

EXTRACTION SITE RECONSTRUCTION FOR ALVEOLAR RIDGE PRESERVATION. PART 1: RATIONALE AND MATERIALS SELECTION

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KEY WORDS

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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.

INTRODUCTION—THE PROBLEM OF EDENTULOUS BONE LOSS

Alveolar ridge resorption is a phenomenon observed following the removal of teeth in an otherwise healthy individual. The condition appears to be progressive and irreversible, resulting in a host of prosthodontic, esthetic, and functional problems. Post-extraction bone loss is accelerated in the first 6 months, followed by a gradual modeling (change in size or shape) and remodeling (turnover of existing bone) of the remaining bone, with as much as 40% of the alveolar height and 60% of alveolar width lost in the first 6 months.¹ Loss of ridge height results in prosthetic instability as the crest of the ridge approaches muscle attachments and mobile mucosa. In extreme cases, there may be involvement of the

maxillary sinus or nasal cavity, requiring extensive reconstructive surgery for traditional or implant-supported prosthetics. Vital structures, such as the mandibular neurovascular bundle, may become vulnerable due to exposure and impingement of the overlying denture.² In the horizontal plane, bone loss occurs largely at the expense of the buccal or facial bone.³ Ultimately, esthetic tooth replacement with implants is complicated by loss of tissue contours.⁴⁻⁶

There was little concern about ridge resorption until the latter part of the 20th century. Initial efforts to determine the etiology and prevent ridge resorption focused on prosthetic techniques and patterns of denture wear.^{7,8} In the 1970s the development of knife-edge mandibular ridges was attributed

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to ill-fitting dentures and methods proposed for prevention of ridge resorption included frequent modification of the prosthesis to compensate.⁹ Surgical treatment included sulcus extension, nerve repositioning, and skin grafting of resorbed ridges. The concept of vital root retention was proposed based on the observation that bone resorption did not occur around retained teeth, but this was later abandoned due to soft tissue complications.^{10,11} Using a similar concept in the 1980s, ridge preservation was done using hydroxylapatite (HA) in the form of root-shaped cones and particles placed into extraction sites.^{12,13} Current methods used to prevent ridge resorption include placement of particulate autografts, allografts, alloplasts, and xenografts.¹⁴⁻²⁰ These biomaterials present advantages and disadvantages and, depending on their structure and biochemical composition, may be resorbable or nonresorbable. With the advent of endosseous implants, ridge preservation techniques now appear to have a dual focus, with implant site development being the latest area of interest.

An estimated 20 million teeth are extracted in the United States each year, with 40% of the population over age 60 having 1 or more edentulous sites.²¹ Many of these patients will suffer prosthetic complications or require extensive reconstructive surgery due to edentulous bone loss. Unfortunately, ridge preservation has not advanced to the standard of care, with most extractions performed in the traditional fashion. In 1998, the US market for bone replacement materials, including alloplasts, xenografts, and human allografts, was approximately \$25 million (Source: US Markets for Dental Implants and Dental Bone Substitutes, Medical Data International, July 1999). Assuming 50% of these materials were placed into extraction sites at an average cost of \$100/cm³, and with a volume of 0.25 cm³ per extraction site, it would appear that only 500,000 sites, or 2.5% of extraction sites, were treated

with ridge preservation techniques. This is equivalent to the number of root form implants placed in 1998.

