CHAPTER 9. SURGICAL THERAPY

Section 1. General Principles

DEFINITIONS

Surgery: That branch of medical science concerned with the treatment of diseases or injuries by means of manual or operative methods.

Periodontal Surgery: Any surgical procedure used to treat periodontal disease or to modify the morphology of the periodontium.

GOAL OF PERIODONTAL SURGICAL THERAPY

To restore health and function to the periodontium and to preserve teeth for a lifetime (Kakehashi and Parakkal, 1982).

INDICATIONS FOR PERIODONTAL SURGICAL THERAPY

Indications for periodontal surgical therapy may include the following (Barrington, 1981):

1. Access for root debridement;
2. Elimination of pockets by removal and/or recontouring of soft or osseous tissues;
3. Removal of diseased periodontal tissues creating a favorable environment for new attachment and/or readaptation of soft and/or osseous tissues;
4. Correction of mucogingival deficiencies or defects (e.g., root coverage, increase zone of keratinized tissue, ridge augmentation);
5. Establishment of tissue contours that facilitate oral hygiene maintenance;
6. Establishment of esthetics by reducing soft tissue sites of enlargement-overgrowth or by augmenting sites with soft and/or hard tissue deficiencies;
7. Creation of a favorable restorative environment;
8. Establishment of drainage or emergent periodontal problems (e.g., gingival or periodontal abscess);
9. Determining or improving treatment prognosis (including exploratory procedures;
10. Biopsy and diagnosis; and
11. Regenerative procedures.

ANATOMIC CONSIDERATIONS IN PERIODONTAL THERAPY

Osseous Structures

The maxilla may be described as a "hollow bony box" consisting of the following four processes: 1) frontal; 2) zygomatic; 3) palatal; and 4) alveolar. The maxillary sinus occupies the entire body of the maxilla and may extend into the zygomatic and alveolar processes. This may be clinically significant since no medullary component may exist between the cortical bone investing the teeth and the sinus proper. The sinus may also extend into edentulous areas (pneumatization). The bony crest on the lateral surface of the maxilla is termed the zygomaticoalveolar crest. This bony ridge determines vestibular height in the maxillary molar region. Palatal tori may be present at the midline of the hard palate while smaller exostoses are frequently observed over the palatal roots of the molars (Clarke and Bueltman, 1971).

The mandible is a horseshoe-shaped bone which is grossly characterized by the mental protuberance, body, and ramus. It contains paired foramina (F) per side (inferior alveolar F; mental F) which transmit neural/vascular structures, bearing the same names. Other important landmarks include the mylohyoid ridge, genial tubercles, temporal crests, alveolar processes, and external oblique ridges (Clarke and Bueltman, 1971).

Vascular Supply

The vascular supply of the periodontium originates from branches of the external carotid artery. The main branches which supply structures in the oral cavity are the lingual, facial, and maxillary arteries. The inferior alveolar and greater palatine arteries are branches of the maxillary artery (Clarke and Bueltman, 1971).

The blood supply of the gingiva is derived primarily from supraperiosteal vessels which represent terminal afferent branches of the following arteries: 1) sublingual; 2) mental; 3) buccal; 4) facial; 5) greater palatine; 6) infraorbital; and 7) the posterior superior dental. These vessels anastomose with those supplying the alveolar bone and periodontal ligament. Prior to entering the apical foramina respective dental arteries (branches of superior or inferior alveolar dental artery) are the originating sites of the intraseptal arteries. Coursing coronally, these alveolar vessels provide numerous lateral/terminal branches (rami perforantes) which traverse the lamina dura at all levels, anastomosing with vessels in the periodontal ligament (PDL) space which also originate apically. The PDL vessels derive apically from the dental artery (previously described) and rami perforantes coursing into the PDL space forming a circumferential net. A plexus of vessels with numerous venules (dento-gingival plexus) is located beneath the junctional epithelium; in health, capillary loops are not found in this plexus. In contrast, the subepithelial plexus of the free and attached gingiva manifest capillary loops (7 μm) which supply individual connective tissue papilla. While a basic understanding of the periodontal vasculature is facilitated by reviewing individual anatomic sources, this unit

actually represents a functional vascular syncytium which significantly impacts the technical provision of periodontal therapy (Klaus et al., 1989; Schluger et al., 1990).

Innervation

The oral cavity is innervated primarily by branches of the trigeminal nerve (5th cranial nerve [CN]). The sensory portion supplies the skin of the face, oral mucous membranes, and the teeth. The motor portion supplies the 4 paired muscles of mastication, and the mylohyoid and digastric muscles. The maxillary (second) division of the trigeminal nerve sends anterior, middle, and posterior superior branches to the maxillary teeth. The infraorbital, nasopalatine and the greater palatine nerves supply sensation to areas of skin and mucous membrane. The mandibular (third) division branches are the buccal, lingual, inferior alveolar, and mylohyoid nerves. The terminal branches of the inferior alveolar nerve are the mental and incisive nerves (Clarke and Bueltman, 1971).

Musculature

The four primary muscles of mastication are innervated by the mandibular division of the trigeminal nerve. The primary function of the temporalis, medial pterygoid, and masseter muscles is elevation of the mandible, while the lateral pterygoids are mainly responsible for protrusion. These muscles work in concert with the accessory muscles of mastication allowing coordinated, functional mandibular movements. The buccinator (also considered a muscle of facial expression) is innervated by the facial nerve (7th CN). The anterior digastric muscles help depress the mandible and are innervated by the mandibular division of the 5th CN. The mylohyoid functions to depress and retract the mandible. The geniohyoid has a similar function as the mylohyoid and is innervated by the cervical plexus (DuBrul, 1980).

Anatomic Spaces

Potential anatomic spaces of the oral cavity are found within subcutaneous or submucosal connective tissues and sites delineated by fascial membranes which may allow communication with the orbit, the neck, and the mediastinum. These spaces are the canine, buccal, masticator (pterygomandibular), mental, submandibular (made up of the submental, sublingual, and submaxillary spaces), lateral pharyngeal, and retropharyngeal (parapharyngeal) spaces (Clarke and Bueltman, 1971).

Surgical Anatomy

A detailed understanding of surgical anatomy is essential if complications during periodontal surgery are to be avoided. The depth of the vestibule in the mandibular anterior region may be limited by the attachment of the mentalis muscle and prominence of the mental tuberosity. An unusually high or large genial tubercle may impede osseous recontouring in the area. The extent of the external oblique ridge may also limit the surgical treatment of intrabony defects, or make apical positioning of flaps difficult. The vertical bony prominence of the mandibular ramus may limit treatment possibilities for the distal aspect of terminal mandibular molars. On the lingual aspect of the mandible, incision of the lingual nerve and/or lingual artery must be avoided. Surgical manipulation of the tissues in this area can generally be safely accomplished by careful reflection of a full thickness flap. Perforation of the periosteum and damage to structures within the flap can be avoided by following the lateral flare of the mandible in this region maintaining bony contact during tissue retraction and elevation (Clarke and Bueltman, 1971).

The maxillary sinus closely approximates the roots of the maxillary molar teeth and should be noted radiographically when considering extensive osseous recontouring, regenerative procedures or placement of implants. The greater palatine artery must be avoided during flap reflection or graft (hard or soft tissue) harvesting in this region. Vertical incisions in the posterior palate should be avoided. Prominent palatal exostosis or a flat palate may render osseous interproximal ramping difficult (Clarke and Bueltman, 1971).

CLINICAL CONSIDERATIONS

General risk factors accompanying periodontal surgical therapy include hemorrhage, transient bacteremia, stress, and infection.

Flap design and incisions of the envelope type are adequate for most situations. Vertical incisions have limited use, but when used judiciously may be helpful; they are best avoided on the posterior palate and mandibular lingual areas (Clarke and Bueltman,1971; Hunt, 1976).

Excessive hemorrhage may be controlled by direct pressure, vasoconstriction from the local anesthetic solution, suture ties, and burnishing the offending vessel against bone. Synthetic hemostatic agents may also be used. Longer procedures tend to produce more blood loss. Baab et al. (1977) studied blood loss (BL) during periodontal flap surgery, reporting mean loss of 134 ml (16 to 592 range) per site. Duration of surgery and amount of local anesthetic used were significantly correlated with BL; however, there was no correlation between number of teeth in the surgical field or length of incisions. For procedures less than 2 hours, no more than 125 ml BL occurred. Mandibular surgery was associated with greater BL (151 ml) when compared to maxillary surgery (110 ml). IV fluid replacement was recommended when BL exceeds 500 ml or if orthostatic hypotension occurs (i.e., drop in systolic BP of 20 mm or diastolic of 10 mm).

Nerve trauma may occur in several ways. Incision during flap reflection may result in paresthesia of the lip or tongue. Damage to the inferior alveolar nerve may occur during preparation for implant placement or during placement of the implant itself. Nerve damage may also occur

as a result of post-surgical infection or progressive pathosis. General safety factors include a thorough understanding by the surgeon of the bony and soft tissue anatomy in the surgical area and periphery. Soft tissues should be protected with metal retractors when using rotary instruments. Stable fingers are also fundamental to good surgical technique (Clarke and Bueltman, 1971; Hunt, 1976).

The postoperative infection rate following periodontal surgery is about 1% (Pack and Haber, 1983). Infections should be treated aggressively pursuant to diagnosis. It is imperative that affected sites be adequately debrided and proper drainage established. A decision to prescribe antibiotics should be based on the systemic health of the patient and presence of objective clinical indicators. Infections in the area of the maxillary anterior teeth may involve the canine space and can spread to the orbit and/or the buccal space. Infections of the buccal space may spread to the masticator space with potential communication with the parotid and the lateral pharyngeal spaces. Infections in the area of mandibular anterior teeth can involve the mental space and may spread to the buccal space. Infections on the lingual aspect of the mandible may affect the submandibular space which is composed of the sublingual, submaxillary and submental spaces. Route of extension is via the submaxillary space through the lateral pharyngeal space into the retropharyngeal space. Infections in the retropharyngeal space may drain into the mediastinum if the alar fascia ruptures. Ludwig's angina is a cellulitis of the submandibular space. The patient may be febrile with a protruding tongue, "board-like" swelling of the floor of the mouth and dyspnea. This is a life-threatening situation due to the possibility of asphyxiation and requires immediate hospitalization and aggressive therapy (Hunt, 1976).

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Section 2. Electrosurgery

DEFINITION

Electrosurgery: Division of tissue by high-frequency electrical current applied locally with a metal instrument or needle.

GENERAL INFORMATION

Electrosurgery utilizes controlled high-frequency currents ranging from 1.5 to 7.5 million cycles per second. While it has been used for nearly a century, it became more popular in the late 1960s when improved technology afforded better control of the electrical current. The filtered, fully rectified, high-frequency current was developed by Dr. Irving Ellman in the early 1970s. In contrast to this electrosective current, partially rectified current (damped) provides good electrocoagulative properties. Oral electrosurgery utilizes a biterminal technique. The active electrode consists of a small wire which is used at the operative site while the passive electrode is a conductive plate placed at a distant site. The 3 classes of active electrodes include: 1) single wire electrodes for incising tissue; 2) loop electrodes for planing tissue; and 3) heavy, bulkier electrodes for coagulation procedures. The 4 electrosurgical techniques are electrosection, electrocoagulation, electrofulguration, and electrodesiccation.

Electrosection and electrocoagulation are biterminal techniques and are the electrosurgical procedures most commonly used in dentistry. Electrosection requires an undamped or continuous wave train. Three types of electrosection applications have been described and include incisions, excisions, and planing. Incisions and excisions are performed with a single-wire active electrode that can be bent or adapted to the type of cutting procedure. Tissue planing may be accomplished by selection of an appropriate loop electrode. Electrocoagulation employs a damped or interrupted wave train and may prevent or assist in local control of hemorrhage. There are three types of coagulation electrodes: ball, bar, and cone electrodes. Monoterminal techniques are seldomly used and include electrofulguration and electrodesiccation (Flocken, 1980).

MECHANISM OF ACTION

In electrosurgery, radio-frequency energy is concentrated, splitting tissue cells and creating a micro-thin layer of coagulated tissue. Lateral heat due to tissue impedance or resistance accounts for the thin coagulated layer. The thickness of the zone of coagulum and amount of color change are directly related to lateral heat production and may be controlled by the operator. In general, the smaller the color change and thinner the layer of coagulated tissue, the better the healing response. Lateral heat is a product of five factors: duration of contact; dose of current; electrode size and volume; current selection; and tissue impedance. An excess of any one of these factors should be offset by

adjusting and reducing the other factors. Tissue impedance is highest in enamel, followed by dentin and bone, cartilage, dense fibrous tissue, skin, muscle and connective tissue, mucous membrane, and diseased and inflamed tissues. Because of the low impedance of diseased tissue, control of bleeding is more difficult than in healthy tissue. Since the electrosurgery unit is similar to a radio transmitter, tuning of the unit is required for best results. Six factors influence the tuning process: 1) manufacturer variation in the unit; 2) patient variation of impedance; 3) body tissue variation of impedance; 4) grounding potential of operatory environments; 5) current output variation related to local environmental changes; and 6) active and passive electrode proximity. Correct tuning may be defined as adjustment of the above factors to cause the least tissue color change without drag which is the adherence of soft tissue to the electrode which impedes smooth incision. It occurs when insufficient current is being used. Sparking within the tissues during electrosurgical procedures should be avoided. Sparking is caused by: 1) use of current that is too high; 2) excessive tissue dryness at the operative site; 3) failure to use the passive electrode; 4) contact with metal; 5) operating in diseased tissue; or 6) a defective electrosurgical unit (Flocken, 1980).

ADVANTAGES OF ELECTROSURGERY

Flocken (1980) outlined several possible advantages of electrosurgery over traditional surgical techniques. This modality: 1) permits any degree of hemorrhage control desired; 2) prevents bacterial seeding into the incision site; 3) has active flexible electrodes, which can be shaped to conform to any requirement; they never need sharpening; they are self-sterilizing and require no digital pressure to function; 4) permits planing of soft tissue; 5) provides a better view of the operative site; 6) eliminates scar formation; 7) increases operative efficiency; 8) reduces chair time for each operation; 9) improves the quality of restorations; 10) reduces operator fatigue and frustration; and 11) minimizes postoperative discomfort and treatments. Only two drawbacks to the use of electrosurgery were mentioned: it is contraindicated in patients with cardiac pacemakers and produces an unpleasant odor and taste.

TISSUE RESPONSE TO ELECTROSURGERY CONTACT

An appropriate preface to this section is found in an article by Krejci et al. (1987)which reviews controlled clinical studies of oral tissue response to electrosurgery. The authors noted that most studies evaluating electrosurgery have been poorly documented or poorly controlled. With this in mind, the following synopsis of oral tissue response to electrosurgery should be considered.

Epithelium

The electrosurgery incision in epithelium results from volatilization of cells in the line of delivered high frequency energy. This may lead to loss of cellular detail secondary to the lateral heat produced, but subsequent wound healing stages do not appear adversely affected. Use of the instrument in the gingival crevice may result in varying degrees of gingival recession. Although this may not be clinically significant, misuse may result in increased recession (Krejci et al. 1987).

Connective Tissue

Controlled human studies evaluating the histologic changes in connective tissue accompanying electrosurgery reported a small denatured zone (averaging 100 microns) resulting from lateral heat adjacent to the path of incision (Kalkwarf et al., 1981, 1983). This zone does not appear to interfere with wound healing and gradually disappears within 14 days. Misuse may cause adverse alterations in the connective tissue and delay the healing response (Krejci et al., 1987).

Bone

Studies reviewed by Krejci et al. (1987) indicate that carefully controlled use of the electrosurgery unit within accepted clinical guidelines (i.e., time of exposure and energy production) may elicit minor, clinically insignificant changes at the alveolar crest. Misuse, however (e.g., longer exposure to the activated electrode or direct contact with denuded bone), may result in bone necrosis and delayed healing. These findings differ from those of Azzi et al. (1983) who compared the effects of electrosection and full thickness flap reflection on alveolar bone in mongrel dogs, reporting destruction extending to the middle one-third of the periodontal ligament in electrosurgical sites. The initial response was acute inflammation which was followed by osteoclastic and osteoblastic bone remodeling. The destructive effects were similar regardless of electrode application time, leading the authors to conclude that any contact of the electrode with bone should be avoided.

Cementum and Periodontal Attachment

Electrode contact with the root surface may create root resorption and cemental shrinkage, inhibiting connective tissue reattachment (Krejci et al., 1987).

Pulpal Tissue

Pulpal studies indicate that intermittent contact of a metallic restoration with an active electrosurgery electrode (less than 0.4 seconds) results in the delivery of well-controlled current which results in minor pulpal stimulation capable of spontaneous recovery. Exposures exceeding 0.4 seconds or with uncontrolled intensity are capable of eliciting pulpal necrosis. Electrosurgery use for pulpotomy procedures appears to be biologically acceptable (Krejci et al., 1987).

GUIDELINES FOR CLINICAL USE OF ELECTROSURGERY

Krejci et al. (1987) have provided the following clinical guidelines for use of electrosurgery: 1) use a higher fre-

quency unit tuned to optimal power output and a fully rectified, filtered waveform; 2) use the smallest possible electrode; 3) make incisions at a minimum rate of 7 mm per second; 4) allow an 8-second cooling period between successive incisions using a needle electrode at the same surgical site; this period should be increased to 15 seconds if a loop electrode is being used; 5) allow for gingival recession when an electrosurgical incision is used for troughing or excising the gingival crevice; 6) avoid contact of the active electrode with the cemental surface when connective tissue reattachment is desired; 7) anticipate slight osseous remodeling of a clinically insignificant nature with proper electrosurgery use; however, improper use may produce irreversible changes capable of resulting in diminished periodontal support; 8) limit contact with metallic restorations to less than 0.4 seconds; 9) electrosurgery may be used for pulpotomy procedures; 10) use the electrosurgery unit to provide electrofulguration and subsequent hemorrhage control only when all other clinical methods have failed and expect delayed healing response after fulguration; and 11) use electrosurgery to safely excise inflammatory papillary hyperplasia.

INDICATIONS FOR ELECTROSURGERY

Indications for the use of electrosurgery as described by Flocken (1980) may include crown lengthening, contouring edentulous ridges, removing hyperplastic tissue, desensitization of hypersensitive dentin, gingivectomy or gingivoplasty, frenectomy and operculectomy, biopsy, incision and drainage of abscesses, and periodontal surgery. Cautious application is recommended.

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Section 3. Gingivectomy/ Gingivoplasty

DEFINITIONS

Gingivectomy: The excision of a portion of the gingiva; usually performed to reduce the soft tissue wall of a periodontal pocket.

Gingivoplasty: A surgical reshaping of the gingiva.

OBJECTIVES AND INDICATIONS

Objectives include: 1) eradication of pockets; and 2) creation of a physiologic gingival sulcus and contours (Waite, 1975). Indications for gingivectomy include gingival overgrowth or enlargement, pseudo-pockets, idiopathic gingival abromatosis, and minor corrective procedures commensurate with patient needs (Rateitschak et al., 1985).

INDICATIONS FOR GINGIVOPLASTY

Gingivoplasty may be used to correct soft tissue deformities (e.g., post-orthodontic treatment, post-periodontal surgery, ANUG), and to enhance esthetics (e.g., altered passive eruption) (Pollack, 1964).

CONTRAINDICATIONS FOR GINGIVECTOMY

Contraindications for gingivectomy include: intrabony defects, thickening of marginal alveolar bone, and absence (or a narrow zone) of attached gingiva (Rateitschak et al., 1985).

TECHNIQUE

Waite (1975) reviewed the gingivectomy technique, noting that preoperative scaling facilitates resolution of inflammation and allows assessment of the patient's oral hygiene. The surgical procedure includes measurement and transgingival marking of the pseudo-pockets with a probe or marking forceps and excision at the pocket wall apically to assure elimination. The remaining soft tissues are contoured to restore physiologic gingival form. Clinically, removal of granulation tissue may necessitate curettage to the periosteum or alveolar bone.

Epithelization: Tritiated Thymidine

In a radioautographic study of healing in monkeys following gingivectomy, Engler et al. (1966) concluded that epithelial cells begin wound coverage 12 to 24 hours following surgery. demonstrating maximum cell division during the second day. While complete healing required 4 to 5 weeks, surface healing was obtained after 2 weeks. The authors noted that epithelium migrated at a rate of 0.5 mm per day and that increased thymidine uptake was limited to a zone of 2 mm from the wound margin.

In an electron microscopy study, Listgarten (1972) demonstrated complete re-establishment of the junctional epithelium as early as 12 days post-operatively, following gingivectomy in monkeys. In animal and human studies, Stahl et al. (1972) reported epithelialization at 7 to 14 days and connective tissue maturation 10 to 30 days following gingivectomy.

Connective Tissue

In a radioautographic study of connective tissue (CT) healing following gingivectomy in Rhesus monkeys, Ramjford et al. (1966) concluded that healing begins 0.3 to 0.5 mm beneath the protective "poly band" surface. Following surface epithelization, CT proliferation of all supracrestal

tissues occurred up to the basement membrane of the new epithelium. The authors noted that CT begins 1 to 2 days after the gingivectomy and peaks at 3 to 4 days. Formation of a physiologic gingival crevice, functional regeneration, and maturation of the gingival CT required 3 to 5 weeks.

Alveolar Bone Response

Slight loss of continuity of the osteoblast layer on the outer aspect of the alveolar crest occurs during the initial 12 hours. This was followed by new bone formation as early as the fourth day. New cementoid formation appeared at 10 to 15 days (Glickman, 1972).

CLINICAL STUDIES

Wennstrom (1983), in a human study, compared the regeneration potential of the zone of keratinized and attached gingiva following the surgical removal of the entire zone of existing gingiva via a gingivectomy versus a flap-excision (FLEX) procedure. Results revealed that a new zone of keratinized gingiva consistently regenerated, following surgical excision of the entire portion of the gingiva. This zone of keratinized gingiva was wider in the gingivectomy units than in the FLEX units. The granulation tissue which developed adjacent to the teeth following each procedure was seen as having the capacity to induce keratinization of the covering epithelium, particularly that which formed following the gingivectomy procedure.

