissue completely bridging the defect by two weeks. After six weeks of healing, osteogenic repair was observed at the margins of the defects, with islands of woven bone seen in the central areas. After 10 weeks of healing, complete ossification was observed on the n-PTFE-treated side. The control defects exhibited very little osseous regeneration, and rounding of the defect margins was observed after 10 weeks of healing. These results indicate that high-density n-PTFE can serve effectively as a guided tissue regeneration barrier in certain bone defects.

Allograft References

Borg TD, Mealey BL.

Histologic healing following tooth extraction with ridge preservation using mineralized versus combined mineralized-demineralized freeze-dried bone allograft: a randomized controlled clinical trial. *J Periodontol*. 2015 Mar;86(3):348-55.

Background: Mineralized and demineralized freeze-dried bone allografts (FDBAs) are used in alveolar ridge (AR) preservation; however, each material has advantages and disadvantages. Combinations of allografts aimed at capitalizing on the advantages each offers are available. To date, there is no evidence to indicate if a combination allograft is superior in this application. The primary objective of this study is to histologically evaluate and compare healing of non-molar extraction sites grafted with either mineralized FDA or a 70:30 mineralized:demineralized FDA combina-

tion allograft in AR preservation. The secondary objective is to compare dimensional changes in ridge height and width after grafting with these two materials.

Methods: Forty-two patients randomized into two equal groups received ridge preservation with either 100% mineralized FDA (active control group) or the combination 70% mineralized: 30% demineralized allograft (test group). Sites were allowed to heal for 18 to 20 weeks, at which time core biopsies were obtained and dental implants were placed. AR dimensions were evaluated at the time of extraction and at implant placement, including change in ridge width and change in buccal and lingual ridge height. Histomorphometric analysis was performed to determine percentage of vital bone, residual graft, and connective tissue/other non-bone components.

Results: There was no significant difference between groups in AR dimensional changes. Combination allograft produced increased vital bone percentage (36.16%) compared to the FDA group (24.69%; $P = 0.0116$). The combination allograft also had a significantly lower mean percentage of residual graft particles (18.24%) compared to FDA (27.04%; $P = 0.0350$).

Conclusions: This study provides the first histologic evidence showing greater new bone formation with a combination mineralized/demineralized allograft compared to 100% mineralized FDA in AR preservation in humans. Combination allograft results in increased vital bone formation while providing similar dimensional stability of the AR compared to FDA alone in AR preservation.

Suture References

Silverstein LH, Kurtzman GM, Shatz PC

Suturing for optimal soft-tissue management. *J Oral Implantol* 2009;35:82-90.

For optimal postsurgical wound healing, non-tension primary wound closure of various soft tissue flaps must be established. Surgical procedures that require clinical flap manipulation (such as those used with traditional periodontal therapy, periodontal plastic cosmetic surgery, hard and soft tissue regeneration, and the excision of pathologic tissue) also require excellent execution and a thorough understanding of the various techniques of surgery, suturing, and the materials currently available for the desired clinical results. This article discusses the rationale behind specific suturing techniques and suture materials to aid the clinician with optimal wound closure.

Silverstein LH

Suturing principles: Preserving needle edges during dental suturing. *PPAD* 2005;17:562-564.

The evolution of suture materials has presented today's clinician with numerous alternatives when performing dental suturing. Contemporary sutures not only eliminate some of the difficulties that the surgeon may have encountered previously during closure,

but also decrease the potential of postoperative infection and help provide optimal healing. Despite the sophistication of the suture materials (ie, Perma Sharp, Hu-Friedy, Chicago, IL) and surgical techniques now available, closing a wound still involves the same essential procedure used by physicians who tended to the Roman emperors. The practitioner still utilizes a surgical needle to pull the suture strand as it is placed within the tissue.