First attributed to disuse atrophy, it is now apparent that alveolar ridge resorption is a complex process involving structural, functional, and physiologic components. Surgical trauma from tooth extraction induces microtrauma to surrounding bone, which may accelerate bone remodeling.²² Anatomic features, such as facial morphology, have been suggested to play a role. Age and sex are believed to have an effect on the extent and timing of ridge resorption, with females tending to form knife-edge residual ridges.^{23,24} Systemic conditions such as osteoporosis, renal disease, and vascular and endocrine disorders may accelerate alveolar bone loss by altering normal bone physiology and metabolism.²⁵⁻²⁷ Functional forces such as bruxism, complete denture wear, and heavy bite forces have been implicated as contributing factors in accelerated bone loss.^{28,29} Presently, the molecular events in the bone remodeling process are being studied in order to arrive at a more complete understanding of this disorder.³⁰

Observation of the dentoalveolar complex in a state of health reveals a dynamic, interdependent system of tooth roots, periodontal attachment, and bone, vascular, and cellular elements. It is well accepted that bone is maintained in a state of health by the constant compressive and tensile forces transmitted by the tooth roots. These forces, according to Wolff's law, cause a distinctive pattern of bone formation and maintenance along lines of stress. Structural changes in the bone occur through cellular processes of osteoclastic resorption and osteoblastic deposition of collagen and subsequent mineralization of the collagen matrix. Ultimately, it is by modification of these mechanical, cellular, and molecular events that ridge preservation may be achieved following the loss of teeth.

DEVELOPMENT OF EXTRACTION-SITE GRAFTING PROCEDURES

Numerous animal and clinical studies validate the concept of ridge preservation by the placement of alloplasts into fresh extraction sites. Quinn and Kent,¹² in a study of hydroxylapatite (HA) implants placed in baboon jaws, concluded that maximum preservation of ridge form requires immediate graft placement following tooth extraction. Bell³¹ reported in a clinical study of HA cones and particles that the implantation of particles was associated with fewer intraoperative and postoperative complications and was the preferred method of ridge preservation.³¹

The routine use of HA cones for ridge preservation has not seen widespread clinical acceptance, however. Human trials conducted at several centers in the 1980s using HA cones demonstrated that the technique was fraught with postoperative problems. Most of these problems relate to the problem of maintaining adequate soft tissue closure over the grafts.³²⁻³⁵

SELECTION OF GRAFT MATERIALS

Generally, materials available for the placement into extraction sites are considered either nonresorbable or resorbable. Actually, even the nonresorbable materials undergo some physiochemical dissolution. However, for the purposes of this presentation, nonresorbable materials will be discussed in the context of long-term ridge preservation. The nonresorbable materials are not suitable for placement into sites that may later receive dental implants.

There is a group of materials marketed as being resorbable but more accurately may be considered as transitional bone grafting materials. For practical purposes, these materials may be considered useful for increasing bone density and for medium-term ridge preservation. They are especially useful as adjuncts in guided tissue regeneration around teeth and implant site development. The most important feature of these materials is the ability

to place endosseous implants into the grafted site, even in the presence of some unresorbed particles.

Finally, a third group of materials may be considered short-term resorbable materials because they are readily resorbed and replaced by host tissue over the typical healing period. Similar in use to the transitional materials, they may increase bone density, prevent early ridge resorption, and facilitate the placement of dental implants. Due to the more rapid turnover of these materials, they should be selected when implant placement will be done within 3 to 6 months, before significant ridge resorption takes place.

MATERIALS FOR LONG-TERM RIDGE PRESERVATION

Synthetic HA is a calcium phosphate material that varies in density, structure, and surface chemistry. These variables, determined by the HA source and manufacturing process, affect the bone bonding characteristics and longevity of the material in situ.³⁶ Particulate, dense HA (Calcitite®, Sulzer Calcitek, Carlsbad, Calif; OsteoGraf®/D, CeraMed Dental Products, LLC, Lakewood, Colo.) is a proven material for long-term ridge preservation.^{13,14,31,37} Upon implantation, the material bonds to adjacent bone via natural apatite deposition on its surface and interaction with host cells. Particles placed in sites remote from adjacent bone (more than a few millimeters) usually are surrounded by a dense fibrous tissue matrix. Due to their high modulus of elasticity and limited osteoconductive activity, these materials are not suitable for placement into sites where implants are planned. However, these same characteristics make them excellent for long-term ridge maintenance.