Donnenfeld and Glickman (1966) examined the biometric effects of gingivectomy and reported that it eliminates pockets without significant clinical or statistical change in the location of the healed sulcus or width of the attached gingiva. The 0.3 mm reduction in width of attached gingiva was attributed to coronal migration of the mucogingival junction and slight apical shift shift of the healed sulcus base. Rosling et al. (1976) conducted a 2-year clinical study which compared the apically positioned flap (APF), APF and osseous surgery (OS), Widman flap (WF), WF and osseous surgery, and gingivectomy. Although all of these proved effective to varying degrees, the gingivectomy was accompanied by reduced pocket depths, greatest reduction of alveolar bone height, and the least regeneration of intrabony defects.

INSTRUMENTATION

Instruments that have proven useful in the gingivectomy procedure include surgical knives (e.g., Kirkland, Buck); gingivectomy clippers (including surgical scissors); coarse rotating abrasive stones; ultra-speed diamond stones; electrosurgery; and cryotherapy (Waite, 1975). Pick and Colvard (1993) described the use of the dental laser to perform gingivectomy.

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Section 4. Repositioned Flaps

DEFINITIONS

Flap: A loosened section of tissue separated from the surrounding tissues except at its base.

Modified Widman Flap: A scalloped, replaced, mucoperiosteal flap, accomplished with an internal bevel incision, that provides access for root planing.

Repositioned Flap: A flap that is moved laterally, coronally, or apically to a new position.

ANTERIOR CURTAIN PROCEDURE

Frisch et al. (1967) described a modified surgical approach for periodontal defects in this area. In the presence of healthy mid-labial sulci, a curtain of tissue which includes the labial one-third of the labial interproximal papilla is preserved facially. Lingual interproximal defects are managed by gingivectomy or a palatal flap, depending on the presence of osseous involvement. Advantages of this procedure include its simplicity, conservative nature, esthetic preservation, minimization and avoidance of speech defects, and minimization of labial alveolar bone loss. Disadvantages include less than ideal labial contour, greater oral hygiene demands, and application limited to the maxillary anterior sextant.

OPEN DEBRIDEMENT

Becker et al. (1986) studied the repair of narrow, medium, and wide 3-wall intrabony defects following open flap debridement procedures in humans. After calculus removal and root planing, hydrocolloid impressions were made of the surgical defect and greatest width recorded clinically. Surgical re-entry and clinical measurement were accomplished at 9 to 16 months. Mean defect fill was 2.56

mm (61%) on models and 3.26 mm based on direct measurements. The authors concluded that open debridement of intrabony defects has potential for repair with significant, but varying, amounts of bone.

MODIFIED WIDMAN FLAP

Ramfjord and Nissle (1974) described the modified Widman flap (MWF). The procedure emphasizes conservative surgical flap access using sharp incisions to avoid excessive tissue trauma and close interproximal flap adaptation of healthy collagenous tissues to root planed tooth surfaces.

Ramfjord (1977) reviewed the present status of the modified Widman procedure. Following a detailed description of the MWF procedure, the author noted that creation and maintenance of a biologically acceptable root surface is the key to success. The procedure is indicated for deep pockets, intrabony pockets, and when minimal recession is desired. The advantages of the procedure include ability to coapt the tissues to the root surfaces, access to the root surfaces, esthetic results, less likelihood of root sensitivity and caries, and a favorable environment for oral hygiene maintenance. Disadvantages include flat or concave interproximal soft tissue contours often present following dressing removal. Meticulous oral hygiene is emphasized for such areas. Smith et al. (1987) and Svoboda et al. (1984) evaluated the effect of retention of gingival sulcular epithelium following MWF and intrasulcular incision techniques. Comparable clinical results were observed in patients receiving both techniques, leading the authors of both studies to conclude that removal of sulcular epithelium during periodontal surgery provided no therapeutic advantage.

EXCISIONAL NEW ATTACHMENT PROCEDURE [ENAP]

Yukna and Lawrence (1980) described the ENAP as a means of treating suprabony pockets consisting essentially of subgingival curettage with a surgical knife. Internally bevelled incisions extend from the gingival margin to the base of the pocket, allowing debridement, root preparation, and primary closure. The modified ENAP includes an initial incision directed toward the alveolar crest (rather than the root surface), affording better access and maximizing healing capabilities of the periodontal ligament. A disadvantage is the potential for attachment loss that may accompany removal of intact supracrestal connective tissue fibers. Healing of the ENAP (and modified ENAP) consists of a long junctional epithelium to the depth of the surgical wound with occasional presence of connective tissue adhesion.

In a 5-year evaluation of the ENAP, Yukna and Williams (1980) reported a net gain in clinical attachment of 1.8 mm and an overall mean decrease of 1.8 mm in probing depth (3.0 mm). Probing depths increased slightly and new attachment gain decreased slightly at the 1, 3, and 5-year post-operative evaluation periods. This report supports the clinical success of the ENAP at 5 years.

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Section 5. Mucogingival Surgery

DEFINITION

Mucogingival Surgery: Periodontal surgical procedures used to correct defects in the morphology, position, and/or amount of gingiva.

INTRODUCTION

While over the past decade there has been less emphasis on mucogingival procedures to increase the amount of attached gingiva, they continue to play an important role in the comprehensive management of the periodontal patient. This discussion will examine the indications and rationale for mucogingival surgical procedures, including free autogenous soft tissue grafts and pedicle grafts.

INDICATIONS FOR MUCOGINGIVAL PROCEDURES

Historically, mucogingival surgery was used to increase the amount of attached gingiva. A certain amount of attached gingiva was considered necessary to maintain gingival health and prevent gingival recession. Factors influencing this relationship included prominence of the tooth in the arch, amount of attached gingiva present, and ability of the patient to adequately control the accumulation of bacterial plaque. Although establishing an adequate width of keratinized tissue has been emphasized, the thickness of this tissue is at least equally important in preventing soft tissue recession in the presence of bacterial plaque. Other indications for mucogingival procedures include elimination of frenum and muscle attachments, increasing vestibular depth, coverage of gingival clefts, modification of edentulous ridges prior to prosthetics, establishing a zone of attached gingiva prior to coronally positioning a graft, and for restorative considerations, particularly if subgingival

margins are contemplated in areas of thin tissue (Nery and Davies, 1977).

GENERAL PRINCIPLES

Morman and Ciancio (1977) used fluorescein angiography in human biopsy specimens to examine alterations in gingival circulation following various modifications of mucogingival flap design. Blood supply to a flap was primarily directed caudo-cranially from the vestibule to the gingival margin. Internal beveled incisions severing the anastomosis between the gingival and periodontal/interdental vasculature had no effect on circulation, verifying circulatory independence. The following concepts were suggested when designing periodontal flaps: 1) flaps should have a broad base which includes major gingival vessels; 2) a flap's length to width ratio should not exceed 2:1; 3) minimal tension should be produced by suturing techniques and the tissue should be managed gently during the surgical procedure; 4) partial thickness flaps covering avascular areas should not be too thin, so that more blood vessels are included in them; and 5) the apical portion of periodontal flaps should be full thickness when possible.

Cattermole and Wade (1978) compared linear and scalloped incisions in the reverse bevel elevation of full thickness buccal and palatal flap reflections in humans. Although both flaps healed after 4 weeks, the linear incision showed interdental tissue that was not fully mature and more inflamed. At 12 weeks, it was difficult to distinguish which type of incision had been used and no significant differences in healing, pain, GI, PI, and GCF were observed.

Lindhe and Nyman (1980) examined alterations in gingival margin position on the buccal surfaces of human teeth professionally maintained for 10 to 11 years following periodontal surgery. Regardless of the presence or absence of keratinized soft tissue, changes observed in gingival margin position were similar. Gingival recession was not produced by daily tooth brushing combined with professional maintenance care. Conversely, approximately 1 mm of coronal regrowth of the gingival margin occurred. Their results supported those of Dorfman et al. (1980), showing that sites with or without adequate attached gingiva maintain attachment levels over a long period of time. Hangorsky and Bissada (1980) also demonstrated that the absence of keratinized gingiva does not jeopardize gingival health. Hall (1981) reviewed the mucogingival therapy literature and concluded that a minimum width of attached soft tissue necessary for health had not been established. It is difficult to predict if recession will occur in areas of narrow or absent attached gingiva; however, recent successes in covering exposed root surfaces through various grafting procedures have made prophylactic grafting less of a concern. Creeping attachment was found to enhance root coverage in many cases of soft tissue grafting by a mean of 0.89 mm over the first postoperative year. Noting the high degree of success when placing grafts on either denuded bone or periosteum, the author concluded that perforation of the periosteum during receptor bed preparation is probably of little concern.

Allen (1988) discussed the use of mucogingival procedures with particular emphasis on maxillary esthetics. Indications for the possible need for mucogingival corrective procedures include: 1) inadequate keratinized gingiva; 2) gingival recession; 3) excessive gingival display; 4) insufficient clinical crown length; 5) asymmetric gingival margins; 6) flat marginal contour; 7) improper gingival margin relationships; 8) lack of harmony with the lip line and gingival margins; and 9) alveolar ridge deficiencies. The ideal relationships of the gingival margins of the maxillary anterior teeth were described. The gingival margins of the central incisors are symmetric and are either even with or 1 mm apical to the margins of the lateral incisors. The gingival margins of the canines are 1 mm apical to the level of the lateral incisors. A line drawn horizontally at the level of the canine gingival margins should parallel the interpupillary line. The incisor gingival margins should peak slightly to the distal giving the appearance of distal inclination. The smile should expose minimal gingiva apical to the centrals and canines and should be in harmony with the smile line. The crowns of central incisors and canines can usually be exposed to an overall length of 11 to 12 mm to attain maximal gingival reduction. The lateral incisors should be exposed 1.5 mm less than the length of the centrals.

Partial Thickness Flaps

Wood et al. (1972) used human re-entry to compare crestal radicular bone responses to full and partial thickness flaps (PTF). Regardless of the flap procedure, loss of crestal bone depended to a great extent on the thickness of preexisting bone. Teeth with the thinnest radicular bone demonstrated greater bone loss postoperatively. Mean bone loss for full and partial thickness flaps was 0.62 mm and 0.98 mm, respectively. Use of the PTF in areas of thin gingiva resulted in a very thin non-protective layer of connective tissue which provided significant osteoclastic activity. It was also speculated that the compromised vasculature of a thin PTF could produce necrosis of the flap margin, resulting in exposure of the poorly protected underlying bone and increased susceptibility to resorption. The authors concluded that partial thickness flaps are not indicated in areas of thin connective tissue.

Staffileno et al. (1966) studied histologic repair of the periodontium in dogs following resection of a split thickness flap. Results demonstrated that split thickness flaps with periosteal retention produced minimal tissue destruction, rapid repair, slight alteration of the dentogingival junction, and maximum preservation of periodontal supporting structures.

Karring et al. (1975) histologically examined the development of granulation tissue after periosteal retention and

denudation procedures in monkeys. Following both procedures, granulation tissue originated from the residual periosteal connective tissue, PDL, bone marrow spaces, and the adjacent gingiva and alveolar mucosa. Bone resorption was generally more severe with the denudation procedure; however, greater amounts of loss were occasionally seen following periosteal retention. The point of transition between keratinized and non-keratinized epithelium was found to correspond to the junction between connective tissue with and without regenerated elastic fibers, demonstrating the inductive influence of connective tissue on the overlying epithelium.

Wilderman et al. (1960) studied histologic wound healing of exposed alveolar bone in dogs. Differences in the anatomy of interdental and radicular bone appeared responsible for varying degrees of osteoclastic resorption. Where adequate marrow spaces remained (interdentally), there was complete restoration of bone. In contrast, radicular areas showed 50% bony restoration, demonstrating functional repair with double the fibrous attachment of new gingiva as compared to the original condition and an epithelial attachment located more apically compared to interdental sites.

Hiatt et al. (1968) examined healing and reattachment of mucoperiosteal flaps in dogs. At 2 to 3 days, flap adhesion was mediated by fibrin which prevented downgrowth of epithelium if the flap was well-adapted. Accelerated repair observed in tightly-adapted flaps was attributed to the decreased time required for fibrin resorption and replacement by connective tissue. Retained vital cementum appeared to accelerate connective tissue attachment. Dentin surfaces which had been denuded of cementum by root planing underwent resorption prior to new cementum formation.

Frank et al. (1972) demonstrated differentiation of new attachment apparatus at the ultrastructural level in humans. These results supported the electron microscopic observations of Listgarten (1967, 1972), showing re-establishment of new epithelial attachment in monkeys after gingivectomy and mucoperiosteal surgery. Thilander and Hugoson (1970) also demonstrated re-establishment of an attachment apparatus in cats after deep scaling.

Pedicle Grafts

Pedicle grafts differ from free autogenous soft tissue grafts in that the base of the flap contains its own blood supply which nourishes the graft and facilitates the re-establishment of vascular union with the recipient site. Pedicle grafts may be split or full-thickness. Some early studies (Pfeifer and Heller, 1971; Sugarman, 1969) reported that the use of full-thickness lateral sliding grafts resulted in a connective tissue attachment to the root surface (one half CT, one half JE) while a partial thickness flap yielded a long junctional epithelial attachment. While it has been felt that a split-thickness flap with preservation of a periosteum over the donor site would protect underlying bone from resorption, Wood et al. (1972) observed increased crestal bone resorption with split-thickness flaps as compared to full-thickness counterparts (0.98 mm versus 0.62 mm).

Grupe and Warren (1956) were the first to report on the use of a lateral sliding flap to repair isolated gingival defects. The procedure consisted of removing the epithelial lining surrounding the defect and freshening the wound margins. A full-thickness flap was elevated one tooth away from the defect and rotated to cover the defect. Corn (1964) reported the use of pedicle grafts to correct mucogingival defects, utilizing an edentulous area as the donor site.

In 1967, Hattler described a procedure to correct conditions where the attached gingiva on the facial surfaces of 2 or 3 consecutive teeth was deemed inadequate. This technique involves the development of partial thickness flaps around the involved teeth and sliding the entire flap 1/2 tooth width, placing the interdental papillary tissues over the buccal surfaces of the affected teeth.

Cohen and Ross (1968) described the double-papilla repositioned flap to cover defects where a sufficient amount of gingiva was not present or where there was insufficient gingiva on an adjacent area for a lateral sliding flap. The papillae from each side of the tooth were reflected and rotated over the midfacial aspect of the recipient tooth and sutured. This technique offers the advantages of dual blood supply and denudation of interdental bone only, which is less susceptible to permanent damage after surgical exposure.

Coronally-Positioned, Free, Autogenous, Soft Tissue Grafts

Bernimoulin et al. (1975) first reported the coronally-positioned (previously-placed) free, autogenous, soft tissue graft as a two-stage procedure. First, a free autogenous soft tissue graft is placed apical to an area of denuded root surface. After an adequate healing period, the graft is coronally positioned over the denuded root surface. In 1977, Maynard presented 6 requirements for success of coronally positioned grafts: 1) presence of shallow crevicular depths on proximal surfaces; 2) approximately normal interproximal bone heights; 3) tissue height should be within 1 mm of the CEJ on adjacent teeth; 4) adequate healing of the free graft prior to coronal positioning (6 weeks); 5) reduction of any root prominence within the plane of the adjacent alveolar bone; and 6) adequate release of the flap at the second-stage procedure to prevent retraction during healing. The second-stage procedure utilizes a split-thickness dissection with mesial and distal vertical releasing incisions until adequate flap mobility is obtained. The flap is sutured 0.5 to 1 mm coronal to the CEJ and covered with a periodontal dressing. This procedure is indicated when root sensitivity or cosmetic concerns relative to recession become therapeutic considerations.

Guinard et al. (1978) and Caffesse and Guinard (1980) compared lateral sliding flaps and coronally positioned flaps in the treatment of localized gingival recessions. In the 6-

month report (Guinard et al, 1978), they found that both techniques rendered satisfactory results and no differences were reported regarding gain of tissue coverage, sulcus depth or gain of attached gingiva. An average of 2.71 mm of soft tissue coverage was obtained, with an average coverage of 67% of the recession. The only difference between the 2 techniques was an increase in root exposure of approximately 1 mm at the lateral sliding flap donor site while no additional recession was observed with the coronally positioned flap. Results were stable 1-month post-therapy and remained so after 3 years. The 1 mm of gingival recession created on the donor tooth when a lateral sliding flap was used did not repair over the 3 years of observation (Caffesse and Guinard, 1980).

Allen and Miller (1989) reported the use of a single-stage coronally positioned flap in the treatment of shallow marginal recession. The defects were Miller Class I and had a minimum keratinized tissue width of 3 mm. Recession ranged between 2.5 to 4 mm. The technique consisted of citric acid root treatment, a split-thickness flap extending into the vestibule, and surface gingivoplasty of the papillae to produce a bleeding bed. Flaps were sutured into position and dressed. Complete root coverage was attained in 84% of the sites, with a mean gain of 3.18 mm root coverage.

Tarnow (1986) described the semilunar coronally positioned flap. A semilunar incision is made that follows the curvature of the free marginal gingiva and extends into the papillae, staying at least 2 mm from the papilla tip on either side. The incision is made far enough apically to ensure that the apical portion of the flap rests on bone after repositioning. A split-thickness dissection of the flap is made and the flap is repositioned and held in place with light pressure and dressed. Advantages of the technique according to the author include: 1) no tension on the flap after repositioning; 2) no shortening of the vestibule; 3) no reflection of the papillae, thereby avoiding esthetic compromise; and 4) no suturing.

Free, Autogenous, Soft Tissue Grafts (FASTG)

Sullivan and Atkins (1968) explored the feasibility and healing patterns of the FASTG and correlated plastic surgical principles to the practice of periodontics. This procedure involves the preparation of a recipient site which is accomplished by supraperiosteal dissection to remove epithelium, connective tissue, and muscle down to the periosteum. Placement of a FASTG directly on denuded bone was reported by Dordick et al. (1976), James and McFall (1978), and Caffesse et al. (1979) who demonstrated comparable success rates compared to grafts placed on the periosteum. James and McFall (1978) reported less shrinkage of FASTG placed on bone (25% versus 50% on periosteum). Dordick et al. (1976) reported a firmer, less mobile grafting results when placed on denuded bone. Caffesse et al. (1979) reported delayed healing during the first 28 days postoperatively when FASTG were placed on denuded bone.

James et al. (1978) performed a histologic comparison of wound healing between FASTG placed directly on denuded bone and periosteum. More marrow space-to-soft tissue communication occurred at "graft to bone" sites. Epithelial thickness was greater over the free grafts placed on bone until the twelfth week, at which time thickness was comparable. Free grafts on bone showed less postoperative swelling, but there was no difference in the degree of inflammation. Resorption of bone occurred at graft-to-bone sites, which allowed an adequate blood supply. However, placement of grafts on thin denuded bone may be contraindicated.

Wilderman and Wentz (1965) reported wound healing events of pedicle flaps in dogs. Four stages of healing were found to occur: 1) adaptation stage (0 to 4 days) when a fibrin clot containing PMNs was present between the flap and the crestal bone; 2) proliferation stage (4 to 21 days) when granulation tissue invaded the fibrin clot, fibroblasts were present on the root surface (6 to 10 days), epithelium migrated apically (10 to 14 days), osteoclastic activity occurred (4 to 14 days) and an average of 1 mm of crestal bone was resorbed; 3) attachment stage (21 to 28 days) when collagen formation was visible, cementum formation occurred and osteoblastic activity reached its peak; and 4) maturation stage (28 to 180 days) showed new PDL fibers orienting perpendicularly to the root surface. Repair consisted of a combination of connective tissue attachment (2.1 mm) and long junctional epithelium (2.0 mm).

Sugarman (1969) confirmed attachment of free soft tissue grafts and pedicle flaps by a combination of connective tissue and long junctional epithelium in humans.

Appropriate graft donor material should consist of keratinized tissue with a dense lamina propria. Studies by Karring et al. (1975) found that the phenotypic expression of epithelial surface was determined by the underlying connective tissue. Common areas for donor material include edentulous ridges, attached gingiva, and palatal mucosa. Donor tissue should be approximately 33% larger than the anticipated healed graft due to shrinkage during healing (Egli et al., 1975). According to Sullivan and Atkins (1968), a thick graft will have greater primary contraction (immediately after removal) due to the increased amount of elastic fibers but less secondary contraction during healing (due to cicatrization) and will have greater resistance to functional stresses. A thin graft will have less primary contraction and more secondary contraction. Split-thickness grafts are further categorized as thin, intermediate, and thick based on the thickness of their lamina propria.

Sullivan and Atkins (1968) recommended using of intermediate split-thickness grafts and full thickness grafts. Soehren et al. (1973) reported that the thickness of the palatal epithelium ranged from 0.1 to 0.6 mm with a mean thickness of 0.34 mm. These authors recommend the use of grafts no less than 0.75 to 1.25 mm in thickness to assure

that there is an adequate connective tissue component. The graft should be sutured to the periosteal bed for optimum immobilization between the graft and the recipient bed. A periodontal dressing may assist in maintaining positive pressure and aid graft immobilization.

Sullivan and Atkins (1968) reported the use of the FASTG to cover root recession. Root recession was classified into one of four types: 1) deep-wide: extends into alveolar mucosa; most difficult to treat; can expect 1 to 2 mm of new tissue over the apical portion; 2) shallow-wide: also expect 1 to 2 mm of new tissue over the apical portion; may get coverage of a large part of the defect; 3) deep-narrow: extends into alveolar mucosa; rarely seen; may be completely covered; and 4) shallow-narrow: maintained by conservative therapy, graft gives predictable results.

Creeping attachment following grafting has been reported by Matter (1980). This is a phenomenon of additional root coverage during healing which may be observed between 1 month and 1 year post-grafting. The author also reported an average of 1.2 mm of coronal creep at 1 year with no additional change.

In a 2-year study comparing graft versus no graft, Dorfman et al. (1980) concluded that plaque control was more important than the width of the attached gingiva in determining eventual breakdown and recession. They also found that the use of the FASTG was a predictable means of increasing the width of the attached gingiva. In a follow-up study 2 years later, these authors reported basically the same results except that 10% of the non-grafted cases showed additional soft tissue recession with equivalent plaque scores compared to grafted sites (Dorfman et al., 1982).