Bone Scraper References

Trombelli L, Farina R, Marzola A, Itró A, Calura G
GBR and autogenous cortical bone particulate by bone scraper for alveolar ridge augmentation: A 2 case report. *Int J Oral Maxillofac Implants* 2008;23:111-116.

Scientific literature describes autogenous bone as the gold standard among graft materials for alveolar reconstructive procedures. Alveolar ridge augmentation has been clinically achieved with different forms of autogenous bone, including autogenous cortical bone particulate (ACBP). However, few histologic studies demonstrating the biologic potential and healing dynamics following the use of ACBP are currently available. This case report presents 2 patients in whom atrophic edentulous alveolar crests were submitted to a vertical/lateral ridge augmentation prior to implant placement. The technique was performed through the use of a titanium-reinforced expanded polytetrafluoroethylene (e-PTFE) membrane with an ACBP graft obtained from the retromolar region with a specially designed bone scraper. Bone biopsy specimens were harvested at 9 months after graft placement. Analysis of the reconstructed bone revealed bone with a lamellar quality characterized by a mature osteonic structure. Sparse particles of grafted bone were evident in direct contact with the regenerated bone. Marrow spaces showed a normal stromal component with limited grafted particles.

Zaffe D, D'Avenia F

A novel bone scraper for intraoral harvesting: A device for filling small bone defects. *Clin Oral Implants Res* 2007;18:525-533.

Aim: To evaluate histologically the morphology and characteristics of bone chips harvested intraorally by Safescraper, a specially designed cortical bone collector.

Material And Methods: Bone chips harvested near a bone defect or in other intraoral sites were grafted into a post-extractive socket or applied in procedures for maxillary sinus floor augmentation or guided bone regeneration. Core biopsies were performed at implant insertion. Undecalcified specimens embedded in PMMA were studied by histology, histochemistry and SEM.

Results: Intraoral harvesting by Safescraper provided a simple, clinically effective regenerative procedure with low morbidity for collecting cortical bone chips (0.9-1.7 mm in length, roughly 100 µm thick). Chips had an oblong or quadrangular shape and contained live osteocytes (mean viability: 45-72%). Bone chip grafting

produced newly formed bone tissue suitable for implant insertion. Trabecular bone volume measured on biopsies decreased with time (from 45-55% to 23%). Grafted chips made up 50% or less of the calcified tissue in biopsies. Biopsies presented remodeling activities, new bone formation by apposition and live osteocytes (35% or higher).

Discussion And Conclusions: In conclusion, Safescraper is capable of collecting adequate amounts of cortical bone chips from different intraoral sites. The procedure is effective for treating alveolar defects for endosseous implant insertion and provides good healing of small bone defects after grafting with bone chips. The study indicates that Safescraper is a very useful device for in-office bone harvesting procedures in routine peri-implant bone regeneration.

Al-Sebaei MO, Papageorge MB, Woo T

Technique for in-office cranial bone harvesting. *J Oral Maxillofac Surg* 2004;62(suppl 2):120-122.

Purpose: This is a report of a technique of cranial bone harvesting suitable for the outpatient setting.

Materials And Methods: Bone scrapers are used for the harvesting of cranial bone shavings with the patient under intravenous sedation or general anesthesia.

Results: Graft volumes larger than that usually obtainable from intraoral sites and the tibia have been harvested utilizing this technique. In a series of 8 first patients, the largest volume of bone obtained was 14 cc with no complications related to the donor sites. These cases include the following types of pre-implant reconstructive procedures: large unilateral sinus grafting, bilateral sinus grafting/guided-bone regeneration of an entire alveolar ridge, inlay grafting of the alveolus, inlay grafting in association with distraction osteogenesis, subnasal grafting, alveolar cleft grafting, closure of large oroantral defects combined with sinus grafting, and grafting of a grossly atrophic mandible with simultaneous placement of dental implants via the submental approach.

Conclusion: This is a safe bone harvesting technique providing an alternative source of autogenous bone graft. ■



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