Porous coralline HA (Interpore/rm 200, Nobel Biocare, Yorba Linda, Calif), sourced from sea coral and treated by a hydrothermal process, is useful for long-term ridge preservation. This material is essentially a dense HA structure with interconnect-

ing pores that allow bone and soft tissue ingrowth within the particle.^{38,39}

Bioactive glass (Bioglass®, US Biomaterials Corporation, Baltimore, Md) materials are suitable for long-term ridge preservation but may be more expensive than dense HA. Following implantation, a silica gel forms on the particle surface, which is subsequently mineralized with apatite crystals, providing a bridge to host bone. Similar to dense HA, these materials are osteoconductive and are believed to be more or less resorbable, depending on particle size.^{15,40} Bioglass materials of small particle size distribution are claimed to be osteoconductive and resorbable¹⁹ (Biogran®, Implant Innovations Inc, Palm Beach Gardens, Fla; Perioglass®, Block Drug Inc, Jersey City, NJ).

Porous polymethyl methacrylate (PMMA) beads have also been used for ridge preservation¹⁶ and treatment of local periodontal defects (Bioplant HTR®, Septodont, Inc, New Castle, Del). This material is reported to serve as a scaffold for new bone formation when in close contact with alveolar bone but otherwise may be surrounded by connective tissue. In one case report, unresorbed particles were observed 30 months following implantation, indicating potential as a long-term ridge preservation material.⁴¹

MATERIALS FOR TRANSITIONAL RIDGE PRESERVATION

Often, patients may decline implant therapy at the time of tooth loss but express a desire to possibly have implants at a later date. Transitional ridge grafting provides a means to preserve bone mass, allowing the future placement of endosseous dental implants. Increased bone density may result as well. It is well known that certain areas, such as the posterior maxilla, heal with an increased pattern of trabeculation,⁵ and the placement of osteoconductive materials into these sites has been shown to increase bone density.⁴² In addition, the placement of a transitional ridge preservation material improves the interim prosthetic result by

preserving ridge contour. There are three primary goals of transitional ridge preservation: (1) modulation of early-stage ridge resorption, (2) increased bone density, and (3) facilitation of future dental implant surgery.

Transitional ridge preservation requires careful selection of grafting materials and a complete understanding of their fate. If the wrong ridge preservation material is placed (ie, dense HA), it may have to be removed in order to place implants or may prevent implant placement altogether.⁴³ Material for transitional ridge preservation includes anorganic bovine bone matrix (ABM), resorbable calcium phosphate ceramics, and macroporous bioactive glass.

Anorganic bovine bone is currently available in 2 forms: one is processed by heat to remove organic components (OsteoGraf®/N, CeraMed) of the bone and the other uses a chemical process (Bio-Oss, Osteohealth Co, Shirley, NY). Anorganic bovine bone matrix, as a naturally derived product, maintains a similar crystalline structure, porosity, and carbonate content as human bone mineral and, due to the similarity to native bone structure, is claimed to provide a more physiologic osteoconductive environment.^{44,45} Anorganic bovine bone matrix should be considered to be a slowly resorbing material, however. Histological examination of chemically deorganified ABM implants reveals the presences of intact particles from 44 to 60 months postimplantation.^{42,46} Further, the efficacy of chemical deorganification has recently been questioned. A report by Artzi and Nemcovsky⁴⁷ histologically revealed the presence of amorphous protein within the ABM particles, believed to be of bovine origin. A comparative study of the methods for protein extraction in xenografts revealed elevated residual carbon (10× higher), elevated residual nitrogen (8× higher), and lower bioactivity (10× lower) of chemically extracted ABM compared with heat-treated ABM (Tofe A, Sogal A, Hanks T; unpublished data, June 1998).