Edel (1974) reported the use of free connective tissue grafts as an alternative to epithelialized donor tissue. In his report on 14 successful grafts, Edel found that the resultant increase in attached gingiva was stable at 6 months with a mean contraction of 28%. Complete epithelialization of the connective tissue surface was seen at 2 weeks with keratinization evident at 4 weeks. The graft was blended into the surrounding tissues at 6 weeks with formation of well-developed rete ridges. The results of this study confirmed that the connective tissue determines the character of the overlying epithelium.

Holbrook and Ochsenbein (1983) used FASTG in a single procedure to cover denuded root surfaces and were the first to suggest butt joint margins at the junction of the recipient bed and donor tissue. The recipient bed is extended one-tooth width lateral to the denuded roots and 5 mm apical to the gingival margin of the denuded root. Root prominence is reduced by root planing. Donor tissue should cover the gingival bed extending at least 3 mm apical to the margin of the denuded root(s). A graft of approximately 1.5 mm uniform thickness is utilized with butt margins. A precise suturing technique (''Holbrook'') is described utilizing a horizontal continuous suture to stretch the graft 2 to 3 mm. The authors feel this counteracts primary contraction, making the graft more receptive to revascularization. Circumferential sutures compress the graft at the borders of the denuded root and are inserted into the periosteal bed slightly apical to the inferior margin of the graft. Two separate interdental concavity sutures adapt the graft mesially and distally. These sutures are inserted into the periosteum at the depth of the interdental concavity diagonally traversing the graft mesially and distally. In 50 randomly-selected cases, recessions < 3 mm had 95.5% root coverage, recessions 3 to 5 mm had 80.6% coverage and recessions ≥ 5 mm had coverage of 76.6%. The most difficult tooth root to cover was the maxillary canine. Visible recession is the clinically observable root measured from the CEJ to the gingival margin. Hidden recession is defined by the authors as the ''depth of the sulcus or pocket as measured from the soft tissue margin to the junctional epithelium.''

Miller (1985) described a technique for root coverage using a free soft tissue autograft and citric acid treatment. Predictable root coverage depended upon the type of gingival recession and Miller presented an expanded classification of marginal recession. Class I defects present as marginal recession coronal to the mucogingival junction with no periodontal loss in the interdental areas. Class II defects also show no interdental periodontal loss but have recession extending beyond the mucogingival junction. This includes both visible and hidden recession. According to Miller, 100% root coverage can be predictably achieved in both Class I and II defects. Class III defects have recession extending to or beyond the mucogingival junction, but with some soft tissue or bone loss in the interdental areas (only partial root coverage can be expected). Class IV defects are similar to Class III defects except there is severe bone or soft tissue loss interdentally (root coverage cannot be anticipated). Miller's technique includes root planing to reduce root convexity and minimize the mesiodistal dimension of the root before the recipient bed is prepared. Root planing is pronounced along the CEJ to create a butt-type joint for the graft. After root planing, saturated citric acid is vigorously burnished into the root surface for 5 minutes (pellets changed 2 to 3 times/minute). Horizontal incisions are made at the level of the CEJ preserving the interdental papillae (height permitting); vertical incisions at proximal line angles of adjacent teeth facilitate completion of bed preparation. All incisions should result in ''butt joints'' between the recipient and donor tissues. Periosteal fenestration (which may compromise blood supply of bed) is not used. A thick palatal graft with a thin layer of submucosa is placed on a moderately bleeding bed and stabilized with sutures at the papillae and apical corners of the graft extending into periosteum. Results of 100 consecutive grafts showed 100% root coverage in 90% of Class I and

II defects (Class I = 100%; Class II = 88%). In Class III sites, a high percentage of the attainable coverage was obtained. The average root coverage for all sites was 3.79 mm with a mean gain of 4.54 mm in clinical attachment.

Miller (1987) discussed factors associated with incomplete root coverage. This article stressed adherence to several features of the technique: 1) flattening of the root in the CEJ region creating a butt joint; 2) use of citric acid burnished into the root surface for 5 minutes prior to preparation of the recipient site; 3) use of horizontal incisions at the level of the CEJ to preserve interdental papillae for enhanced circulation; 4) utilizing thick graft tissue with right-angle margins, retaining a thin layer of submucosa that is placed as soon as possible on a moderately-bleeding bed; 5) stabilizing the graft with sutures to allow intimate adaptation to the periosteal bed; 6) avoiding pressure over the graft in an attempt to minimize hematoma formation, as pressure may compromise necessary blood flow to the graft; 7) avoiding trauma to the graft during initial healing; and 8) avoiding excessive smoking during the postoperative period, since patients smoking > 10 cigarettes/day are associated with a greater failure rate for 100% root coverage. Miller defines complete root coverage as the soft tissue margin at the CEJ with clinical attachment to the root, sulcus depth < 2 mm and no bleeding on probing. Miller reports a 90% success rate in achieving 100% root coverage compared to Holbrook and Ochsenbein (1983) who report a 44% success rate using a 1-stage approach (Miller's use of figures). Other authors utilizing a 2-stage coronally positioned graft report success rates of 44% (Bernimoulin, 1975) and 36% (Guinard and Caffesse, 1978). Miller emphasizes that no single factor can be credited as the most important factor in successful grafting for root coverage but that inattention to any single factor may result in incomplete coverage.

Raetzke (1985) described a technique for obtaining root coverage using free connective tissue grafts. In this technique, the collar of marginal tissue around a localized area of recession is excised, the root is debrided and planed, and a split thickness envelope created around the denuded root surface. In the premolar/molar region of the palate, two horizontal incisions are made 1 to 2 mm apart to the depth of the palatal mucosa and a wedge of connective tissue is removed with its small band of epithelium. The connective tissue graft is placed in the previously created envelope covering the exposed root surface. The palatal site is closed with sutures. Overall, 80% of the exposed root surfaces were covered, with 5 of 12 cases reporting complete root coverage. Advantages include minimal trauma to both donor and recipient sites with rapid healing, favorable healing over deep and wide areas of recession, and excellent esthetic results. Potential difficulties include difficulty in obtaining sufficient graft material in "thin" palates where necrosis of palatal tissue at the donor site is also a hazard. Palpation for palatal exostoses is recommended prior to selecting donor sites.

Reconstruction of Deformed Edentulous Ridges

Seibert (1983) described the principles and surgical procedures involved in reconstructing deformed partially edentulous ridges utilizing full thickness onlay grafts. Ridge defects were classified according to tissue loss. Class I defects are bucco-lingual tissue deformities with a normal apico-coronal ridge height. Class II defects present with loss of tissue in an apico-coronal dimension with normal buccolingual dimension. Class III defects are combination defects with loss in both bucco-lingual and apico-coronal dimensions. In this technique, recipient sites are minimally prepared by removing surface epithelium and CT to a depth of 1 mm. Margins may be butt-joint or beveled depending upon tissue contours of recipient sites. Full thickness grafts containing fatty and/or glandular submucosa are obtained from palatal tissue medial to premolar/molar areas matching the 3-dimensional shape of the defect in the ridge. After the graft is harvested, a series of deep parallel "stab" incisions are made in the exposed CT of the recipient site. These striations are believed to stimulate capillary growth into the graft from larger vessels leading to a "hematoma-like" reaction (and swelling of the graft) and resultant increase in total volume. The onlay graft is trimmed, if necessary, to obtain a snug fit against the exposed CT and sutured in place. Palatal hemostasis is obtained with a hemostatic dressing and a palatal stent. A provisional prosthesis may be placed with light contact against the graft surface and adjusted as necessary at future visits for patient comfort. If sufficient ridge reconstruction is not obtained after the initial attempt, a secondary procedure may be accomplished 6 weeks after the initial surgery. Very little primary or secondary shrinkage has been observed with full thickness onlay grafts and they appear to be dimensionally stable after 3 months of healing.

Frenectomy

Insertion points of the frena may become troublesome when the gingival margin is involved (Corn, 1964). This may result from an unusually high insertion of the frenum or because of recession. Frenal insertions can distend and retract the marginal gingiva or papilla when the lip is stretched. The author emphasized that the importance of the frenum attachment in the etiology of recession must be addressed directly.

West (1968) observed that frenectomy may result in scar formation which could prevent the mesial movement of the central incisors. Edwards (1977) indicated that orthodontic closure of diastemata without excision of the associated frena has been clinically associated with relapse separation of the teeth. It is noted that a frenectomy may be needed after orthodontic therapy.

The histologic morphology of frena has been another

area of controversy in the literature. Henry et al. (1976) studied 11 fresh biopsy specimens and concluded that excision of the superior labial frenum could not be based on removing muscle tissue (allegedly responsible for the "muscle pull" or tension) because no trace of muscle was found in the biopsies. The "destructive capacity" of frena was attributed to the elastic and connective tissue components rather than muscular elements.

In contrast, Ross et al. (1990) retrospectively examined biopsies of 40 frenal specimens from various intraoral sites (including 21 maxillary labial) and found that approximately 37.5% contained skeletal or striated muscle.

Regardless of the presence of muscle tissue in the frenum, it can be concluded that a frenectomy may be indicated if it is associated with a receded gingival margin, inability to adequately cleanse or debride the area or if any other indication exists for a mucogingival procedure. Frenectomy may be accomplished in conjunction with flap reflection and placement of a free gingival graft.

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Section 6. Osseous Resective Surgery

DEFINITIONS

Osseous Surgery: Periodontal surgery involving modification of the bony support of the teeth.

Osteoplasty: Reshaping of the alveolar process to achieve a more physiologic form without removal of supporting bone.

Ostectomy: The excision of a bone or portion of bone. In periodontics, ostectomy is done to correct or reduce deformities caused by periodontitis in the marginal and interalveolar bone and includes the removal of supporting bone (other terms for supporting bone are: alveolar bone proper, cribriform plate, and bundle bone).

Historical Perspective

Prior to 1935, bone associated with periodontal disease was considered infected or necrotic, and the most accepted treatment was surgical removal. Kronfeld (1935) demonstrated that bone was neither necrotic nor infected, and advocated the control of inflammation as the proper way to treat periodontitis. As a result of Kronfeld's work, and the introduction of the gingivectomy by Orban (1939), interest in osseous surgery declined; however, the recurrence of pockets following gingivectomy soon became a concern. Interest in osseous surgery was renewed by Schluger in 1949, when he advocated osseous resection and recontouring as the best way to maintain minimal pocket depth.

Theoretical and Diagnostic Approaches to Osseous Resective Surgery

Basis and Indications for Osseous Resective Surgery. According to Schluger (1949), frequent regrowth of soft tissue following gingivectomy is due to its inability to follow sharp and irregular contours of bony deformities. The author notes that since bone remodels more slowly than soft tissue, it should be contoured to facilitate gingival conformity. This may be achieved by making a long sweeping incision apical to the deepest pockets in the area, which usually results in exposed bone and post-operative pain; or, by gingivectomy, which precedes reflection of remaining soft tissue and osseous resection.

Indications for osseous resection include: 1) failure of the gingivectomy technique; 2) mesial of tipped molars; 3) deep isolated pockets; 4) some deep buccal and lingual pockets; and 5) saucer-shaped interproximal pockets. Soft tissue can tolerate variations in alveolar bone height up to 30° (60° in cases of prominent roots). Schluger (1949) recommends thinning thick bony ledges around teeth to a knife-edge margin. If pocket elimination will result in furcation exposure or sacrifice of too much bone on adjacent teeth, osseous resection may be contraindicated.

Osteoplasty/Ostectomy. Friedman (1955) further elaborated on the concept of osseous surgery and re-emphasized that irregular bony contours are not followed by the gingiva since the soft tissues tended to restore a regular scalloped contour. He classified osseous surgery into osteoplasty and ostectomy, advocating reshaping of underlying alveolar bone and pocket elimination in order to achieve proper gingival architecture. Indications for osteoplasty included deep interproximal pockets in posterior teeth involving buccal interdental bone; pockets in areas with thick bony ledges; and tilted lower second molars. Ostectomy was indicated for correction of shallow interproximal bony defects.

Advantages/Disadvantages of Osseous Resective Surgery. Siebert (1976) listed the advantages of osseous surgery as 1) visualization of osseous defects (dependability); 2) minimal treatment time; 3) simplicity; and 4) elimination of additional surgical sites. The main disadvantage is loss of attachment. Factors that should be considered prior to surgery include: 1) length and shape of roots; 2) location and dimensions of the defect; 3) width of investing bone; 4) root prominence; and 5) relationship of the intrabony defects to adjacent teeth and other anatomic structures. Gingivoplasty following osseous surgery should be done at 14 days as needed.

Palatal Exostoses. Nery et al. (1977) noted that palatal gingivectomies in molar areas often heal slower than other sites due to the presence of palatal exostoses. Of 681 skulls examined, 40% had palatal exostoses. The 40 to 55 year age group had the highest prevalence (50%), followed by the 56 year or older group (30%), and the 17 to 39 year group (19%). Nery et al. classified palatal exostoses into 5 groups: small nodule (most common), large nodule, sharp ridge, spike projection, and combination. The presence of palatal exostoses must be considered when surgically managing in the palatal molar area.

Bone Sounding. Easley (1967) described "bone sounding" as a technique for determining bony contours, bony

ledges, exostoses, and interdental defect morphology. In addition to vertical probing, horizontal probing is used to determine facial and lingual alveolar crestal bone heights.

Techniques Involved in Osseous Resective Surgery

Palatal Approach. Ochsenbein and Bohannan (1963) described the palatal approach to osseous crater removal. The advantages of the palatal approach include: 1) existence of keratinized tissue on the palate; 2) greater surgical access to larger palatal embrasures; 3) cleansing effect of the tongue on the palatal; and 4) less post-surgical bone resorption on the palatal due to the presence of increased cancellous bone. Thin facial bone and inadequate embrasure space make crater removal from the facial approach more difficult. Ochsenbein and Bohannan (1964) classified craters as Class I, 2 to 3 mm deep with thick facial and lingual walls; Class II (most common), 4 to 5 mm deep with thinner facial and lingual walls; Class III, 6 to 7 mm deep with a sharp drop from the walls to a flat base; and Class IV (least common), a crater of varying depth but with very thin facial and lingual walls. Class I craters can be managed by palatal ramping, while Class II and III craters require both facial and palatal ramping. Class IV craters usually require removal of both the facial and lingual walls. The treatment of the maxillary first molar is complicated by a facial root trunk length that averages only 4 mm and prominent facial roots due to arch position, which result in less radicular bone covering the facial roots. The authors emphasize that exposure of furcations during osseous surgery must be avoided.

Lingual Approach. Tibbetts et al. (1976) described the lingual approach to osseous surgery for the mandibular posterior area. Factors (advantages) supporting a lingual approach to osseous surgery in the mandibular posterior area include 1) avoidance of thick shelves of bone (e.g., external oblique ridge) which limit elimination of osseous defects facially; 2) presence of shorter root trunk lengths on the facial of mandibular molars; 3) lingual inclinations of the mandibular posterior teeth (9° for second premolar; 20° for molars), which places the lingual furcation more apical; 4) more lingual location of interdental craters (directly below the contact area); and 5) the creation of better access for surgery and hygiene, since the lingual embrasure is usually wider than the facial. Additional advantages to the lingual approach include: thicker bone; more attached gingiva; and greater vestibular depth on the lingual. Precautions include avoidance of the lingual nerve and artery.

Effects of Osseous Resective Surgery. Selipsky (1976) reported that properly performed osseous resective surgery results in an average loss of 0.6 mm of supporting bone height around the circumference of the tooth (maximum circumferential loss 1.5 mm). The maximum supporting bone lost around a single root surface was 3.0 mm. More bone was removed when treating isolated defects. Removal of buccal or lingual bone has a smaller impact on tooth support than removal of interproximal bone, due to the smaller surface area of buccal and lingual roots. Teeth treated with osseous resection had increased mobility that returned to the presurgical levels after 1 year. The technique sequence described for osseous resection includes: vertical grooving between teeth and roots; buccal and lingual osteoplasty; removal of lips of remaining craters; and buccal and lingual ostectomy. The author felt that vertical grooving prevented overzealous ostectomy by making the roots more prominent, allowing the gingiva to assume a more scalloped architecture.

Intrabony Defect Depth Versus Root Trunk Length. Ochsenbein (1986) noted that the extent of osseous resective surgery depends on the relationship between depth of the interproximal defects and molar root trunk length. Maxillary molars have short root trunks (3 to 5 mm, average 4 mm) based on measurements from the CEJ to the furcation entrance. Respective measurements for mandibular molars are 2 to 4 mm (average 3 mm). Shallow craters (1 to 2 mm) can usually be eliminated by a palatal approach even in the presence of short root trunk length. If complete elimination of medium (3 to 4 mm) or deep (> 5 mm) defects would result in furcation exposure or reverse architecture, only partial crater elimination should be attempted. Craters in the maxillary premolar regions are usually palatally located and can be treated from a palatal approach. The author suggested that osseous craters in the maxillary anteriors should be treated without osseous resection for esthetic reasons and that mandibular molars should be managed with the lingual approach, while avoiding unnecessary removal of bone adjacent to teeth. In the case of deep craters, compromised treatment may be necessary, including acceptance of reverse architecture.

Healing after Osseous Resective Surgery

Resorption of Exposed Bone. Pfeifer (1963) histologically evaluated the healing response of normal human bone following apical positioning of flaps 2 mm below crestal bone. Leaving bone exposed resulted in minimal bone resorption. Bone and soft tissue repair was rapid with connective tissue proliferating from the PDL at days 2 through 10, resulting in a 2 mm or greater band of connective tissue attachment to the root. Osteoclastic activity peaked at 4 to 10 days.

Osteoplasty Versus Flap Curettage. Donnenfeld et al. (1970) compared osteoplasty to flap curettage by examining pocket elimination, clinical attachment level, and alveolar bone height in four patients. Control segments were treated surgically with defect and root debridement, while experimental segments were treated similarly but included osteoplasty. Results indicated that pockets were eliminated in all control and experimental areas. Osteoplasty sites lost more

bone and attachment than the control sites; however, differences were not statistically significant. Re-entry at 6 months suggested that flap reflection alone resulted in comparable osseous reshaping to that obtained by osteoplasty, but that the combined effect of "bone grinding" and remodeling can contribute to greater reduction of bone support than the flap procedure alone. The authors concluded that the need for grinding to establish an ideal bony architecture is not necessary for gingival health.

Temporary Versus Permanently Exposed Bone. Wilderman (1964) studied healing of alveolar bone in dogs following temporary exposure (replaced flap) and permanent exposure (denudation or apically positioned flap). Permanent bone exposure resulted in undermining resorption of alveolar bone at 2 to 10 days. Interdental and furcation areas consist of a broad base of cancellous bone which will repair completely. Radicular bone generally consisted of a thin zone of cancellous bone between cortical plates and regenerated to 50% of its original height. From 6 to 14 days, soft tissue repair occurred by migration of granulation tissue from wound edges and exposed PDL. By 21 days, epithelial proliferation from the wound edges covers newly formed granulation tissue, with complete epithelial and connective tissue maturation complete by 6 months. Temporary bone exposure (replaced flap) resulted in resorption (days 4 to 8) followed by repair at 21 to 28 days. Unlike permanent bone exposure (undermining resorption), bone healed by primary intention with almost total repair. The author demonstrated gain in attached gingiva when alveolar bone was denuded, but at the expense of alveolar crest height (2 to 4 mm loss) and/or vestibular depth. Osseous denudation resulted in the least amount of bone loss in areas of broad crestal bone with adequate marrow spaces. Disadvantages of denudation included postoperative pain, slow healing, and potential bone loss. Replaced flap procedures minimize these adverse effects. With the exception of the lateral sliding flap, the author discouraged the use of split thickness flaps (restricted visibility and access to bone), deferring to full thickness flaps.

Long-Term Healing Following Flap and Osseous Surgery. Wilderman et al. (1970) studied long-term histologic repair of human tissue following mucogingival flap and osseous surgery and reported that osteoblastic activity was still present 1 year post-osseous surgery. Initial crestal bone loss of 1.2 mm followed by 0.4 mm of new bone apposition resulted in an average reduction in the alveolar crest height of 0.8 mm. Bone thickness was an important determining factor of the amount of post-operative bone loss. Thick bone with marrow spaces exhibited less resorption and greater repair than thin bone. Similar values were reported by Moghaddas and Stahl (1980) in humans 6 months following osseous surgery. The authors used a facial approach to eliminate osseous craters and reported occurrence of remodeling during healing. At 6 months, loss of crestal bone at interdental, radicular, and furcation sites was 0.23 mm, 0.55 mm, and 0.88 mm, respectively. The authors concluded from re-entry measurements and stone models that regeneration of crestal bone does not occur and that healing occurs by repair. Following treatment of ligature-induced angular bony defects in monkeys, Caton and Nyman (1981) reported a loss of connective tissue attachment of 0.45 mm 1 year after ostectomy and a reduction of 0.6 mm in interdental bone height.

Long-term healing results following flap and osseous surgery are summarized in Table 1.

The effect of rotary diamond instrumentation on alveolar bone in dogs was studied by Lobene and Glickman (1963). At 28 days following thinning of facial radicular bone with slow speed, water cooled, rotary diamonds, bone levels ranged from 0.1 mm gain to 1.7 mm loss (mean 0.88 mm loss). In control sites (flap reflection only), facial bone levels ranged from 0.1 mm gain to 0.5 mm loss (mean 0.13 mm loss). The authors reported that final post-surgical bone contours could not be predicted at surgery because of the extensive bone remodeling occurring after grinding. It was also concluded that grinding on alveolar bone results in bone necrosis, reduction in bone height and delayed healing.

Long-Term Effectiveness of Osseous Resective Surgery

Lindhe and Nyman (1975) published 5-year results of an evaluation of 1,620 teeth in 75 patients who had advanced periodontal disease and were treated with surgical pocket elimination. Prior to surgery, 113 of 247 teeth with furcation invasion (45%) were extracted. The remaining 134 teeth with furcation invasion were treated by scaling/root planing or furcation odontoplasty (41%), root resections (51%), and tunneling procedures (7%). All patients had excellent oral hygiene and were recalled every 3 to 6 months for 5 years. At 5 years, plaque and gingival index scores were decreased; probing depths decreased from a mean of 5.7 mm to less than 3 mm; radiographic bone scores indicated no further bone loss; mobile teeth decreased from 57% to 26%; and no teeth were lost. Of the original 75 patients in the aforementioned study, 61 were evaluated at 14 years after osseous surgery (Lindhe and Nyman, 1984). The results reported at 5 years were maintained at 14 years in most patients. Only 0.8% of the sites developed $>$ 2 mm loss of attachment. The authors concluded that pocket elimination surgery combined with good oral hygiene and periodic scaling and root planing resulted in periodontal health.

Comparative Studies

The effectiveness of osseous surgery and open flap curettage was studied by Smith et al. (1980). Twelve patients with moderate periodontitis were included in the study. Two to 3 months after presurgical therapy, contralateral posterior sextants were treated with either apically positioned flaps with osseous recontouring, as described by

TABLE 1. EFFECTS OF OSSEOUS SURGERY ON BONE HEALING

Study	Model	Healing Time	Results
Pfeifer (1963)	Human	21 days	Leaving bone exposed resulted in minimal bone resorption.
Lobene and Glickman (1963)	Dog	28 days	Osteoplasty with diamond rotary instruments resulted in more bone loss (0.88 mm average) than flap reflection alone (0.13 mm average).
Wilderman et al. (1970)	Human	545 days	Osseous surgery resulted in 0.8 mm net reduction of alveolar crest (initial loss of 1.2 mm followed by 0.4 mm new bone apposition).
Donnenfeld et al. (1970)	Human	6 months	Grinding on bone with subsequent remodeling resulted in greater attachment loss than flap elevation alone (serious) weaknesses in this study.
Moghaddas and Stahl (1980)	Human	6 months	Osseous surgery resulted in 0.23 mm interdental bone loss; 0.55 mm loss in alveolar crestal bone height; and 0.88 mm furcation bone loss.
Caton and Nyman (1981)	Monkey	12 months	Osseous surgery resulted in 0.45 mm attachment loss and 0.6 mm interdental bone loss.

Ochsenbein and Bohannan (1963, 1964) and Tibbetts et al. (1976) or open flap curettage. Both procedures were equally effective in reducing plaque, inflammation and probing depth; however, pocket reduction achieved by osseous recontouring was maintained over 6 months while pockets tended to recur after open flap curettage. Osseous surgery resulted in a net loss of attachment of 1.4 mm and open flap curettage resulted in an attachment gain of 0.9 mm. The authors concluded that either procedure could achieve periodontal health.

Olsen et al. (1985) published a 5-year follow-up on 8 of the 12 patients from the aforementioned study. Patients were placed on 6-month recall for the first 2 years and 3-month recall for the last 3 years. At 5 years, plaque and gingival indices for both procedures were similar, but osseous surgery resulted in greater pocket reduction and attachment loss.

Becker et al. (1988) published results comparing scaling, osseous resection, and modified Widman flap procedures on posterior teeth in 16 patients. Patients were seen every 3 months for maintenance. The results after 1 year showed that both modified Widman and osseous surgery are effective in reducing pockets with each resulting in a slight gain of clinical attachment at 1 year. Scaling was effective at maintaining attachment levels but was not as effective in reducing pocket depth.

Kaldahl et al. (1988) reported the 2-year results of a longitudinal study comparing coronal scaling, root planing, modified Widman flap and flap with osseous resective surgery in 82 patients. Results indicated that 1) all therapies reduced probing depth; 2) osseous resection was the most effective in reducing probing depth; 3) probing depths increased in direct proportion to the depth of the pocket; 4) osseous resection produced loss of clinical attachment in the 1 to 4 mm pocket; 5) modified Widman flap and root planing produced the greatest gain of clinical attachment in 5 to 6 mm pockets; and 6) osseous resection resulted in the most recession.

Justification for Osseous Surgery

Disease Activity Studies. In a 1990 study, Badersten et al. monitored non-molar teeth in 39 subjects for 5 years after S/RP seeking a clinical value that may be predictive of loss of probing attachment level > 1.5 mm. The positive predictive value of residual probing depths > 7 mm was 52%, while an increase in PD > 1.0 mm was 78%.

Claffey et al. (1990): 17 patients were monitored for 3.5 years after S/RP to determine a clinical value that may be predictive of loss of probing attachment level > 1.5 mm. They reported a positive predictive value of residual probing depth > 7 mm of 50%. A combination of residual probing depth > 7 mm and bleeding frequency > 75% had a positive predictive value of 67%.

Microflora/Plaque. The following observations were made by Waerhaug (1978A): If complete subgingival plaque removal has occurred, and adequate supragingival plaque control is instituted, no further subgingival plaque will be formed, and periodontal health can be maintained. In 8 out of the 39 experimental teeth (teeth with at least 2 mm of probeable calculus subjected to S/RP), some subgingival plaque remained following scaling, and these remnants gave rise to a rapid reformation of plaque within the pocket. Small or large remnants of subgingival plaque do not cause clinically symptomatic inflammatory reactions if a high standard of supragingival plaque control is maintained. This is the origin of the term "submarginal gingivitis."

In a subsequent study, Waerhaug (1978B) made the following observations. The deeper the pocket depths, the poorer the plaque removal. The numbers for incomplete subgingival plaque removal were: < 3 mm (17%); 3 to 5 mm (61%); > 5 mm (89%). If it is completely removed and supragingival plaque is adequate, then subgingival plaque will not regenerate. The author's definition of a sulcus was a plaque-free crevice. His definition of a pathologic pocket was one with subgingival plaque attached to the root surface. Since plaque reformation is a slow process, it may take months or a year to completely reform. Waerhaug felt that the most predictable means for obtaining adequate sub-

gingival plaque control was to eliminate pathologic pockets ≥ 3.0 mm. Armitage et al. (1982) found a positive correlation between the percentage of subgingival spirochetes and probing depth.

SUMMARY

The principal goal of osseous surgery is the creation of a bony architecture which is compatible with the maintenance of a physiologic gingival architecture (Schluger, 1949).

The amount of bone removed during properly performed osseous resective surgery is minimal and should be considered clinically insignificant; judicious osteoplasty facilitates improved flap adaptation (Selipsky, 1976). Osseous resective surgery effectively reduces probing depth, but is accomplished by clinical attachment loss. Root planing and modified Widman flap procedures result in the greatest gains in clinical attachment, but do not reduce probing depths as effectively as osseous reflective surgery (Kaldahl et al., 1988).

Indications for osseous surgery include thick ridges of bone; tori; exostoses; incipient furcation invasions; furcation invasion defects; furcation invasions requiring root amputation or hemisection; shallow craters; and minor angular defects (Barrington, 1981).

Contraindications for osseous resective surgery include anatomic limitations, esthetic limitations, inadequate or potentially compromised periodontal attachment, and instances where alternative therapy would be more effective (Wilson et al., 1992).

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Section 7. Root Resection and Odontoplasty

DEFINITIONS

Root Resection: Surgical removal of all or a portion of a tooth root.

Root Amputation: The removal of a root from a multi-rooted tooth.

Hemisection: The surgical separation of a multi-rooted tooth, especially a mandibular molar, through the furcation in such a way that a root and the associated portion of the crown may be removed.

Indications for Root Resection

Indications include: 1) severe bone loss affecting one or more roots; 2) Class II or III furcation invasions/involvements; 3) unfavorable root proximity with adjacent teeth; 4) root fracture, perforation, root caries, or root resorption involving 1 or more roots; and 5) when required endodontic treatment of a particular root cannot be effectively performed (Basaraba, 1969).

Contraindications to Root Resection

Contraindications include: 1) insufficient bone supporting the remaining root(s); 2) unfavorable anatomical situations (i.e., long root trunk, convergent or fused roots); 3) significant discrepancies in adjacent proximal bone heights; 4) impossible to perform required endodontic treatment for the remaining root(s); 5) lack of usefulness of remaining root(s); and 6) non-restorability of the remaining root(s) (Basaraba, 1969).

Endodontic Therapy and Root Resection

Haskell et al. (1980) reported 12 cases of vital root amputation of maxillary molars. A pulp cap, consisting of calcium hydroxide powder, zinc-oxide eugenol cement, and an amalgam alloy seal was placed. Within 5 months, 3 of the 12 teeth lost vitality, 1 tooth was removed for periodontal reasons after 7 months, and 8 of the 12 continued to test clinically vital at 1 year. Histological evaluation of the tooth extracted for periodontal reasons demonstrated an almost complete dentin bridge adjacent to the mummified zone where CaOH was attached to the amputation site.

Filipowicz et al. (1984) followed 86 maxillary molar vital root amputated teeth for 9 years. Dycal and amalgam restorations were placed over the pulp stumps. At 6 months, 41% were non-vital; 62% at 1 year, and 87% at 5 years. Gerstein (1977) concluded that vital root resection with anticipated long-term vitality is a high-risk procedure.

Teeth known to require root resection should receive endodontic treatment prior to resection, while teeth with questionable need for amputation should be assessed at the time of periodontal surgery. If resection is accomplished prior to endodontic therapy, pulpal follow-up should be accomplished as soon as possible. Smukler and Tagger (1976) determined that endodontic therapy can be delayed for 2 weeks after vital root amputation without severe adverse clinical or histological effects. Although pulp stumps were left exposed to the oral cavity, no spontaneous pulpal pain occurred 2 weeks post-amputation. Pulp polyps occurred in 11 of the 26 teeth (21 maxillary molars, 5 mandibular molars) and thermal sensitivity increased in 12 teeth. While endodontic therapy was not greatly hindered by the procedure, difficulty in achieving anesthesia was encountered in most teeth. Periodontal healing was unaffected by delaying endodontic therapy.

Longitudinal Studies of Molar Teeth—Resection Versus Non-Resection

Erpenstein (1983) reported 1 to 7 year (mean 2.9 years) re-evaluations of 34 root resected molars (7 maxillary molars, 27 mandibular molars); only 9 of the resections were accomplished for periodontal reasons. Only 4 of the 34 teeth were evaluated for longer than 5 years. Seven teeth failed, 6 for endodontic and 1 for periodontal reasons. Resections were accomplished with and without surgical access and no osseous surgery was done.

Hamp et al. (1975) treated 310 periodontally involved multirooted teeth. Forty-four percent (44%) were extracted during initial treatment and 50% (87) of the remaining teeth received root resection. Resections were accomplished during pocket elimination surgery. Only 1 root was preserved in 25 of 39 (64%) root-resected maxillary molars. None of the resected teeth were lost during 5 years of maintenance therapy, although 5 developed caries. The authors contributed their success to total elimination of plaque retention areas in the furcations and meticulous patient oral hygiene in conjunction with regular maintenance therapy. In a 10-year follow-up study, Langer et al. (1981) reported on 100 teeth (50 maxillary molars, 50 mandibular molars) which had received root resection primarily for periodontal reasons. In the first 5 years, only 16% of the teeth failed; however, by 10 years, 38% had failed (84% of all failures occurred between 5 and 10 years). Root fracture accounted for 47.4% of the failures, progressive periodontal breakdown for 26.3%, endodontic failure for 18.4%, and cement washout for 7.9%. Nearly twice as many mandibular molars failed as maxillary molars. Mandibular teeth primarily failed due to root fracture (15/25), while periodontal breakdown accounted for most maxillary failures (7/13). The authors attributed the high incidence of fractures to parafunctional nocturnal habits, small size of roots, and weakening of the tooth due to endodontic and prosthetic (post and cores; long spans) treatment.

Green (1986) observed 122 molar teeth (1 to 20 years) that had received root resection following furcal invasion. Sixty-two (62) of these teeth were lost with 24% (15) of the failures occurring during the first 5 years; 58% during the first 8 years; and 73% during the first 10 years. Loss was primarily due to continued breakdown of the periodontium despite 3 to 6 month maintenance.

Buhler (1988) evaluated 28 root resected teeth over a 10-year period. No failures occurred during the first 4 years, 10.7% (3) failed during 5 to 7 years, and a total of 32.1% (9) had failed by 10 years. Failure included endodontic reasons (3), periodontal reasons (2), combination endo-periodontal reasons (2), root fracture (1), and prosthetic reason (1).

Carnevale et al. (1991) studied 488 resected molars, reporting the results for the 3 to 6 year group (62.4%) and a 7 to 11 year group (37.6%). The major reason for resection was periodontal, including Class II or III furcation invasion (81.4%), and deep marginal osseous defects (16.2%). Resection due to endodontic reasons accounted for only 2.2%. All teeth received cast restorations and only 12.8% were restored with single crowns. There were 28 failures (5.7%), 18 of which required extraction. The highest cause of failure was root fracture, followed by caries. Of the failing teeth, there was a higher percentage of teeth requiring extraction in the group that failed due to caries. Only 3 teeth (0.6%) had a recurrence of periodontal breakdown (PD > 5 mm). A higher rate of failure and tooth loss was observed in the 3 to 6 year group when compared to the 7 to 11 year group. A low rate of endodontic failure was found. Only 4 teeth were extracted for endodontic problems, 3 teeth received retrograde fillings, and 2 teeth were endodontically retreated. Undoubtedly, furcation sites respond differently than non-furcation sites.

Kalkwarf et al. (1988) reported additional attachment loss in furcations 2 years post-treatment despite various treatment modalities/quadrant consisting of coronal scaling only, scaling and root planing, scaling and root planing plus modified Widman surgery, and scaling and root planing plus osseous resection. Retrospective longitudinal studies have consistently recorded a high mortality of teeth with furcation invasion regardless of whether the patient's response was categorized as well-maintained, downhill, or extreme downhill (Table 1).

Ross and Thompson (1978) maintained 88% (341/387) of maxillary molars with furcation invasion over a period of 5 to 24 years without root resection or osseous surgery. Treatment consisted of scaling, curettage, occlusal adjustment, gingivectomy/gingivoplasty, and apically positioned flaps in areas of minimal attached gingiva. Eighty-four percent (84%) of these molars had an initial loss of > 50% radiographic bone loss. Forty-six (46) molars were extracted, with 33% (15) functioning for 11 to 18 years and 22% (10) for 6 to 10 years following initial treatment.

Prosthetic Treatment of Root Resected Teeth

Gerstein (1977) advocated full coronal coverage due to the high risk of fracture in endodontically treated root resected teeth. Loss of integrity of the marginal ridge, transverse ridge, and encroachment on the buccal-lingual cusp thickness predisposes the tooth to fracture. A thorough knowledge of the anatomy of the tooth after root resection is essential because the final crown preparation is dictated by the unique contours of the remaining portions of the resected tooth. Abrams and Trachtenberg (1974) advocated: the use of a provisional restoration to resolve any problems in restorative contour, plaque control, and gingival health; smooth continuous contours adjacent to the missing root; adequate embrasures for hygiene access; and flat or concave transitional line angles. Basaraba (1969) recommended: occlusal narrowing; establishment of centric contacts that direct forces along the long axis of the tooth; and elimination of all lateral contacts in root resected teeth.

Keough (1982) noted that root resection in maxillary molars creates an L-shaped configuration when viewed from an occlusal aspect. When the angle between the two legs of this "L" is acute, a cul-de-sac is present which hinders oral hygiene access. The restoration should be designed to compensate for this angle and allow access to this area. Root concavities dictate the outline of the final preparation, and the periodontist should perform odontoplasty (barrel-in) coronal to these concavities to ensure a restoration that will conform to the contour of the remaining tooth.

Majzoub and Kon (1992) performed disto-facial root amputations on 50 extracted maxillary molars and measured the radicular areas. The mean concavity depth on the distal aspect of the teeth was 2.47 mm. The mean minimal mesio-distal dimension of remaining tooth structure was 3.67 mm. The mean distance from the floor of the pulp chamber to the most coronal area of root separation was only 2.70 mm. The results suggest that the depth of concavity will significantly impact maintenance and hygiene; the minimal width of tooth structure can favor fracture; the narrow dimension from chamber floor to furcation opening will often violate biologic width (2.04 mm).

Although splinting of root resected teeth has been advocated in the past, Klavan (1975) observed that removal of 1 root of a maxillary molar does not increase the mobility of the tooth in normal function and that splinting does not seem to be indicated. Only 3 of 33 resected maxillary molars examined had measurable mobility during the 11 to 84 month post-resection evaluation. Two of these 3 teeth were removable partial denture abutments. The author concluded that the use of resected teeth for removable partial denture abutments seems questionable at best.

Tunnel Preparations

Hamp et al. (1975) described the use of a tunnel to provide a complete opening of the furcation, enabling post-surgical access with an interdental toothbrush, and aiding elimination of pathologically deepened soft and hard tissue pockets. They reported 5-year post-tunnel treatment of 7 teeth (6 mandibular first molars and 1 maxillary first premolar) with initial degree III furcation invasion. Three of the teeth had probing depths exceeding 3 mm while 4 of 7 (57%) had caries within the tunnels (3 were extracted).

Hellden et al. (1989) evaluated 149 teeth which had received tunnel preparation 10 to 107 months earlier (mean

37.5 months). The majority of probing sites were less than 3 mm, 11.5 to 36.6% ranged from 4 to 6 mm, and less than 3.8% were greater than 6 mm. Overall, 23.5% of the teeth developed caries. Carious lesions were equally distributed between "inside the tunnel," "outside the tunnel," or a combination of both locations. When root caries incidence was expressed as percent of available root surfaces, 11% of the surfaces developed caries. When compared to Ravald and Hamp's (1981) findings of less than 5% incidence of new caries on exposed root surfaces 2 and 4 years following surgical treatment, tunneled teeth appear to be at higher risk for the development of caries (Table 2).

TABLE 1. PERCENT OF TEETH LOST INITIALLY DIAGNOSED WITH FURCATION INVASION

	Well-Maintained	Downhill	Extreme Downhill	Total
Hirschfeld and Wasserman, 1978	19.3%	69.9%	84.4%	31.4%
McFall, 1982	27.3%	68.9%	92.3%	56.9%
Goldman et al. 1986	16.9%	66.0%	93.0%	43.5%

SUMMARY

Root resection is accepted as a valid treatment modality, when the extent of periodontal involvement dictates (Basaraba, 1969). Endodontic therapy should be completed prior to resection if root resection is a certainty; however, when resection is uncertain, vital root resection can be accomplished during periodontal surgery with minimal sequelae. Endodontic therapy should follow vital root resection in a timely manner. Resection should be accomplished via surgical access. Improved root access allows for proper debridement, pocket elimination, improved flap adaptation, and proper contouring of the resected surface. The distofacial root is the most commonly resected root of maxillary molars, while the mesial root is the most commonly resected root of mandibular molars. The restorative treatment plan should be tailored to the individual tooth. Restorative treatment should allow for adequate access for hygiene and elimination of lateral occlusal forces. Resected teeth may not perform well as removable partial denture abutments. Teeth with tunnel preparations should be monitored closely as they are at increased risk for caries development.

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TABLE 2. ROOT RESECTION STUDIES

Study	Length	Number and Type of Teeth	Root(s) Resected	Reason for Resection	Number Lost and Cause	Additional Findings
Hamp et al. 1975	5 years	87 teeth (39 maxillary molars; 44 mandibular molars; 4 premolars)	DB = 31 MB = 18 P = 15 M = 25 D = 19	Furca involvement	None lost at 5 years	25 maxillary molars had 2 roots removed; 135 of initial 310 multirooted teeth extracted during initial tx; 5 resected teeth developed caries
		7 tunnels (6 mandibular molars)			3 extracted due to caries	4/7 developed caries; 3/7 had pocket depths > 3 mm
Klavan 1975	11-84 months (mean 38.4 months)	34 maxillary molars	DB = 32 MB = 2 P = 1	Periodontal involvement	Abscess and furca invasion, 1	24 not splinted 7 FPD abutments 2 RPD abutments (both became mobile)
Smukler and Tagger 1976	2 weeks	26 molars (21 maxillary 5 mandibular)	DB = 13 MB = 5 P = 3 M = 2 D = 3	Became necessary in course of routine periodontal practice	NA	Pulp polyps formed in 11 Thermal sensitivity in 12 (no coverage of exposed pulps)
Haskell et al. 1980	1-3 years	12 maxillary molars (1st molar = 11)	DB = 8 MB = 4	Intrabony lesions around at least one root	Periodontal conditions, 1	Vital root amps, 8/12 vital at one year

Table 2. Continued

Study	Length	Number and Type of Teeth	Root(s) Resected	Reason for Resection	Number Lost and Cause	Additional Findings
Langer et al. 1981	10 years	100 molars (50 maxillary 50 mandibular)	NA	Most due to periodontal condition (no number given)	Root fx = 18 Periodontal condition = 10 Endodontic = 7 Cement washout = 3	Maxillary failures 13 (perio = 7) Mandibular failures 25 (fx = 15) 4 years = 6% failure 7 years = 27% failure 10 years = 38% failure (84% of failures occurred at 5-10 yrs)
Erpenstein 1983	1-7 years (mean 2.9)	34 molars (7 maxillary, 27 mandibular)	DB = 1 MB = 4 P = 1 M = 24 D = 3	Periodontal condition = 9 Endodontic = 20 Caries = 4 Other = 1	Periodontal = 1 Endodontic = 6	Only 16 patients had periodontal examination recorded; of these, 9 had advanced periodontitis
Filipowicz et al. 1984	5 years	86 maxillary molars	NA	NA	6 months (41% non-vital) 12 months (62% non-vital) 5 years (87% non-vital)	Vital root amps Dycal and amalgam Pulp caps
Green 1986	1-20 years	122 molars	NA	All had furca invasion	62 failures (41 maxillary, 21 mandibular), most due to periodontal breakdown	
Buhler 1988	10 years	28 teeth (16 maxillary molars, 1 premolar 14 mandibular molars)	DB = 15 MB = 5 P = 4 M = 13 D = 1	Periodontal treatment	fx = 1, Periodontal condition = 2 Endodontic = 3 Periodontal condition/ endodontic = 2 Other = 1	4 years = 0 failures 7 years = 10.7% failure 10 years = 32.1% failure
Hellden et al. 1989	10-107 months (mean 37.5)	149 teeth (6 maxillary premolars; 91 maxillary molars; 52 mandibular molars)			6 extracted due to caries 6 hemisected due to caries 3 others extracted 23 additional molars developed caries	23.5% developed caries; 11% of surfaces

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Section 8. Osseous Grafting

DEFINITIONS

Regeneration: Reproduction or reconstitution of a lost or injured part.