Synthetic resorbable materials are available in several forms. Among them are microporous resorbable HA (OsteoGraf®/LD, CeraMed), microcrystalline, nonceramic resorbable HA (OsteoGen®, Implants Ltd, Holliswood, NY), and Beta-tricalcium phosphate (B-TCP, Augmen®, Miter Inc, Warsaw, Ind). While they are chemically similar to bone, they differ from ABM in crystalline structure, carbonate content, and porosity and resorb primarily through physiochemical dissolution and fragmentation.⁴⁴ By providing an osteoconductive lattice and a mineral source, these materials are believed to increase bone density. The use of any of these materials alone will require from 4 to 12 months for significant graft turnover and bone formation to occur. In large defects, even longer periods may be required for mature bone formation.

Due to the eventual resorption and replacement of these materials by host bone, the duration of ridge preservation cannot be accurately predicted. A reasonable time frame for most sites, in the author's experience, would be from 3 to 5 years. After that time, physiologic bone remodeling may ultimately cause the grafted ridge to assume its natural state, albeit at a slower pace than if untreated. More studies are indicated in this area to determine the long-term effects of the slowly resorbable bone replacement materials.

MATERIALS FOR SHORT-TERM RIDGE PRESERVATION

The objective of short-term ridge preservation is to maintain bone mass during the initial healing stage in preparation for dental implants—over a 3 to 6 month period. Typically, demineralized freeze-dried bone allograft (DFDBA) or autogenous bone is combined with a low-density HA, TCP, or ABM product in a 50:50 or 75:25 ratio. The function of this composite graft is to provide a synergistic scaffolding for new bone formation to take place. The DFDBA or autogenous bone used alone has not been shown to significantly in-

crease bone density in extraction sites,^{48,49} probably due to its rapid turnover time. The addition of the calcium phosphate increases the turnover time and provides a ready mineral source, enhancing the osteoinductive properties of DFDBA or osteogenic properties of autogenous bone.⁵⁰ This technique results in near total ridge preservation, providing a smooth, dense, and anatomically pleasing implant site. By contrast, untreated extraction sites, on reentry to place implants within 6 months, often contain fibrous tissue that must be removed and present an irregular surface for placing implants.

MECHANISM OF RIDGE PRESERVATION

While there is little doubt regarding the benefits of alveolar ridge preservation, the exact mechanism has not been fully explained in the literature. Alveolar bone resorption and socket repair involve a complex cascade of events. Likewise, any successful ridge preservation technique is likely to have multiple mechanisms of action. Based on the current understanding of bone-implant interactions, several key concepts emerge for consideration.

Biomechanical stimulation

Multiple authors have suggested that the grafting of extraction sites provides physiologic and bioelectric stimulation of the adjacent bone via attachment and load transmission during normal jaw function.⁵¹⁻⁵³ Under a conventional prosthesis, compressive, shear, and tensile forces are transmitted to the grafted ridge by direct pressure from the prosthesis. Conceivably, the random orientation of a particulate graft could transmit this load from particle to particle and from particle to bone in a manner similar to the periodontal apparatus of a natural tooth. Elevated remodeling activity in adjacent bone may result from mismatch in elastic modulus between graft material and bone,²² resulting in increased bone density. Finite element modeling of the human mandible indicates substantial bending moments and tensile strains

in dynamic loading.⁵⁴ Thus, indirect forces on the bone-graft interface may contribute to bone preservation if these forces are within the physiologic range.

Wound isolation and scaffolding effect

Bone formation in extraction sites proceeds in an apical to coronal fashion along a dense network of collagen fibers. At 6 weeks, the socket is approximately two thirds filled with new bone.^{55,56} Soft tissue proliferation and invagination result in a convex bone defect, with the bone fill somewhat below the level of the alveolar crest. Modeling of the alveolar crest follows, resulting in the high rate of bone loss seen in the first few months following extraction.

The principles of guided tissue regeneration appear to be applicable to socket healing. Wound isolation by means of an occlusive membrane has been demonstrated to prevent invagination of the aggressive oral epithelium into the healing socket, favoring the repopulation of the socket with cells with bone regenerating potential and leading to more complete bone fill.^{57,58} Isolation of the underlying tissue may also concentrate growth factors and cellular elements necessary for healing.