Repair: Healing of a wound by tissue that does not fully restore the architecture or the function of the part. Historical note: Although in the past, fiber orientation was used to determine new attachment, it is now believed that parallel fibers can be a result of early stages of periodontal ligament (PDL) development or a parallel orientation may be the result of low power microscopic evaluation (at higher magnifications, fibers appear attached in a perpendicular manner).

Reattachment: To attach again. The reunion of epithelial and connective tissues with root surfaces and bone such as occurs after an incision or injury. Not to be confused with new attachment.

New Attachment: The union of connective tissue or epithelium with a root surface that has been deprived of its original attachment apparatus. This new attachment may be epithelial adhesion and/or connective tissue adaptation or attachment and may include new cementum.

Osteogenesis: Development of bone; formation of bone.

Autograft: Tissue transferred from one position to another within the same individual.

Allograft: A graft between genetically dissimilar members of the same species.

Goal of Osseous Grafting

Schallhorn (1972) reported that the objectives of osseous grafting were pocket elimination, restoration of the lost alveolar process, and regeneration of a functional attachment apparatus.

Factors Influencing Graft Success

Factors include: oral hygiene, defect morphology (number of walls, narrow versus wide), furcation involvement, operator technique, and graft material used. Another characteristic that may influence grafting success is the particle size of the graft material. Zaner and Yukna (1984) examined particle size of autogenous bone obtained by high and low speed burs and hand chisels, freeze-dried bone allograft obtained from a bone bank, and several alloplastic implant materials. They determined that bone-blend had the smallest and most uniform particle size (210 x 105 μm) and hand chiseled bone chips, the largest and least uniform particle size (1559 x 789 μm). Grafts obtained with high and low speed burs had a particle size of roughly 300 to 500 μm. Since a minimum pore size of 100 μm is needed between particles to allow vascularization and bone formation, it was concluded that a particle size of about 380 μm would be most appropriate.

GRAFT SOURCES

Autografts

Autogenous **iliac crest marrow** grafts are considered the most predictable method of osseous regeneration. This may be due to osteogenic, osteoinductive, and osteoconductive properties associated with undifferentiated cells or osteoblasts surviving within the graft material that may form new bone; necrosis of the graft material and release of substances that may stimulate new bone formation; and nonviable cellular elements within the graft that may act as a scaffold for new host bone formation. In a study of 182 transplant sites, Schallhorn et al. (1970) utilized fresh and frozen cancellous bone and marrow from the iliac crest. The mean increases in crestal bone height in "no-wall" defects was 2.57 mm. While 1-walled defects demonstrated complete fill in 11 of 21 sites and a mean increase in bone height of 3.75 mm, 2-walled defects all demonstrated complete fill to the coronal margin of the existing bony walls with a mean increase in bone height of 4.18 mm. Overall, the mean bone fill for all defects was 3.33 mm. Teeth with furcation invasion (mostly Class II) demonstrated complete furcation fill in 7 of 8 sites, while the remaining furcation showed partial fill of two-thirds of the original defect. The mean increase in height of the furcation grafts was 4.5 mm. The frozen specimens demonstrated the greatest mean bone apposition, which was believed to be due to cellular breakdown and release of an inductive substance. New attachment was present at 3 months.

Dragoo and Sullivan (1973A) evaluated fresh autogenous iliac bone grafts clinically and histologically over a 2 to 8 month period. Clinically, there was a 2.1 mm increase in bone level as measured by bone sounding and a 1.56 mm radiographic increase, with the difference attributed to measurement error. Histologically, the authors found 1.4 mm of gingival recession, 1.02 mm sulcus depth, 1.34 mm of epithelial attachment, a connective tissue attachment of 1.02 mm, and supracrestal bone regeneration of 0.7 mm. New cementum was present as early as 2 months, with a functionally oriented PDL noted at 3 months. Osteoblastic activity was greatest at 2 months, but persisted at 8 months. Also at 8 months, the PDL was completely matured. Autogenous iliac crest marrow may be used fresh or may be stored prior to use. In a study in dogs, Bierly et al. (1975) found that iliac bone could be stored in minimum essential medium (MEM) at refrigeration temperature (4°) for a maximum of 7 days before sustaining a dramatic decrease in graft viability. Sottosanti and Bierly (1975) reviewed storage techniques for iliac marrow. They suggested that mar-

row to be used within 7 days of harvest could be stored in MEM in a standard refrigerator and that marrow to be stored longer than 7 days should be placed in MEM containing 12 to 15% glycerol as a cryopreservative and then slowly cooled prior to placement in freezer. Material should not be stored frozen for longer than 2 months. When ready for use, the authors state that the marrow should be quickly warmed in a 37°C water bath prior to placement. They felt that there was no need to remove the glycerol at this low concentration. Marx et al. (1979) studied cellular survival of iliac marrow-cancellous bone specimens over a 4-hour period by placing cell suspensions in 6 different media and testing each specimen every half-hour using vital dye exclusion and tritiated thymidine uptake to measure the percent viability. Five percent dextrose in water (D5W), normal saline, and tissue culture medium number 199 demonstrated 92 to 100% cell viability over the 4-hour period. Distilled water retained 0% viable cells. This study showed that a high survival rate can be obtained with D5W, normal saline, or tissue culture media with long delays (4 hours) between harvest and placement of the graft.

Schallhorn (1972) described 5 categories of postoperative complications associated with autogenous iliac grafts including infection; sequestration (the most common complication); variable healing time; rapid defect recurrence related to poor oral hygiene; erratic maintenance schedules or poor nutritional status; and root resorption. Viability of the marrow elements is thought to play a role in root resorption, with previously frozen marrow not demonstrating a resorptive association. Excessive root preparation with dentin exposure, hypermobility, and hypomobility have also been implicated in root resorption. Dragoo and Sullivan (1973B) reported that 2.8% of 250 sites which received fresh iliac grafts showed root resorption. Furthermore, root resorption was always associated with chronic inflammation of the adjacent gingiva, while resolution of the inflammation was accompanied by arrest and repair of the resorptive lesion. All cases of root resorption originated at or coronal to the bony crest. Possible etiologic factors include undifferentiated cells from the marrow, proteolytic enzyme activity of PMNs, macrophages, and other host cells and spread of the resorptive process from sequestered bone.

Autogenous intraoral bone has also been used as donor material in osseous grafting. High or slow speed handpieces, chisels, trephines, or rongeurs may be used to remove bone from donor sites. In addition, a technique has been described where bone from an area adjacent to the defect is forcibly pushed into direct contact with the root surface without separating the bone from its base. This procedure was called bone swaging by Ewen (1965) or a contiguous autogenous transplant by Ross et al. (1966).

Diem et al. (1972) introduced a **bone blend** and its preparation in which intraoral cortical and/or cancellous bone from an extraction site, edentulous ridge, exostosis, or the region of the defect was placed in a sterile amalgam capsule with a pestle and triturated for 60 seconds.

Hiatt and Schallhorn (1973) compared grafts with **cortical-cancellous** material obtained from the maxillary tuberosity, edentulous ridges, and extraction sites to those using iliac crest bone. A mean increase in bone height of 3.44 mm accompanied intraoral bone grafts. Measurements taken from 9 months to 7 years, consisting of radiographic evaluation and measurement of bone height, re-entry, or bone sounding showed no significant difference between the 3 types of donor tissue. With the exception of furcations and crestal defects, the results of grafts using intraoral bone were comparable to those obtained with iliac grafts. Histologic evaluation of a single block section demonstrated formation of new cementum, bone, and PDL. The importance of site morphology was discussed with an increased number of osseous walls resulting in an increased predictability and degree of success. The authors noted that marrow from the maxilla had the greatest probability of containing foci of red marrow with associated pleuripotential cells. Kucaba and Simpson (1978) investigated the maxillary tuberosity for presence of hematopoetic marrow. They found that 53% of autopsy specimens contained red marrow mainly located in the most superior, posterior aspect of the tuberosity. However, none of the 11 specimens taken from these sites in live patients during periodontal surgery contained hematopoetic marrow.

Other sources of intraoral graft material include edentulous ridges, exostoses/tori, healing extraction sites, and surgically-created osseous defects. Evian et al. (1982) investigated the optimal time period for obtaining graft material from extraction sites. They found that by 8 to 12 weeks there was a substantial quantity of mature bone present which contained osteoblasts and osteoid. Soehren and Van Swol (1979) noted that it took longer in the mandible (12 weeks) than in the maxilla (8 weeks) to obtain similar grafting material. The difference in maturation time between the maxilla and mandible may relate to the more vascular nature of the maxilla. The impacted third molar extraction site yielded the best material. Halliday (1969) used a trephine to surgically create defects in the mandible which were re-entered in 6 to 8 weeks for retrieval of graft material.

Langer and Geib (1977) evaluated early re-entry procedures after the placement of intraoral cancellous bone grafts from the tuberosity and extraction sites into combination 1-, 2-, and 3-walled defects. No pre-surgical initial preparation was completed at graft sites and surgical flaps did not completely cover the bone grafts. Re-entry with connective tissue fiber retention was performed 3 months following surgery. Upon re-entry, reattachment was judged by clinical connective tissue attachment. Results indicated that re-entry at 3 months did not adversely affect the maturation of a graft.

Robinson (1970) discussed the use of graft material derived from grindings of cortical intraoral bone which were mixed with blood to form an **osseous coagulum**. The author believed that this technique would offer an adequate source of bone as well as provide small particles. While success has been noted with this technique (Mellonig et al. 1981), no quantitation of results in large populations has been noted.

Allografts

Schallhorn and Hiatt (1972) treated 194 sites of varying morphology with **iliac crest allografts** which were matched to the patient by human lymphocyte antigen (HLA) typing. Success was determined by pre- and post-osseous charting 26 months after surgery. Bony apposition averaged 3.62 mm in 1-, 2-, and 3-walled defects; 3.30 mm in furcations; and 2.0 mm in no-walled defects for a total mean apposition of 3.07 mm. Limited histology indicated replacement of the allograft with viable bone and evidence of root resorption. While no adverse periodontal reactions were noted with grafts, 3 of 20 patients developed cytotoxic antibody activity to a panel of human lymphocytes.

Sepe et al. (1978) reported the use of **freeze-dried bone allografts** (FDBA) placed by 53 periodontists in over 800 defects with varying morphology. Re-entry on 189 sites was performed at 1 year and demonstrated that 60% of the sites had more than 50% bone fill. Osseous regeneration was least effective in the furcations. Again, no adverse effects were noted. In an attempt to compare osseous grafting with open flap curettage in a controlled manner, Altiere et al. (1979) treated 10 pairs of intraosseous defects. Irradiated FDBA was compared to control sites which received a flap curettage only. At 40 to 50 weeks, there was no significant difference between FDBA-treated defects and control defects with respect to pocket reduction, osseous regeneration, or amount of new attachment. While this study reports the worst performance of osseous grafts, it differs in that irradiated bone was used. This may remove or compromise the inductive potential present in the graft material.

Shapoff et al. (1980) found that small particles (100 to 300 μm) of FDBA enhance osteogenesis when combined with autogenous marrow to a much greater degree than do large particles (1000 to 2000 μm) of FDBA. They suggest that smaller particles may increase surface area around which new bone may form; increase the surface area for resorption, leading to exposure of greater amounts of bone morphogentic protein in the bone matrix and thus increase osteoinduction; increase the number of pores, physically enhancing osteogenesis; and/or enhance necrosis of marrow with release of osteogenic substances and facilitation of osteoblast differentiation. The reconstitution of FDBA with a tetracycline solution resulted in enhanced bone formation from 3 to 5 weeks in nylon mesh chambers placed in bony defects in maxilla and mandibles of baboons (Drury and Yukna, 1991).

Quattlebaum et al. (1988) investigated the antigenicity of FDBA in human periodontal osseous defects and could not detect anti-HLA antibodies in any of the 20 patients at any time. However, the authors also noted that it is possible that the amount of FDBA used during routine periodontal grafting procedures provides an insufficient antigenic challenge to the patient. The safety of FDBA was shown by Mellonig et al. (1992) who evaluated HIV-spiked human cortical bone and bone obtained from an AIDS patient. The bone was tested for the presence of HIV both before and after processing. The acid decalcification process and use of virucidal agents destroyed the HIV, thus showing the safety of DFDBA. Only 2 cases of HIV transmission from grafting have been known to occur and both were with unprocessed fresh or frozen bone allografts.

The osteogenic potential of **demineralized freeze-dried bone allografts** (DFDBA) has been investigated by Quintero et al. (1982). In a clinical study of DFDBAs in 1-, 2-, and wide 3- walled defects using a re-entry procedure at 4 to 6 months, these authors reported an average bone fill of 65% (2.4 mm). This was accompanied by a mean increase in probing attachment level of 1.9 mm. Histology was not performed, so the character of the new soft tissue attachment could not be determined. Mellonig et al. (1981) surgically created defects in guinea pig calvaria to evaluate the osteogenic potential of 4 different grafting materials. Samples of FDBA, DFDBA, autogenous osseous coagulum, and autogenous bone blend were placed in the defects and the areas examined histologically at varying time intervals. There was a significantly greater amount of new bone formation with the DFDBA than with any of the other materials. Osseous coagulum and bone blend were equally osteogenic/inductive, while the FDBA showed the least amount of new bone formation. Data from this animal model showed that the amount of new bone 28 to 42 days after grafting was virtually equal among the various grafting techniques.

Rummelhart et al. (1989) compared DFDBA to FDBA in 22 intra-patient paired defects in 9 patients. Grafted sites were re-entered 6 to 12 months post-operatively. No significant differences were found between treatment groups in any parameter measured. Mean osseous repair of 1.7 mm occurred with DFDBA and 2.4 mm with FDBA. The clinical response of both treatment groups may have been affected by a predominance (55%) of 1-walled defects treated.

Sanders et al. (1983) compared the clinical effects of FDBA alone and **composite FDBA/autogenous bone grafts** (FDBA/ABG) in a large number of 1-, 2-, and wide 3-walled defects as well as furcation defects. The ABGs were either bone blend, osseous coagulum, or iliac marrow. In results similar to Sepe et al. (1978), 63% of FDBA grafts showed more than 50% bone regeneration, while 80% of composite FDBA/ABG grafts resulted in more than 50% bone fill, with complete fill in 33%. Successful grafts (50%

bone fill) were related to good primary wound closure and vital teeth. The difference was most pronounced in furcations and 1- and 2-walled defects. The apparent success of the composite grafts may have been due to the osteoinductive effect of either the FDBA or the autogenous material. A greater success rate (more than 50% fill) was noted when antibiotics were used (85%) than when they were not used (38%). There was a lower success rate noted for grafts adjacent to endodontically treated teeth; however, this may have been related to difficulty in diagnosing residual endodontic pathology and to possible inadequate initial endodontic treatment.

Controlled Studies

One of the criticisms of the osseous grafting literature is the lack of comparison to ungrafted controls in many of the studies (Bowers et al., 1982). In the last of a series of articles, Froum et al. (1976) compared osseous coagulum-bone blend to open curettage with respect to osseous fill of 1-, 2-, and 3-walled defects as measured at a 7 to 13 week surgical re-entry. The average osseous fill was 70.6% (2.98 mm) in osseous coagulum grafted sites, 60.7% (4.36 mm) in iliac crest sites (1975 study), and 21.8% (0.66 mm) fill in the open debridement sites. In a subset of the patients who received both procedures, grafted sites demonstrated 2.18 mm of fill (3.22 mm initial defect depth) compared to 0.75 mm of fill (2.55 mm initial defect depth) for the open debridement sites. The original defect depth was greater in grafted than non-grafted sites. The deeper defects tended to show greater fill regardless of the treatment. Seven to 13 weeks may have been too early to adequately evaluate healing, since Dragoo and Sullivan (1973A) had previously shown that osteoblastic activity was still present at 8 months.

Histologic Studies

Radiographs, bone sounding, and re-entry procedures have often been used as methods of evaluating regeneration. However, none of these procedures is capable of demonstrating the formation of a new attachment apparatus. In an attempt to demonstrate that autogenous grafts were capable of forming a functional PDL, Moskow et al. (1979) presented the histologic assessment of a single 1-, 2-, and 3-walled combination osseous defect treated with cancellous alveolar bone taken from an edentulous ridge. A block section obtained 28 weeks after grafting revealed a long junctional epithelium between the root surface and the newly formed bone. The only areas of newly formed cementum and functionally oriented and inserted PDL were at the very base of the defect, a finding expected with any procedure due to the proximity of the PDL to the base of the defect. The clinical evidence of newly formed bone did not necessarily connote the presence of new attachment; i.e., new cementum and functional PDL. Listgarten and Rosenberg (1979) treated 1-, 2-, and 3-walled and combination defects with autogenous intraoral bone, iliac crest allografts, or no grafts. Grafts were placed with or without root planing, and patients were not placed on regular maintenance intervals. Oral hygiene was ineffective. Fifteen (15) block sections were obtained after 6 to 12 months for histologic preparation. Sections demonstrated the presence of a long junctional epithelium below the alveolar crest at 52 to 85% of the total defect depth in all grafted and non-grafted sites. A long junctional epithelium was frequently found apical to the grafted bone, between the bone and root surface. Conversely, Dragoo and Sullivan (1973A) found histologic new attachments as early as 3 months after grafting with fresh autogenous iliac marrow, with complete maturation of the attachment apparatus at 8 months. In a single case treated with autogenous intraoral bone, Hiatt and Schallhorn (1973) showed formation of new attachment in the grafted site. Bowers et al. (1982) compiled the results of 26 studies which histologically evaluated new attachment in intraosseous lesions treated with grafting and non-grafting techniques. New bone formation was seen in 87% of grafted specimens and new cementum in 85%. A functional PDL was reported in most of the cases, although some reported a parallel orientation. The junctional epithelium was found apical to the alveolar crest in 19% of grafted cases. In general, non-grafted sites showed less bone fill, less new cementum, and a greater chance of repair by a long junctional epithelium rather than regeneration of a functional attachment.

New Attachment Studies

As mentioned previously, presence of bone fill subsequent to grafting procedures does not prove new attachment. Bowers et al. (1985, 1989) compared the potential for regeneration in osseous defects associated with submerged and non-submerged roots, with and without DFDBA, in a 6-month human histologic study. Non-submerged, non-grafted sites were found to heal by long junctional epithelium, while non-grafted submerged defects healed by connective tissue attachment (< 1 mm new attachment). Ninety-six percent (96%) submerged and 68% of non-submerged defects grafted with DFDBA formed a new attachment apparatus with bone and cementum formation. This attachment usually extended from the base of the defect to < 1 mm coronal to the sub-calculus notch. The authors pointed out that while epithelial exclusion may be necessary for regeneration to occur, it is only one of several factors, as only limited bone and cementum formation were observed even under these circumstances. Epithelial exclusion in this study was associated with a greater degree of regeneration and new connective tissue attachment in the absence of root resorption or ankylosis.

Karring et al. (1984) reported the effect of epithelial downgrowth on periodontal wound healing using the monkey model. Periodontally involved teeth were extracted, root planed, and reimplanted with 1 surface in contact with the bone and the other with the connective tissue surface

of the repositioned flap. Epithelial migration was allowed to occur by surgical exposure of the coronal surface at periods up to 24 weeks. The authors reported root resorption at the connective tissue interface and ankylosis at the bone interface, the degree of which was dependent on the duration of implantation. The portions of the roots covered with epithelium showed no resorption. The authors concluded that epithelium forms a protective barrier which prevents root resorption and ankylosis. The root resorbing properties of gingival connective tissue and the ability of granulation tissue derived from alveolar bone to induce root resorption and ankylosis in animal models were discussed. The infrequent occurrence of such events following osseous grafting in humans may be explained by coronal migration of PDL cells and/or apical migration of the junctional epithelium.

SUMMARY

There are numerous reports showing the success of osseous grafting; however, the majority have not used controls. Additionally, the method of assessing success was generally through radiographs or osseous measurements. Long-term studies utilizing adequate controls and histologic evaluation are needed to make firm conclusions on the efficiency of osseous grafting as a means of providing regeneration of the periodontal attachment apparatus (Gara and Adams, 1981).

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Section 9. Alloplastic Materials for Treatment of Intrabony Defects

DEFINITIONS

Graft: 1. Any tissue or organ used for implantation or transplantation. 2. A piece of living tissue placed in contact with injured tissue to repair a defect or supply a deficiency. 3. To induce union between normally separate tissues.

Implant: 1. An alloplastic material or device that is surgically placed into the oral tissue beneath the mucosal or periosteal layer or within bone for functional, therapeutic, or esthetic purposes. 2. To insert a graft or alloplastic device into the oral hard or soft tissue for replacement of missing or damaged anatomical parts, or for stabilization of a periodontally compromised tooth or group of teeth.

INTRODUCTION

If the present goal of periodontal therapy is to provide a healthy dentition that will function for life, then the ideal goal for the future is the reconstitution of bone and connective tissue attachment which has been destroyed by the disease process (Zander et al., 1976). At present, one of the most widely used periodontal regenerative modalities is bone graft therapy. Unfortunately, bone graft materials derived from the host or other living tissues may be complicated by inherent limitations. Consequently, dental research and industry have been increasingly concerned over the past 2 decades with biologically inert, synthetic materials for implantation into intrabony periodontal defects. The first major breakthrough for modern alloplastic bone implant materials came during the past 2 decades with the development of advanced processing techniques for the calcium phosphate ceramics. This led to significant improvement in the bioproperties of these materials, making them a feasible alternative for use as alloplastic implant materials (Han and Carranza, 1984; Krejci et al., 1987). Subsequent extensive clinical investigation of calcium phosphate ceramics as implant materials, along with documented clinical success, has contributed to the current demand for alloplastic implant materials.

OSSEOUS GRAFT AND IMPLANT MATERIALS–ADVANTAGES AND DISADVANTAGES

Since each graft or implant material has unique strengths and weaknesses, the practitioner must become familiar with these prior to selection and use. Autogenous materials, such as iliac crest bone marrow, bone blend, and osseous coagulum, have the advantage of safety and no potential for immunogenicity or cross contamination. Autogenous bone has a well-documented osteogenic potential and is logically the material of choice. However, in cases where insufficient autogenous material is available or an additional surgical site is contraindicated, other materials must be considered. Allograft materials such as bone marrow and decalcified freeze-dried bone have virtually unlimited availability and a purported osteogenic potential comparable to autogenous bone. However, a slight risk of immunogenicity and pathogenicity exists (MMWR, 1988; Buck, 1989). Mellonig et al. (1992) demonstrated that processing of demineralized freeze-dried bone allografts results in inactivation of HIV. After HIV-spiked and AIDS bone donor samples were processed, the HIV was destroyed. The authors attribute the HIV inactivation to the demineralization and the virucidal processing agent (ethanol and non-ionic detergent). The inherent shortcomings of bone autografts and allograft materials have focused considerable attention on synthetic materials for the treatment of periodontal defects. These materials are available in unlimited quantity, require no donor surgical site, and are non-antigenic and sterile (Bissada and Hangorsky, 1980; Ferraro, 1979; Han and Carranza, 1984).

Ideal Properties of Alloplastic Implant Materials

Although some of the current alloplastic implant materials have a great deal of potential, no ideal material exists today. Any successful laboratory-synthesized alternative to autografts and allografts must possess properties that clinically appeal to the practitioner. They should also afford the highest potential for restoring lost form and function to the periodontium. The following qualities are necessary if an alloplastic implant material is expected to meet these therapeutic goals: biocompatibility with host tissues–nontoxic, non-allergenic, non-carcinogenic, and non-inflammatory; sufficient porosity to allow bone conduction–growth of bone into and around the implant; ability to stimulate bone induction; resorbability with replacement by bone; radiopacity which permits radiographic visualization; capability to withstand sterilization procedures without compromising desired characteristics; easy to obtain and inexpensive; similar physical properties to the tissue it replaces; and stable to variations in temperature and humidity (Bissada and Hangorsky, 1980; Frame et al., 1980; Levin et al, 1974A; Alderman, 1969; Ganeles et al., 1986).

NON-CERAMIC ALLOPLASTIC IMPLANT MATERIALS

Although most synthetic materials currently used to treat periodontal defects are calcium phosphate ceramic compounds (tricalcium phosphate, porous hydroxyapatite, nonporous hydroxyapatite or combinations of hydroxyapatite and tricalcium phosphate [biphasic calcium phosphate]), a number of non-ceramic synthetic materials have also been used in recent years. These include materials such as calcium sulfate (plaster of paris) which is readily available, inexpensive, easy to handle, and sterilizable. Although it has been shown to be biocompatible and readily absorbed, there is no evidence that it has any osteoinductive properties (Shaffer and App, 1971).

Hard Tissue Replacement (HTR)

HTR is a calcium-layered composite of a polymethylmethacrylate core (PMMA) with polyhydroxylethyl meth-

acrylate (PHEMA or polyhema). It is microporous, non-resorbable, sterile, and ready to use in granular or molded forms. Treated with barium to promote radiopacity, it is also touted as being strong, easy to use, inexpensive, hydrophilic for easier handling, and electrically charged in order to promote osteogenesis (Ashman and Bruin, 1985; Ashman, 1988). Its most important dental application to date has been for bone maintenance, i.e., placement in extraction sockets to prevent bone loss and for ridge augmentation (Leake, 1988). There is some evidence that fibroblasts attach to this material, suggesting that it may augment connective tissue repair and promote wound healing (Kamen, 1988). HTR has been shown to be well tolerated and easy to handle (Shamiri et al., 1988) and has been used with apparent clinical success for filling periodontal defects (Murray, 1988). Histologically, it resulted in gain in clinical closure varying from epithelial adhesion to degrees of functionally oriented new connective tissue attachment to cementum. Limited bone formation was also noted at the periphery of some particles (Stahl et al., 1990). Compared to open flap debridement alone, use of HTR has been shown at 6 months post-implantation to result in greater decrease in probing depth and gain in clinical attachment (Yukna, 1990). Although most reports indicate that this material is biologically well accepted, Kwan et al. (1990) reported 2 cases in which an inflammatory reaction to the material occurred. Since there have been few controlled clinical studies verifying the efficacy of HTR, no conclusions regarding the predictability of the histologic healing responses can be made.

CERAMICS AS ALLOPLASTIC IMPLANT MATERIALS

Ceramics are enticing because of well-documented biocompatibility and chemical and physical resemblance to bone mineral (Han and Carranza, 1984). Another desirable feature includes an ability to develop strong bonding to living bone by natural cementing mechanisms, reportedly stronger than either the constituent bone or ceramic material (Jarcho, 1986). In addition, most calcium phosphate materials are radiopaque, sterilizable, easy to obtain, and stable (Table 1).

The basic manufacturing process of calcium phosphate ceramic implant materials involves preparation of ceramic powders in aqueous solutions. The powders are then subjected to high pressures and high heat, a process known as sintering. Differing manufacturing processes of these ceramics can control particle and pore size, shape, distribution, and density of the material. There are many ceramic periodontal implant materials available on the market with various physical and chemical characteristics, and tissue reaction properties. Most of the ceramics currently used as implant materials are composed of either hydroxyapatite (also referred to as HA, hydroxylapatite, durapatite, or tribasic calcium phosphate) or tricalcium phosphate (TCP or β-TCP) in various forms. Both materials have a calcium to phosphate ratio similar to bone and have been shown to be biologically compatible (Froum et al., 1982; Moskow and Lubarr, 1982; Rabalais et al., 1981). These materials are further grouped as either porous or non-porous, and resorbable or non-resorbable. Those materials with moderate sized particles (0.3 to 0.5 mm, 40 to 60 mesh) are generally used for filling periodontal defects, while those with larger particles (0.5 to 1.0 mm, 20 to 40 mesh) are more appropriate for ridge augmentation procedures.

Tricalcium Phosphate (TCP)

This processed ceramic material, also referred to as β-tricalcium phosphate, should not be confused with tribasic calcium phosphate, a generic name for hydroxyapatite (Metsger et al., 1982). Tricalcium phosphate is a highly purified, multicrystalline, porous form of calcium phosphate. The calcium/phosphate ratio of TCP is 1.5 and is similar to that found in bone mineral (1.7). However, it is not a natural component of bone mineral (Han and Carranza, 1984). TCP is partially resorbable and is often considered desirable for repair of non-pathologic sites where resorption of the implant material and concurrent bone replacement might be expected (Jarcho, 1986). When used to repair marginal periodontal defects, TCP may provide degrees of repair equal to or exceeding autogenous bone (Metsger et al., 1982).

Animal Studies. Numerous animal studies have shown that TCP is compatible with host tissue and elicits no adverse reactions (Bhaskar et al., 1971; Levin et al., 1974A and B, 1975; Nery et al., 1975; Cameron et al., 1977; McDavid et al., 1979). Ingrowth of bone into the pores of CP has been observed in dogs with repair of the periodontium (Nery et al., 1975; Cameron et al., 1977). Additionally, TCP seems to undergo progressive degradation and replacement by calcified bone as shown in dogs (Bhaskar et al., 1971; Cameron et al., 1977; Ferraro, 1979) and may even stimulate bone formation (Levin et al., 1974B). Histologically, a long junctional epithelial attachment, rather than a connective tissue attachment, occurs in the healing defect (Caton et al., 1980A and B).

Human Studies. The relative success of TCP that was demonstrated in animal studies precipitated a number of human clinical investigations. These have provided further evidence of TCP's biocompatibility (Nery, 1978; Strub and Gaberthal, 1979; Hoexter, 1983; Judy, 1983; Snyder et al., 1984; Baldock et al., 1985; Bowers et al., 1986; Stahl, 1986; Froum and Stahl, 1987). They also indicated that use of TCP results in partial defect fill; i.e., bone and/or ceramic (Nery, 1978; Strub and Gaberthal, 1979; Snyder et al., 1984; Baldock et al., 1985; Stahl and Froum, 1987; Froum and Stahl, 1987; Saffar et al., 1990). At 6 months, TCP has been shown to be well retained, provide flap support, reduce mobility, and preserve function (Hoexter, 1983).

Nery (1978) clinically evaluated TCP-treated periodontal osseous defects in 6 patients over 2 to 16 months. A mean

TABLE 1. HUMAN STUDIES USING CERAMIC IMPLANT MATERIALS TO TREAT OSSEOUS PERIODONTAL DEFECTS

Study	Design	Material(s)	Re-entry Time	Defect Fill*	Probing Depth Reduction	Clinical Attachment Gain/Gain in Closure
Strub and Gaberthal 1979	8 pts 29 defects TCP compared to 18 defects allogenic frozen bone—same mouth	TCP and frozen bone	12 months	TCP-1.2 Bone-1.5	TCP-1.8 Bone-2.0	†
Snyder et al. 1984	10 pts 15 defects No controls	TCP	18 months	2.8	3.6	2.7
Baldock et al. 1985	2 pts 13 defects No controls	TCP	Block biopsy at 3, 6, 9 months; no reentry	1.8 (X-ray only)	4.5	2.0
Stahl and Froum 1986	4 pts 8 defects No controls	TCP	Block section 3-8 months; no reentry	†	5.6	2.6
Froum and Stahl 1987	1 pt 5 defects No controls	TCP	Block section 13-18 months; no reentry	†	5.1	2.3
Rabalais et al. 1981	8 pts 37 defects HA compared to 29 defects debrided controls—same mouth	Non-porous HA (250–425 μm particles)	6 months	HA-1.7 Cont-0.5	HA-2.6 Cont-2.3	HA-1.0 Cont-0.9
Meffert et al. 1985	12 pts 16 HA defects compared to 12 defects debrided controls—same mouth	Non-porous HA (40–60 mesh particles)	9 months	HA-3.4 Cont-0.5	†	†
Yukna et al. 1986	14 pts 50 HA defects compared to 31 defects debrided controls—same mouth	Non-porous HA (40–60 mesh particles)	6 months	HA-1.6 Cont-0.4	HA-2.5 Cont-2.3	HA-1.0 Cont-0.8
Yukna et al. 1989	6 pts 62 HA defects compared to 32 defects debrided controls—same mouth	Non-porous HA (40-60 mesh)	5 years soft tissue measurements only; no reentry	†	HA-2.8 Cont-1.4	HA-1.1 Cont-0.5
Kenney et al. 1985	25 pts 25 HA defects compared to 25 defects debrided controls—same mouth	Porous HA	6 months (15 exp and 15 control defects)	HA-3.5 Cont-0.7	HA-4.3 Cont-2.5	HA-3.6 Cont-1.2
Stahl and Froum 1987	3 pts 12 HA defects No controls	Porous HA	Block sections; no reentry	†	4.4	2.8
Kenney et al. 1988	10 pts 10 solid porous HA defects compared to 10 granular porous HA defects—same mouth	Porous HA	No reentry	†	Solid-5.2 Gran-4.2	Solid-3.0 Gran-2.6
Krejci et al. 1987	12 pts Comparison of 12 non-porous, 12 porous, and 12 debrided control defects—same mouth	Non-porous HA vs. porous HA	6 months	Por-1.0 Nonpor-1.4 Cont-0.5	Por-3.0 Nonpor-2.3 Cont-2.4	†
Bowen et al. 1989	6 pts 17 HA defects compared to 17 DFDBA defects—same mouth	DFDBA vs. porous HA	6 months	HA-2.1 DFDBA-2.2	HA-2.9 DFDBA-2.9	HA-1.6 DFDBA-2.1

TABLE 1. Continued

Study	Design	Material(s)	Re-entry Time	Defect Fill*	Probing Depth Reduction	Clinical Attachment Gain/Gain in Closure
Oreamuno et al. 1990	24 pts 24 porous HA defects compared to 24 DFDBA paired defects—same mouth	DFDBA vs. porous HA	6 months	HA-3.3 DFDBA-2.4	HA-4.3 DFDBA-3.8	HA-2.9 DFDBA-2.1
Barnett et al. 1989	7 pts 19 HA defects compared to 19 FDBA defects—same mouth	FDBA vs. porous HA	6-12 months	HA-1.3 FDBA-2.1	HA-1.4 FDBA-3.0	HA-1.3 FDBA-2.2

*Mean values in millimeters
†Information not available

gain in hard tissue height (bone and/or ceramic) of 5.2 mm was found. No histology or re-entry was accomplished, controls were absent, and results were based largely on standardized radiographs.

Baldock et al. (1985) evaluated the use of TCP ceramic implant material in 13 osseous defects in 2 patients. Histological (at 3, 6, and 9 months), and clinical and radiographic evaluations (no controls) were used. Clinically, a mean gain of probing attachment level of 2.0 mm and a radiographic "fill" of 1.8 mm occurred. Histologically, TCP particles were encapsulated by fibrous connective tissue and failed to stimulate bone growth. New cementum was observed, but there was limited evidence of new attachment. Radiographic fill appeared to have occurred by mechanical obstruction rather than new bone growth. Minimal ingrowth of bone occurred and TCP was not totally resorbed at 9 months. In the absence of histologically substantiated bone formation or new connective tissue attachment, it was concluded that TCP had little beneficial effect on defect repair.

Bowers et al. (1986) histologically evaluated 4 TCP-treated sites from 1 patient. At 1 year post-implantation, bone and osteoid formation around TCP particles was observed. It was concluded that TCP might serve as a nidus for new bone formation in the intrabony defect. While resorption of the material may continue to occur over a period of years, active bone formation can occur supracrestally and in the soft tissue coronal to the defect after 1 year.

Stahl and Froum (1986) and Froum and Stahl (1987) also studied intraosseous healing histologically at 3 to 8 months and then 13 to 18 months after placement of TCP in 8 intrabony lesions in 4 patients. An average gain in clinical closure (clinical attachment gain) of 2.6 mm and 2.3 mm was observed respectively. Histologic evidence failed to indicate any osteogenesis, cementogenesis, or new connective tissue attachment. Instead, slowly resorbing TCP particles, acting as an inert fill material, became well encapsulated by gingival connective tissue. Active root resorption was seen immediately apical to the junctional epithelium at 1 site and wound closure was by a long junctional epithelium.

Saffar et al. (1990) evaluated 5 biopsies of defects implanted with TCP at 16 to 40 months after implantation. The findings suggested that TCP does promote bone formation as it slowly resorbs. At 1 year, the mean linear bone gain, as quantified on standardized radiographs, was 4 mm (80% fill). Both defect fill and resorption of TCP varied between individuals, taking as long as 40 months to occur in some instances. This may explain why previous short-term studies could not demonstrate bone formation and integration of the material after grafting.

Tricalcium Phosphate/Collagen Complexes as Implant Materials. Bell and Beirne (1988) have hypothesized that a composite TCP and collagen graft complex might serve as a biocompatible resorbable binder in periodontal defects. Sugaya et al. (1990) found that defects in dogs treated with a TCP-atelocollagen complex had a significantly higher suppression of epithelial downgrowth and a higher rate of new cementum and bone formation than controls.

Biphasic Calcium Phosphate (BCP). This material is a 2-phased calcium phosphate material composed of varying amounts of hydroxyapatite and TCP. Because of the TCP content, it is considered to be partially resorbable. Nery (1990A) found that BCP mixed with fibrillar collagen was superior to surgery alone in periodontal defects in dogs. Nery (1990B) further showed that in humans, use of this material without collagen was no more effective than autogenous bone or open flap curettage at 3 years. Nery et al. (1992) used varying concentrations of HA and β-TCP as implants in experimentally created periodontal defects in dogs and concluded that ratios of HA/β-TCP of 65/35 and 85/15 resulted in the greatest gains in attachment level. All BCP combinations improved attachment levels when compared to non-implanted controls.

Hydroxyapatite (HA)

HA is a non-resorbable ceramic material used as an implant material for the treatment of osseous periodontal de-

fects. Like TCP, this material has been the subject of extensive study, largely due to its close crystal and chemical resemblance to vertebrate tooth and bone mineral (calcium/phosphate ratio of 1.7, the same as that of bone mineral). HA is non-inflammatory, non-antigenic, and highly biocompatible to human tissues; it is commercially available in two basic forms, non-porous and porous.

Non-Porous Hydroxyapatite. Often generically referred to as durapatite, this material is an extremely dense, pure, non-resorbable ceramic material possessing great strength. Because of its physical qualities, and its similarities to human hard tissues, it has long been considered for use as a bone replacement material.

Animal Studies. Early studies showed HA was biocompatible in animals (Jarcho et al., 1977; Frame, 1981). HA particles become encapsulated by fibrous connective tissue and there is no evidence of new bone associated with the implant material.

Human Studies. In the first human study utilizing this material in periodontal defects (Rabalais et al., 1981), HA was implanted in 38 osseous defects and compared to 29 debrided controls in 8 patients. At the 6 month post-surgical re-entry, the HA was enmeshed in a soft connective tissue matrix. The implantation sites were hard, resisted probe penetration, and had significantly more defect fill (1.7 mm) versus controls (0.5 mm). Regardless of original probing depth, no difference between experimental and control sites was found with regard to clinical attachment gain, decrease in probing depth, or soft tissue recession. Only 16% of the HA implanted sites failed, compared to almost 50% of the controls. It was also noted that graft effectiveness appeared to increase with increased probing depth.

In a histological assessment (Froum et al., 1982), 4 sites in 4 different patients with osseous defects exceeding 4 mm in depth were examined at 2 to 8 months after placement of HA implants. The material served adequately as a foreign body fill, was well tolerated, and afforded no new attachment. Moskow and Lubarr (1983) histologically evaluated a single site implanted with both HA and autogenous bone chips. At 9 weeks, fibrous encapsulation of the HA particles was observed without any evidence of inflammation or extrusion. Although new bone was associated with the bone fragments, no indication of osseous changes adjacent to the HA particles was observed. Meffert et al. (1985) noted less crestal bone resorption with HA than surgical curettage after 9 months. The resistance of the implant material to probe penetration and its acceptance by hard and soft tissues suggested an ability to stabilize the remaining osseous structure. Shepard et al. (1986) observed new bone associated with the fibrous interstitium surrounding the HA crystals but could find no evidence of new attachment. Healing was by long junctional epithelium to the depth of the original defect. Ganeles et al. (1986) examined HA implant biopsy material and reported osseous regeneration in association with the HA granules in only 2 of 19 cases. Healing was generally by a long junctional epithelium.

In recent years the most extensive work using HA as an alloplastic implant material for treatment of periodontal defects has been by Yukna et al. (1984, 1985, 1986, 1989A, 1989B). These studies compared both short- and long-term (up to 5 years) response of HA-implanted periodontal osseous defects to defects in the same mouth treated with debridement alone. It is also important to consider the limitations of this work when evaluating the significance of the results. Most of the data were obtained from soft tissue measurements only; i.e., gingival recession, clinical attachment level, and probing depth. Direct assessment of long-term hard tissue changes (re-entry) was not accomplished in most cases and no histological evaluations were made. A summary of Yukna's findings indicates that the use of HA ceramic as a bone implant material in periodontal osseous defects yields at least as good and often better results than those following surgical defect debridement alone. The HA-treated sites were stable for a 5-year post-surgical period and showed clinical improvement, while flap debridement sites were not stable and regressed at a rate 3 to 5 times that of the implanted sites. Yukna (Yukna, 1989A) concluded that use of HA is clinically beneficial in most cases, provided it is used judiciously, only when indicated, and with realistic expectations; at present, however, these materials are little more than "clinically useful, biocompatible fillers that allow certain therapeutic goals to be reached and maintained."

Non-Porous HA Summary. Non-porous HA characteristics include: 1) non-porous HA is a hard, inert, highly biocompatible filler for osseous defects; 2) although it may help stabilize the remaining structure, it may stimulate formation of some new connective tissue attachment apparatus; healing generally is by long junctional epithelium rather than connective tissue attachment; 3) its crystals become surrounded with a fibrous encapsulation and may be associated with osseous regeneration; however, such new bone formation is not a predictable event, and 4) since its use produces similar and perhaps even better long-term clinical results than surgical debridement alone, it may be clinically beneficial.

Porous Hydroxyapatite. Porous HA is a ceramic implant material formed by hydrothermal conversion of the calcium carbonate exoskeleton of the Porites coral into hydroxyapatite. This conversion, known as the replamineform process, yields a material similar to the microstructure of natural bone. The interconnecting channels of this material are reportedly of sufficient size (190 to 230 μm) to support fibrovascular ingrowth and subsequent bone formation (White et al., 1972, 1975, 1986). Porous hydroxyapatite is currently being marketed and used as an implant material for intrabony periodontal defects . Available in both solid

and granular forms, both appear equally effective (Kenney, 1986A).

Animal Studies. The biocompatibility of porous HA has been adequately verified in animals (Piecuch, 1982; West and Brustein, 1985; Minegishi et al., 1988). Although bony ingrowth has been a consistent finding with porous HA, El Deeb et al. (1987) showed that this material is osteoconductive rather than osteoinductive; i.e., a scaffold for bone growth. When porous HA was implanted into surgically created periodontal defects in dogs, West and Brustein (1985) found evidence of fibrovascular tissue, bone, and periodontal ligament formation around the implant. In surgically created osseous defects in monkeys (Minegishi et al., 1988), the implanted porous HA granules were rapidly surrounded by fibrous connective tissue or new bone. At 1 year, the surgically created bone defects were almost completely repaired. The granules were integrated with new bone and the periodontal ligament reformed between the thin cementum and the new bone.

Human Studies. Kenney et al. (1985, 1986, 1987, 1988A, 1988B) have extensively investigated the use of porous HA graft material in periodontal defects. Porous HA was placed in angular intrabony periodontal defects in 25 patients (Kenney et al., 1985, 1987), while non-grafted matched defects in the same patients served as controls. Surgical re-entry at 6 and 12 months revealed greater reduction in probing depth and increase in attachment levels, as well as more bone fill in the implanted sites as compared to controls. No mobility of the grafts was noted and the surrounding bone appeared to be incorporated into the implant. The graft material and surrounding bone were similar in appearance. Similarly, superior clinical results have been obtained at 3 years after implantation (Frentzen et al., 1989). Defect fill consisting of a mixture of HA granules and regenerated bone was noted as early as 10 weeks.