Osteoconduction is the process where the presence of a material promotes a bone healing response throughout a defined volume. The presence of a bioactive framework or scaffold allows bone formation to be distributed more efficiently within a given space,⁵⁹ in this case, an extraction site. In particular, anorganic bovine bone has been shown to support osteoblastic cell attachment and proliferation.⁶⁰ Thus, the combination of membrane isolation and an osteoconductive implant material facilitates complete bone fill in the socket.

Modification of cellular activity

The implantation of a bioactive substance evokes a cellular response from the adjacent tissues. Whether this response is destructive or reparative in

nature depends on the physiochemical, structural, and surface characteristics of the implant. The host response is mediated by molecular cell signaling processes that modulate extracellular or intracellular events. The presence of particulate graft materials may modify the remodeling process by these molecular mechanisms. For example, by effecting a change in the closely coupled remodeling sequence, ie, decreasing the cellular resorptive phase by osteoclast inhibition⁵⁷ or increasing formation phase by osteoblastic stimulation, increased bone density could result. A current approach to modifying cellular behavior is to exploit the normal physiologic mechanisms of cell proliferation and migration through the use of biomimetic techniques. For example, the addition of a specific cell-binding domain of type 1 collagen (P-15) to anorganic bovine bone increases cellular attachment and doubles the amount of DNA and protein synthesis of human fibroblasts in vitro.^{61,62} A subsequent clinical study of ABM/P-15 demonstrated superior results when compared with DFDBA alone in human osseous periodontal defects.⁶³ These techniques not only offer insight into the mechanism of action of current materials but offer promise in developing biomaterials with enhanced bioactivity.

A NEW STANDARD OF CARE?

Ridge resorption is a significant disorder, and there are methods available for its prevention. What then prevents this form of extraction therapy becoming the standard of care? Apparently, there are 3 major areas of concern: (1) issues of time, cost, and reimbursement, (2) uncertainty by dentists about which materials to use, and (3) lack of a standardized and predictable technique.

The cost/benefit issue needs to be examined closely. The average extraction site can be grafted with as little as \$30 to \$40 in materials and 1/3 hour of treatment time. When the benefits of preservation are explained and com-

pared with the devastating effects of ridge resorption, the majority of patients, if they are able to afford even routine restorative care, will opt for ridge preservation. Third-party reimbursement for bone regeneration is frequently available and is included in the current CDT-3/2000 insurance codes.

Advances in the field of bone replacement materials have led to the development of a host of similar materials, all of which claim superiority over competing products. An increasing number of products inevitably leads to confusion and uncertainty about material selection. For this reason, despite their interest, the majority of general dentists choose to avoid bone replacement in their practices or referral for the procedure due to fear of the unknown.

Similarly, the majority of surgical specialists do not routinely graft extraction sites. While reasons vary, procedural difficulty and the additional time required for patient education and surgery are common objections. Dental specialists are accustomed to having the need for their services explained, to some degree, in advance by the referring doctor. If ridge preservation is not included in the reason for the referral, they may be reluctant to offer this service. In addition, the lack of standardized protocols and lack of long-term data on ridge preservation materials prevents some specialists from performing this procedure on a routine basis.

CONCLUSION

The prevention of ridge resorption using particulate grafting materials is predictable, convenient, and available at a reasonable cost. With the introduction of membrane techniques, results are enhanced by providing containment of the graft particles and preservation of soft tissue contours. Ridge preservation may be long term or transitional depending on the physicochemical properties of the material placed into the sockets. Prosthodontic results are substantially improved and

bone mass may be preserved for the subsequent placement of dental implants. Further studies are needed to evaluate the long-term effects of ridge preservation materials and to develop standardized protocols for their use. Educational efforts should be developed by implantologists, surgical specialists, and academic training programs to increase awareness, develop referral patterns, and encourage widespread use of this modality.

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