When porous HA was placed in Class II furcation defects in mandibular molars and compared to grafted controls (Kenney et al., 1988B), bone fill of grafted defects was accompanied by improvement in probing attachment levels and probing depths. Lekovic et al. (1990) used porous HA in conjunction with polytetrafluoroethylene membranes (PTFE) to treat Class II furcation defects in lower molars. In each subject, 1 of 2 paired defects was implanted with porous HA and then covered with PTFE membrane, while the other defect was treated with debridement and PTFE only. At 6 months, both procedures resulted in similar reduction in probing depth, but the porous HA/PTFE sites resulted in less gingival recession and more horizontal and vertical defect fill.

Kenney et al. (1986) histologically examined samples of porous HA at 6 months following implantation into osseous periodontal defects. For the first time, evidence of this material's ability to stimulate osteogenesis within the porous structure of the implant was obtained. Since block sections were not obtained, it was not possible to determine if new connective tissue or cementum was formed. No evidence of resorption of the material was observed, indicating that biodegradation of this material occurs slowly, if at all.

Stahl and Froum (1987) evaluated porous HA clinically and histologically using block sections. At 1-year post-implantation in 12 human periodontal defects, acceptable tissue response with attachment gain and reduced probing depths was observed. Histological evaluation revealed bone formation in the implant pores, as well as peripherally; however, there was no evidence of new attachment and closure was by long junctional epithelium. Similar histological findings were obtained by Carranza et al. (1987) on 2 block sections at 5 and 6 months after implantation. Although 1 of the sections exhibited some new cementum formation opposite the implanted material, the conclusions were the same. Porous HA has the potential for bony ingrowth into the pores and ultimately within the lesion itself, but no new connective tissue attachment can be expected.

Porous HA Versus Bone Allografts. It, therefore, appears that use of porous HA may produce better clinical results in treating osseous defects than surgical debridement alone. But it is equally important for the clinician to know how this alloplastic material compares with biologically derived grafting materials, such as decalcified and non-decalcified freeze-dried bone allograft. Bowen et al. (1989) compared porous HA to decalcified freeze-dried bone allograft (DFDBA) in 6 patients having at least 2 comparable periodontal defects (total of 17 pairs of defects) respectively grafted with DFDBA and porous HA. Standardized radiographs and clinical measurements were taken after initial preparation and again at 6 months post-implantation. The 6-month re-entry revealed that although both treatment modalities reduced probing depth and demonstrated a gain in clinical attachment levels, there were no significant differences in any of the soft or hard tissue measurements (2.2 mm bone repair with DFDBA and 2.1 mm with HA). Although no histological evaluation substantiated the presence or absence of new attachment, the authors concluded that if regeneration of the periodontium is the desired goal, then DFDBA may be the proper choice. If defect "fill" is the objective, then, based on this study, DFDBA or porous HA might be equally effective.

In a study of similar design by Oreamuno et al. (1990), no apparent difference in healing patterns was noted between porous HA and DFDBA, but greater probing reduction and gain in attachment level were observed with the porous HA. Re-entry at 6 months revealed crestal bone loss with DFDBA and significantly greater defect fill with porous HA. Although the apparent advantage of the porous HA may be clinically insignificant, the relative efficacy of both materials was demonstrated.

Barnett et al. (1989) compared porous HA to non-decalcified freeze-dried bone allograft (FDBA). Nineteen (19)

matched pairs of intrabony defects in 7 patients were either implanted with porous HA or grafted with FDBA and re-entered 7 to 11 months later. Mean bone fill for FDBA was 2.1 mm, compared to 1.3 mm for porous HA. The mean decrease in probing depth was 3.0 mm and 1.3 mm, respectively, although recession accounted for more decreased probing depth in the FDBA than porous HA. Attachment gain for the FDBA was 2.2 mm, compared to 1.3 mm for the porous HA. Osseous repair of at least 50% was observed in 74% of the FDBA grafted defects and 42% of the porous HA implanted ones. The FDBA treated sites could be debrided to a solid surface, but the porous HA sites often retained fibrotic tissue at the base of the defect. Histologic analysis of curetted graft material revealed little osteogenic activity associated with either material. The authors concluded that little difference exists in repair potential between porous HA and FDBA.

Porous HA in Combination with Other Biologically Derived Materials. Minabe et al. (1988) compared porous HA alone to porous HA combined with collagen in the treatment of periodontal defects in dogs. Findings indicated that the addition of the collagen resulted in an increased amount of new cementum formation. While no such porous HA/collagen implant systems are currently available for human use, further research may be warranted.

Porous HA Summary. Porous HA characteristics include: 1) porous HA is biocompatible with human tissues and can generally be expected to result in greater improvement in probing depth, attachment level, and depth of the osseous lesion, than non-implanted surgically treated defects; 2) although porous HA provides for bony ingrowth into its pores and ultimately within the lesion itself, there is no evidence that it stimulates new attachment formation; closure is by long junctional epithelium; 3) similar clinical results might be expected with the use of porous HA, as compared to bone allografts, in the fill and subsequent healing of osseous periodontal defects; however, true regeneration is more likely with bone allograft materials (Table 2).

TABLE 2. CURRENTLY AVAILABLE CERAMIC ALLOPLASTIC IMPLANT MATERIALS

Property/Trade Name	Material	Comment
Resorbable		
Synthograft	Tricalcium phosphate	Identical to Synthograft
Peri-Oss	Tricalcium phosphate	Ridge augmentation material
Augmen	Tricalcium phosphate	May not be truly resorbable
Osteogen	Hydroxyapatite	
Partially resorbable		
Triosit	Biphasic calcium Phosphate (BCP)	A combination of HA and TCP
Porous non-resorbable		
Interpore 200	Replamineform hydroxyapatite	Available in block or granules
Permagraft	Replamineform hydroxyapatite	Similar to Interpore 200
Periograf	Hydroxyapatite	
Calcitite 2040	Hydroxyapatite	Ridge augmentation material
Calcitite 4060	Hydroxyapatite	
Non-porous non-resorbable		
Alveograf	Hydroxyapatite	Ridge augmentation material
Orthomatrix HA-500	Hydroxyapatite	
Orthomatrix HA-1000	Hydroxyapatite	Ridge augmentation material
Bioglass	Glass	
Cervital	Glass	European version of Bioglass

SUMMARY

It is extremely difficult to form definitive conclusions as to the relative efficacy of alloplastic implant materials in the management of periodontal defects. Considerable variation exists in the limited number of clinical human trials which have been conducted using these materials with respect to use of controls, evaluation techniques, re-entry procedures, and histological data. Consequently, direct comparison of results can easily lead to invalid conclusions, unless variations in study design are considered. Bearing this in mind, the following overall observations may be made:

1. Although all currently available alloplastic implant materials appear to be biologically compatible, non-antigenic, non-inflammatory, and otherwise safe, use of the patient's own bone remains the best choice for treating periodontal defects. This assumes that harvesting procedures are feasible and an adequate donor source is present.

2. Use of alloplastic implant materials can be expected to produce at least equal long-term (5 year) clinical results, compared to surgical debridement alone.

3. Currently available alloplastic implant materials might be considered a reasonable alternative to bone allograft material, especially if moral/religious reservations, fear of cross contamination, or immunologic responses to allograft material exist. Clinical closure and defect fill is generally similar in both biological and synthetic materials but regeneration is far more likely with bone allograft.

4. Although new bone formation may be seen in association with some alloplastic implant materials, there is no evidence that any are predictably osteoinductive or able to stimulate the formation of a new connective tissue attachment apparatus.

5. No currently available alloplastic implant material is clearly superior to any other in treating periodontal defects. All are inert osteoconductive fill materials which serve as a nidus or scaffold for new bone formation. Their use generally results in defect fill, stabilization of the remaining

osseous structure, clinical attachment gain, and decreased probing depths. Healing is characterized by one or a combination of the following: fibrous encapsulation of the implant granules, bony ingrowth into the material, slow resorption of the implant, and/or formation of a long junctional epithelium and/or connective tissue adhesion without regeneration of the periodontium.

6. Most documented success and biocompatibility have been obtained with the calcium phosphate materials, i.e., tricalcium phosphate and hydroxyapatite. These materials chemically resemble natural human hard tissues, are radiopaque, sterilizable, easy to obtain, and stable.

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Section 10. Guided Tissue Regeneration

DEFINITIONS

Repair: Healing of a wound by tissue that does not fully restore the architecture or function of the part.

Regeneration: Reproduction or reconstitution of a lost or injured part.

New Attachment: The union of connective tissue or epithelium with root surface that has been deprived of its original attachment apparatus. This new attachment may be epithelial adhesion and/or connective adaptation or attachment and may include new cementum.

Reattachment: To attach again. The reunion of epithelial and connective tissues with root surfaces and bone such as occurs after an incision or injury. Not to be confused with new attachment.

Guided Tissue Regeneration (GTR): Procedures attempting to regenerate lost periodontal structures through differential tissue responses. Barrier techniques, using materials such as expanded-polytetrafluoroethylene, polyglactin, polylactic acid, and collagen, are employed in the hope of excluding epithelium and the gingival corium from the

root surface in the belief that they interfere with regeneration.

Periodontal Regeneration: Restoration of lost periodontium.

Potential Healing Responses of the Periodontal Tissues

Melcher (1976) first presented the basic concepts which have led to the development of the clinical techniques collectively known as GTR. He suggested that there were 4 separate compartments of connective tissue (CT) in the periodontium: the gingival corium, periodontal ligament (PDL), cementum, and bone. Melcher felt that the CT cells in each of these compartments represented different cellular phenotypes capable of repopulation and determining the regenerative response obtained. Based on this concept, he hypothesized that PDL regeneration can only come from the PDL itself. This idea of distinctive progenitor cells in the periodontal ligament has been supported by Aukhil et al. (1986A), who described in vivo differentiation of progenitor cells from the PDL. In this investigation, fenestration wounds were made in buccal cortical plates of the mandibular anterior teeth in 6 beagle dogs. Exposed root surfaces were curetted to remove all cementum and either demineralized with citric acid or washed with saline (contralateral wound). Nucleopore membranes were attached with cyanoacrylate resin to prevent progenitor cell contact with root dentin leaving 0.5 mm denuded root exposed around the membrane border. Histologic analysis of the specimens after 3 months of healing revealed no new cementum over the membrane area attached to root dentin, whereas, at wound borders and in areas where the membrane had detached, new cementum with CT attachment was seen. No root resorption was seen in any of the specimens. These findings suggested that progenitor cells from the PDL may differentiate into cementoblasts upon contacting root dentin, thereby substantiating the potential inductive effects of dentin on cementum.

Additional investigations by Isidor et al. (1986) examined the effects on new attachment formation on preventing coronal growth of PDL tissues during healing. This work provided a model system for exclusion techniques whereby elastic ligatures were utilized to both prevent and allow coronal growth of granulation tissue from the PDL depending upon the tautness of ligature placement. Four primates were utilized and histologic examination of 3-month healing results analyzed. Results indicated that new attachment failed to occur when the coronal growth of PDL tissue was prevented, thereby reinforcing the need for PDL cell repopulation of the root surface for new attachment formation. Apparent prevention of root resorption by epithelial migration during healing was also noted.

A more recent investigation by Iglhaut et al. (1988) studied PDL and bone cellular kinetics following surgical wounding. A total of 4 primates received fenestration wounds, and PDL and cementum removal followed by Millipore filter placement. Both histologic and autoradiographic examination of specimens from 1 hour to 21 days revealed cellular migration into wounded sites at 3 days from both bone and PDL. Results suggested that both bone and PDL contribute cells for wound repopulation when the epithelium and flap CT are excluded from contact with the root during healing. In lieu of these investigations, Melcher (1987) has amended his original hypothesis of isolated compartments of CT in the periodontium to include the influence of bone, thereby disavowing the PDL as a closed compartment.

Investigations of Guided Tissue Regeneration

The healing of periodontal wounds has been confounded by the propensity for rapid epithelial proliferation and resultant mediation of the tooth-soft tissue interface to the base of the defect. Furthermore, changes in the structural morphology of the periodontium, secondary to the destructive effects of chronic periodontitis, have resulted in changes in the spatial relationships of selective CT compartments available for wound healing. Efforts to compensate and/or correct these problems form the conceptual basis for guided tissue regeneration.

Epithelial Exclusion. Ellegaard et al. (1974) attempted to retard the apical migration of the epithelium by using free gingival grafts (FGG) over intrabony defects. This technique included surgical preparation of the intrabony defect, FGG recipient bed preparation, and placement of an autogenous bone graft into the defect. An FGG was then placed over the bone grafted defect to delay apical migration of the epithelium and facilitate maturation of the granulation tissue adjacent to the root surface. Although the term "regeneration" was used to describe the results of this technique, no histologic evidence was provided to validate this claim. Only wide interproximal spaces and areas neighboring edentulous spaces qualify for this technique.

Prichard (1977) was undoubtedly a pioneer of the epithelial exclusion concept with his introduction of the interdental denudation procedure. This technique included excision of all soft tissue in the interproximal region, leaving bare interalveolar bone. Prichard (1983) alluded to the use of epithelial exclusion in the management of vertical bony defects. He discussed a 7-step plan for managing 3-walled intrabony defects. The plan included the following (the first 4 steps being deemed essential for success, with the last 3 of varying importance):

1) Removal of the gingiva to the margins of the bony walls of the defect, thereby leaving the defect open to prevent epithelial migration. (Failure to leave the defect open was thought to be the most common cause of failure.)

2) Removal of the transseptal and alveolar crest fibers of the PDL, as well as granulomatous tissue from the defect.

3) Removal of all calculus but as little cementum as possible.

4) Surgical dressing must not be allowed to enter the defect.

5) An antibiotic (preferably tetracycline) should be prescribed.

6) An occlusal adjustment should be completed if necessary.

7) No presurgical scaling should be done on the root in the intrabony defect.

Becker et al. (1986A) studied changes in intrabony defects following open flap debridement using the Prichard technique. Thirteen (13) patients were treated as described by Prichard (1983) and placed on 3 to 4 month maintenance intervals. Surgical re-entry was completed at 9 to 16 months, during which time repeat measurements and direct defect impressions were obtained. Volumetric analysis of pre- and post-treatment defect size was made on casts by filling defects with gunpowder and comparing the weight differences between residual defects. Volumetric analysis revealed that 50% (7/14) of the defects had a $\geq$ 50% decrease in defect volume. The mean percentage fill was 47.5%. Additionally, Becker et al. (1986B) reported findings from the treatment of 36 intrabony defects in 35 patients using open debridement procedures alone. Scaling and root planing was not completed since the inflamed lesion was thought to have the necessary cell population for repair. Flaps were apically positioned in an attempt to leave the defects open. Patients were maintained on 3 to 4 month recall and surgical re-entry was completed at 14 months postsurgery. Results indicated a mean gain in clinical attachment level of 2.44 mm and a reduction in defect depth by a combination of crestal resorption (mean 0.48 mm) and defect repair (mean 2.55 mm). Results of the Becker et al. (1986A, B) studies are very similar to those reported in other osseous grafting studies regarding percent of defect fill.

Animal Studies. Magnusson et al. (1985) studied the effects of Millipore filters on exclusion of gingival CT and epithelium during wound healing in a primate model. Pore size was varied (0.2 and 5.0 μm) at test sites, while control sites received no filters. Specimens were assessed histologically at 6 months postoperatively. A new fibrous attachment on 50% of the denuded root surface was achieved. This compared favorably to root coverage achieved by Gottlow et al. (1984) utilizing a submerged wound model. Results of these studies imply that the formation of new attachment may be related to isolation and guiding of specific cell populations.

Magnusson et al. (1988) evaluated the use of biodegradable membranes in surgically created defects in 2 mongrel dogs. Bone removal to approximately 25% of its original height on selected teeth in each dog. Eight defects were covered with Millipore filters, 8 with biodegradable membrane (polylactic acid), and 8 controls with no membranes. Results indicated new CT attachment to 46% of the planed cementum within the surgical defects treated with the polylactic acid/biodegradable membranes, with an average of 2.1 mm of coronal bone regrowth. Millipore filter sites displayed new attachment to only 25% of the planed surface with an average 1.7 mm of new bone growth, while control teeth showed new attachment to 12% of the root surface with only 0.8 mm of new bone growth.

Pfeifer et al. (1989) evaluated the effectiveness of resorbable collagen membranes (from bovine dermis) in producing new attachment in surgically created defects in 4 beagle dogs. Both cross-linked and non-cross-linked collagen membranes were placed. Healing was evaluated histologically at 1, 3, 4, and 8 weeks postsurgery. Results indicated that the cross-linked membrane could persist for 6 to 8 weeks and was preferred over the non-cross-linked membrane (which was totally resorbed in approximately 3 weeks). The cross-linked membrane was effective in inhibiting epithelial downgrowth and in producing tissue regeneration. A second surgical procedure was not required for membrane removal.

Seibert and Nyman (1990) conducted a pilot study evaluating GTR on bucco-lingual ridge defects (13 $\times$ 7 mm, created 3 months earlier) as a means to provide ridge augmentation in 2 beagle dogs. On upper quadrants, porous hydroxyapatite (HA) or tissue growth matrix (TGM) implant materials were placed with and without expanded polytetrafluorothylene (ePTFE) membrane. On the lower arch, 3 of the quadrants received ePTFE membrane with no implant, while the other quadrant served as a sham-operated control. Histologic analysis was completed 55 to 90 days following ridge augmentation. Results indicated complete bone fill 90 days following ridge augmentation, in the membrane only and membrane with HA sites. The quadrant with TGM also displayed new bone within the pores adjacent to the existing bone surfaces; however, the pores adjacent to the soft tissue surface were filled with non-mineralized CT. Flap separation or dehiscence proved to be a major cause of surgical failure. This study failed to provide data regarding volumetric fill of existing defects, thus making comparisons of results to other studies difficult.

Pontoriero et al. (1992) attempted to evaluate the critical factors in grafting Class III furcation defects using ePTFE membranes. In the beagle model, they created Class III furcation defects of different sizes in an apico-coronal direction and treated these defects with debridement and ePTFE membrane placement. After 4 months of healing, the sites were evaluated histologically. In the small defects, the bone regenerated to its original height. In the larger defects not only was there little defect fill, but significant soft tissue recession also occurred, exposing the furcation area. Overall, if the defect was $>$ 3 mm in an apico-coronal dimension, gingival recession was more apt to occur with subsequent failure to develop complete new attachment.

Human Studies. Much of the data regarding GTR procedures in humans is based on case reports. In a series of case reports, Gottlow et al. (1986) described new attachment formation in the human periodontium by GTR. A total of 12 teeth in 10 patients were treated with teflon membranes and replaced flaps. Histologic data were evaluated 3 months post-membrane removal revealing 2.8 to 4.5 mm of new attachment in the membrane treated sites versus no new attachment in control sites. Defect morphology (horizontal versus vertical bone loss [best prognosis]) was viewed as a key factor in predictability of regenerative procedures, reinforcing the concept of space dependent cell migration for regeneration.

Becker et al. (1987) described a surgical and suturing method for the subgingival placement of ePTFE as well as the results of 3 treated cases, one of which was biopsied at 3 months. Evidence of clinical and histologic new attachment secondary to ePTFE use was shown. The new tissue observed at re-entry was termed "open probing new attachment" if it did not have the consistency of bone. A simultaneous suturing technique of the ePTFE and the flap was described as a means to maintain the subgingival position of the material. The authors suggested that ePTFE be removed at 4 to 6 weeks post-insertion.

Stahl et al. (1990) presented human clinical and histologic data from GTR in intrabony lesions. The authors used different ePTFE membranes. New attachment was seen with both types of teflon membranes as early as 5 weeks postsurgery. The topography of the bony lesion was considered as a key controlling factor determining regeneration.

Numerous authors have suggested the use of GTR procedures in the treatment of furcation defects. In 2 controlled human clinical trials, similar results with membrane exclusion techniques were obtained. Pontoriero et al. (1987) reported closure in 19 of 21 Class II furcation defects using ePTFE membrane over the furcation entrance (note that 5 of 19 had 1 mm less than complete fill). This was in contrast to surgically debrided control sites in which only 2 of 21 (< 20%) closures occurred. In Class III furcation defects, 4 of 16 exhibited complete closure; 9 of 16 partial closure; and 3 remained as through and through lesions. None of the 16 control sites exhibited complete closure. In a similar study, Pontoriero et al. (1988) reported that in 90% of mandibular molar sites with Class II furcation involvement treated with ePTFE membranes, clinical evidence of complete closure was present at 6 months. However, less than 20% of the control defects demonstrated closure following treatment. Histologic evidence of regeneration was not included in the 2 preceding controlled clinical trials.

In non-controlled human clinical studies, Becker et al. (1988) reported results in 27 patients following placement of ePTFE membranes. The authors noted that the consistency of the tissue in the defects at the time of re-entry was firm, rubbery, and resistant to the forces of probing. They felt that this material was not bone and noted no radiographic changes in affected areas. This tissue which resisted the forces of probing was termed "open probing clinical attachment." There was a mean gain in clinical attachment of 1.3 mm for Class III furcations, 2.3 mm for Class II furcations, and 4.5 mm for 3-walled intrabony defects. Caffesse et al. (1990) reported results in which GTR was used to treat Class II furcation defects in mandibular molars. Clinically there was a mean gain in clinical attachment level of 1.8 mm for GTR (ePTFE) treated sites versus 0.6 mm for control sites (sham-operated). No furcations demonstrated complete closure. Comparisons of results from this case report to the previous work published by Becker et al. (1988) and Pontoriero et al. (1987, 1988) may be difficult due to differences in probing techniques and maintenance regimens. Becker et al. (1988) used only 1 measurement in the middle of the furcation (away from the root surfaces) while Caffesse et al. (1990) recorded probing depth and clinical attachment levels at the furcal aspects of the mesial and distal roots. Pontoriero et al. (1987, 1988) appointed subjects for professional tooth cleaning every 2 weeks, while Caffesse et al. (1990) placed patients on a 3-month recall. Many of these patients had received long-term maintenance therapy, suggesting the "chronic condition" of the treated furcation sites (Caffesse et al., 1990).

Gantes et al. (1988) treated 30 mandibular, buccal Class II furcation defects with a regenerative technique utilizing citric acid root conditioning and coronally positioned flaps secured by crown-attached sutures. In addition, decalcified freeze-dried allogeneic bone grafts were placed in 16 of the 30 defects. Twelve months following therapy, an average of 67% of the defects volume was filled with bone, while 43% of treated defects were completely closed by bone fill. No significant differences were observed between defects treated with and without bone grafts.

Another treatment approach for furcal defects was reported by Schallhorn and McClain (1988). The authors utilized a combined approach of ePTFE membrane, citric acid root conditioning, and composite osseous grafting (autogenous material mixed with either tricalcium phosphate or demineralized freeze-dried bone allograft material) in 95 defects in 39 patients. They reported complete fill in 33 of 46 (72%) furcation defects using the combined approach versus 5 of 16 (31%) furcation defects when membranes alone were used. (Success was measured at the membrane removal appointment.) In a companion study, McClain and Schallhorn (1993) assessed the long-term results of these cases, reporting after 5 years that GTR with composite grafting and root conditioning enhanced complete furcation fill in Class II and III defects. It also led to a 5 year stability of gains in clinical probing attachment levels, and in furcation fill.

Lekovic et al. (1990) reported the use of porous hydroxyapatite (HA) in conjunction with ePTFE membranes

in the treatment of Class II furcation defects. Mean clinical attachment level gains were 2.40 + 0.48 mm for ePTFE only sites and 2.93 + 0.64 mm for ePTFE + HA site. While their results were encouraging, they were less than the probing depth reduction and clinical attachment gain reported by Pontoriero et al. (1987, 1988). The 2-week professional prophylaxis regimen utilized by Pontoriero and coworkers may account for these differences.

Blumenthal and Steinberg (1990) offered another GTR approach, combining demineralized bone-collagen gel (autolysed antigen extracted allogeneic bone and microfibrillar collagen/Zyderm) implants with collagen membrane barriers. At 1 year re-entry, 93% of all intrabony defects treated had 50% or greater fill. The use of non-standardized measurements and patient selection criteria raised questions regarding the accuracy of these results. Blumenthal (1993) also compared the use of collagen membranes with e-PTFE membranes in paired Class II mandibular buccal furcations over 1 year in 12 patients. Both modalities resulted in similar clinical improvements, and both were effective in gaining vertical open probing new attachment and both were effective for horizontal defect fill. Paul (1992) and Van Swol et al. (1993) also demonstrated regeneration in Class II furcations using collagen membranes.

Chung et al. (1990) evaluated a highly cross-linked, bioresorbable, type I collagen membrane in GTR in 10 patients. Mean gains in probing attachment level of 0.56 + 0.57 mm (range: −0.3 to 1.6 mm) and bone defect fill of 1.16 + 0.95 mm (range: −0.2 to 2.4 mm) were observed. These results were likely minimized by the reporting mean values and inclusion of healthy sites in the data.

Lekovic et al. (1991) reported the use of connective tissue grafts including periosteum to cover the furcation opening in 15 Class II furcations. The controls were debrided only with the tissue being replaced back to its original height. Six month re-entry measurements revealed a probing depth of 4.67 for controls and 2.33 for the connective tissue sites. The control group had no gain in mean attachment level, whereas the experimental group responded with 2.40 mm. The horizontal measurements did not change for the control group, but improved by a mean of 1.60 mm for the experimental group. The authors conclude that their results are very similar to ePTFE membrane results.

Handelsman et al. (1991) evaluated the effect of root conditioning with citric acid (3 minute application, pH = 1) prior to using ePTFE membrane material in intrabony defects. Based on clinical measurements taken during a surgical re-entry procedure, no significant differences were found between the control and the citric acid group. Overall, 72% of the sites showed 50% defect fill.

Anderegg et al. (1991) evaluated decalcified freeze-dried bone allograft (DFDBA) in combination with ePTFE membranes in Class II and Class III mandibular molar furcations compared to the membrane alone. Based on re-entry surgery at 6 months to examine hard tissue changes, DFDBA sites showed statistically greater improvement in horizontal and vertical bone repair compared to controls. Horizontal improvement was noted in all 27 Class II furcations, with 4 completely filled and 13 (10 experimental and 3 control) having at least 2 mm of horizontal bone fill. Overall, the DFDBA sites with membranes had an 85% decrease in osseous defect depth compared to a 50% decrease with the membrane alone. Generally the deeper the vertical component of the defect, the greater the osseous fill.

Metzler et al. (1991) compared open flap debridement with open flap debridement and an ePTFE membrane in maxillary Class II furcation defects. The authors judged success by surgical re-entry at 6 months and measured the hard tissue changes in a horizontal and vertical dimension. These measurements were referred to as HOPA (horizontal open probing attachment) and VOPA (vertical open probing attachment). These terms should be distinguished from "open probing clinical attachment" (Becker et al., 1987) which describes not hard, but "rubbery" tissue at membrane removal, usually 4 to 6 weeks.

At 6 months a surgical re-entry procedure was performed to assess the hard tissue changes. No significant differences were observed between the 2 sites for recession, probing depth reduction, attachment level changes, or alveolar crest resorption. There was a significant gain in VOPA (1.5 mm versus 0.6 mm) and HOPA (0.9 mm versus 0.3 mm) for the membrane group over the open flap debridement alone group.

Gantes et al. (1991) reported the treatment of Class III mandibular molar furcation sites using citric acid and coronally positioned flaps in the control group, and DFDBA, citric acid, and coronally positioned flaps in the experimental group. Comparison of the 2 techniques was evaluated by closed clinical measurements. From a total of 27 Class III furcation sites (14 control, 13 DFDBA), complete soft tissue closure was noted in 1 non-grafted site and 3 grafted furcations. The addition of DFDBA did not enhance defect closure compared to coronally positioning the flaps alone. Restoration of Class III furcations was not a predictable procedure. In an observational study of maxillary and mandibular molar teeth extracted for periodontal reasons in a Chinese population, Lu (1992) evaluated the contours present in the area (2 mm below the CEJ) where an ePTFE membrane would be placed during surgery. His data indicated that membrane placement in this area was likely to have a significant gap between the stretched membrane and the tooth surface, and may contribute to failure. The author suggested that supragingival placement of the membrane's coronal margin may be the solution to maintaining epithelial exclusion.

Yukna (1992) compared the use of freeze-dried dura mater allografts to ePTFE membranes in Class II mandibular molar furcations. He reported equal results from the 2 techniques, based on surgical re-entry. However, ePTFE did not give results comparable to other studies using this

material. In no case was there complete closure of the Class II defect with either material. He also noted that the improvement in open probing attachment levels seen at the time of membrane removal was lost over the intervening months, more so for the vertical than the horizontal component.

Gottlow et al. (1992) evaluated the long-term stability of initial clinical gains (bleeding on probing, probing depth, clinical attachment level) observed 6 months post-surgically compared to measurements obtained over 1 to 5 years. Eighty (80) of 88 sites had gained ≥ 2 mm CAL, and 60 of the 80 sites had gained ≥ 3 mm at 6 months. Over 5 years the number of sites followed decreased from 80 to 9. The stability of the sites showed that the clinical gains at 6 months had been maintained with 93% present at 1 year, 92% at 2 years, 90% at year 3, and 100% at years 4 and 5. Contrary to Yukna (1992), the authors concluded that the improvement in clinical parameters can be maintained over 5 years in a majority of cases.

Other applications for the use of GTR have been shown by Pini Prato et al. (1992) who used ePTFE membranes for coverage of previously restored root surfaces. Also, Andregg and Metzler (1993) used ePTFE membranes to treat palato-gingival grooves in 10 patients with good clinical results.

MATERIALS

Free Gingival Grafts (FGG) Overlying Autogenous Bone Grafts

Using FGG over 88 intraoral (sites/tuberosity) bone grafts, Ellegaard et al. (1974) showed complete regeneration (based on clinical and radiographic measures) in about 60% of sites with 10% exhibiting > 3 mm residual pockets compared with 40% to 60% in controls.

Nucleopore/Millipore Filters

These are non-resorbable and require a second procedure for removal (Magnusson et al., 1985; Aukhil et al., 1986A; Iglhaut et al., 1988).

Teflon/ePTFE Membranes

These are also non-resorbable and require a second procedure for removal. These membranes are made of expanded polytetrafluoroethylene (ePTFE) and are biocompatible. They consist of 2 parts: 1) an open microstructure collar to inhibit epithelial migration and 2) an occlusive apron that isolates the root surface from the surrounding tissues (Gottlow et al., 1986; Becker et al., 1987, 1988; Pontoriero et al., 1987, 1988; Schallhorn and McClain, 1988; Stahl et al., 1990; Caffesse et al., 1990; Lekovic et al., 1990; Seibert and Nyman, 1990).

Biobrane Membrane

This is a non-resorbable membrane which requires a second procedure for removal. It is a biocomposite consisting of an ultrathin, semi-permeable silicone membrane mechanically bonded to a flexible knitted nylon fabric and coated with hydrophilic collagen peptides. It is primarily a biological dressing that is used in the treatment of skin burns (Aukhil et al., 1986B).

Polylactic Acid Membranes

These are biodegradable and degradation is primarily by hydrolysis so a second procedure for removal is not required (Magnusson et al., 1988). The commercially available membrane consists of a polymer of polyactic acid which has been softened by a citric acid ester to facilitate handling. The matrix barrier consists of an external and internal layer separated by an interspace designed to allow gingival comnnective integration while excluding epithlium

TABLE 1. SUMMARY OF GUIDED TISSUE REGENERATION STUDIES (modified from Minabe, 1991)

Study	Animal Model/ Number	Experimental Sites	Experimental Model/Defect	Membrane Type/ Pore Size	Observation Period	Treatment Effects		
I. Animal Studies/GTR/Nondegradable Barrier (Closed Type Model)								
Gottlow (1984)	Monkey/3	Premolar/ molar	Dehiscence/ experimental periodontitis	Teflon/ Gore-Tex	3 months	New attachment	Exp.	Control
						0-59%	3	5
						60-99%	2	1
						100%	4	0
						mean:	77% (0.9-6.8 mm)	33% (0-2.5 mm)
II. Animal Studies/GTR/Nonabsorbable Barrier								
Magnusson (1985)	Monkey/6	Premolar/ molar	Wide dehiscence	Millipore Filter/0.25 μm	6 months		Exp.	Control
						New attachment	54% (2.9 mm)	2% (0.1 mm)
						New bone	20% (1.1 mm)	0% (0 mm)
Aukhil (1986)	Beagle dog/6	Premolar	Horizontal/ natural pedoni	Biobrane	4 months	CT attachment	(0.72 mm)	
						New attachment	(0.51 mm)	

TABLE 1. Continued

Study	Animal Model/ Number	Experimental Sites	Experimental Model/Defect	Membrane Type/ Pore Size	Observation Period	Treatment Effects
III. Animal Studies/GTR/Absorbable Barrier						
Magnusson (1988)	Mongrel dog/2	Premolar	Dehiscence	Millipore filter polylactic acid/ (70 μm thick)	2 months	Poly / Milli / Control New attachment 46% / 25% / 12% 2.5 / 1.4 / 0.7 mm New bone 2.1 / 1.7 / 0.8 mm
Pfeifer (1980)	Beagle dog/4	Molar	Furcal defects/ experimentally created	Collagen (bovine dermal) crosslinked/ non-crosslink	1,3,4,8 weeks	Cross-linked membrane persisted 6-8 weeks; non-cross-linked resorbed in approximately 3 weeks.
Siebert (1990) Pilot Study	Beagle dog/2	Max/man arches	B-L ridge defects (13 × 7 mm) surgically created	Interpore 200 (PHA)/tissue growth matrix (TGM w/& w/o Gore-Tex)	55-90 days	No data for volumetric fill; complete bone fill in GTM only and GTM + PHA sites; some bone in TGM
IV. Clinical Studies/GTR/Nonabsorbable Barrier						
Gottlow (1986) Case reports	Human/10	Cuspid/molar	Class II & III furcations/flat surface + angular bony defect	Teflon/Gore-Tex	3 months/ 6 months	New attachment 40% Probing attachment Gain 5.6 mm
Pontoriero (1987)	Human/37	Molar	Class II & III furcations	Teflon/Gore-Tex	6 months	Completely Closed Sites Class II 67%/exp 10%/con Class III 25%/exp 0%/con
Becker (1987) Case reports	Human/3	Cuspid/molar	Case 1: Class III Case 2: 1 wall Case 3: 2 wall	Teflon/Gore-Tex	3 months/ 6 months	Probing Attachment Gain Case 1: 4 mm Case 2: 2-4 mm Case 3: 4 mm
Pontoriero (1988)	Human/21	Molar	Class II furcations	Teflon/Gore-Tex	6 months	Probing Attachment Gain Vert: 4.1 mm/exp 1.5 mm/con Horz: 4.1 mm/exp 1.9 mm/con
Becker (1988)	Human/27	Premolar/ molar	Class II & III furcations; 3 wall defects	Teflon/Gore-Tex	6 months (membrane removed after 6 weeks)	Probing Attachment Gain Class II: 2.3 mm Class III: 1.3 mm 3 wall: 4.5 mm
Schallhorn (1988)	Human/39	Molar	Class II & III furcations; dehiscence/ horizontal/ wide intrabony defects	Teflon/Gore-Tex; citric acid composite grafts	Variable/up to 6 months	Complete fill: combined approach, 72% of furcas; membranes only, 31% of furcas
Caffesse (1990) Case report	Human/9	Molar	Class II furcations	Teflon/ Gore-Tex	6 months	Clinical Attachment Level Gain 1.8 mm/exp GTM 0.6 mm/con no GTM
Lekovic (1990)	Human/15	Molar	Class II furcations	Teflon/ Gore-Tex; PHA grafts	6 months	Clinical Attachment Level Gain (mean values) 2.40 ± 0.48 mm for GTM only 2.93 ± 0.64 mm for GTM + PHA

TABLE 1. Continued

Study	Animal Model/ Number	Experimental Sites	Experimental Model/Defect	Membrane Type/ Pore Size	Observation Period	Treatment Effects
Stahl (1990)	Human/5	Molar/ nonmolar	Intrabony defects	Teflon/Gore-Tex; Emflon	5-8, 14, 22, 30, weeks	Clinical and histological assessment. New attachment seen as early as 5 weeks with both teflon membranes.
Handelsman (1991)	Human/ 16 pts, 18 defects	All teeth	Intrabony defects, est. 4 mm deep	Citric acid 3 min vs. no citric acid, Gore-Tex mem. on all	Clin meas. 6 months, re-entry at 9 months	No differences between citric acid and no citric acid. 60% of original defect fill. 16 sites had > 2 mm bone fill, 10 sites > 3.3 mm fill. 72% of sites showed > 50% defect fill
Anderegg (1991)	Human/15 pts, 30 defects	Max/man molars	Class II or III paired furcation defects	DFDBA vs. no DFDBA, Gore-Tex on all	Clin and surg re-entry at 6 months	No difference for attachment levels, Exper. sites had greater reduction in probing depth 1.7 mm vs. 1.4 mm for control. 4 sites completely closed, HOPA exp: 2.4 mm increase, control: 1.0 mm increase w/o DFDBA Conclusion: combined therapy better.
Metzler (1991)	Human/17	Max molars, 12 pair facial 5 pr. interprox.	Class II furcation	Open flap debride vs. debride and Gore-Tex	6 month re-entry	No difference for recession, probing depth, clinical attachment gain; results unpredictable. Conclusion: Gore-Tex offers little advantage in max Class II furcations.
V. Clinical Studies/GTR/Absorbable Barrier						
Blumenthal (1990)	Human/10	Molar/ nonmolar	Intrabony defects 1,2,3 wall & combination	Collagen gel/ Collagen membrane autolysed/ antigen-extracted allogeneic bone grafts	12 months	93% of all defects had 50% or greater fill
Chung (1990)	Human/10	Molar/nonmolar	Intrabony defects	Perio-Barrier/ cross-linked Type 1 collagen membrane	12 months	Probing Attachment Level Gain (mean values) 0.56 mm/exp −0.71 mm/con bone defect fill (mean values) 1./16 mm/exp 0.00 mm/con
Yukna (1991)	Human/11	11 pairs Man molars	Class II furcas bilateral defects	Freeze-dried dura mater allografts vs. Gore-Tex membrane	12 month re-entry surgery	Equal results for FDDMA and Gore-Tex membrane. More loss of keratinized tissue with Gore-Tex. Defect fill 1.0 mm, Decreased probing depth, Gore-Tex = 0 mm, FDDMA = 1 mm. % Horiz. fill: Gore-Tex = 20%, FDDMA = 40%.
VI. Miscellaneous						
Ellegaard (1974)	Human	N/A	Intrabony defects	Free gingival grafts/ Autogenous bone grafts	N/A	Complete regeneration in 60% of defects; 10% with residual pockets > 3 mm
Gantes (1988)	Human/22	Molars	Class II furcations	Citric acid/ DFD allogenic bone grafts/ coronally positioned flaps—crown attached sutures	12 months	67% defect fill (average) 43% of defects with complete closure with bone fill. No difference with and without bone grafts

with eventual CT integration with the PDL tissue (Gottow et al., 1994).

Collagen

These membranes are biodegradable and do not require a second procedure for removal. Effectiveness depends on the specific collagen type. Cross-linking (chemically with glutaraldehyde) prolongs existence. The material is chemotactic for PDL fibroblasts; a barrier for migrating epithelial cells; hemostatic; fibrillar scaffold for early vascular and tissue ingrowth, and exhibits varying degrees of immunogenicity. Forms of collagen include: membranes, gels, atelocollagen (telopeptides pepsinized making it less antigenic), and avitene (microfibrillar collagen hemostat from purified bovine corium collagen) (Pfeifer et al., 1989; Blumenthal and Steinberg, 1990; Chung et al., 1990).

Freeze-Dried Dura Mater Allografts

This is a resorbable human allograft material that is composed mainly of collagen and is devoid of immunogenicity (Yukna, 1992). While some risk of disease transmission exists, it can be reduced by the lyophilization and sterilization processes used. One documented case of Creutzfeldt-Jakob disease (a fatal CNS degenerative disease of viral etiology) has been transferred from 1 patient to another with a fresh dura mater allograft (non-dental graft) (Thorn et al., 1991).

Salonen and Persson (1990) analyzed the growth and migration of gingival epithelial cells on materials with different surface properties. A total of 125 explants were prepared from specimens of attached gingiva, placed on Millipore-HA filter, Biopore, or ePTFE material, and then histologically examined after culture periods of 4, 6, and 8 days. Results indicated that greater cell migration occurred on the Millipore-HA filter than on the Biopore or ePTFE material. Differences in epithelial cell attachment and migration to varying substrata may be explained by their ability to bind glycoproteins to varying degrees. Millipore-HA consists of mixed esters of cellulose and therefore has a higher protein-binding capacity than either Biopore or ePTFE material. Scanning electron microscopic examination of these materials disclosed surface differences. The Millipore-HA had a non-homologous surface while the others appeared smooth. Overall, these data suggested that the substrata not only provided contact guidance which influenced cell migration by the shape of the substratum surface, but also induced mitosis and migration because of their protein-binding capacity and wettability characteristics (Table 1).

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Section 11. Growth Factors

DEFINITIONS

Growth Factors: A diverse group of polypeptides which have important roles in regulation of growth and development of a variety of organs.

Fibroblast Growth Factor: A family of growth factors with mitogenic properties for fibroblasts and mesoderm-derived cell types.

Platelet-Derived Growth Factor (PDGF): A glycoprotein carried in the α-granules of platelets and released during blood clotting; a potent growth factor for cells of mesenchymal origin, including fibroblasts and smooth muscle cells.

Transforming Growth Factor (TGF): A family of growth factors involved in the regulation of cell growth and differentiation.

Cytokines: A broad family of humoral factors that mediate considerable roles in growth, differentiation, and tissue damage by cellular receptors.

Lymphokine: Soluble factors released from lymphocytes that transmit signals for growth and differentiations of various cell types.

FACTOR OVERVIEW: Wirthlin (1989)

Bone Morphogenetic Protein (BMP) and Osteogenin

BMP and osteogenin are an acid-resistant group of glycoproteins with osteoinductive properties. At least 7 BMPs have been isolated from bovine and human sources including BMP-1, BMP-2 (BMP-2A, OP-2), BMP-3 (osteogenin), BMP-4 (BMP-2B), BMP-5, BMP-6 (Vgr-1), and BMP-7 (OP-1). BMP-2 through BMP-7 have been shown by sequence similarity to be members of the TGF-β superfamily of molecules, while the amino acid sequence of osteogenin matches that of BMP-3. BMP-6 has been shown to be the human homologue of the murine protein Vgr-1, and the proteins OP-1 and OP-2 are identical to BMP-7 and BMP-2, respectively. Purification isolation has yielded 2 μg of BMP per 10 kg of bovine bone.

The implantation of BMP-incorporated bone matrix has resulted in migration and proliferation of mesenchymal cells, differentiation into chondroblasts and chondrocytes, calcification of cartilage matrix, vascularization, resorption of calcified cartilage, and formation and mineralization of new bone matrix. This process appears similar to normal embryonic endochondral bone formation.

Osteoinductive factor (OIF) is a unique bone protein reported to induce the formation of ectopic cartilage and bone

when implanted in combination with TGF-βI or TGF-βII, but has no similarity of amino acid sequence with BMPs or other known growth factors.

Epidermal Growth Factor (EGF)

EGF is a small, heat-stable, single-chain polypeptide of 6,000 daltons best known for its ability to stimulate keratinization and epidermal growth. Cellular growth is the major result of EGF stimulation of a target cell, with EGF serving as a progression factor inducing competent cells to proceed with division. EGF sources include urine, saliva, Brunner's glands, blood, the central nervous system, and amniotic fluid. EGF binds to a surface receptor, the receptor-ligand complex is internalized, followed by the initiation of a tyrosine kinase cascade leading to the complex phosphorylation and increase in free intracellular Ca2+. The ligand-receptor complex internalization is followed by marked changes in cellular morphology, including rapid growth and division. Cells typically dedifferentiate during rapid growth and division until the influence of EGF is removed, at which time differentiation of the collagen producing fibroblasts resumes.

Monocyte-Derived Growth Factors (MDGF)

MDGF is a 40,000 dalton growth factor synthesized by macrophages and which acts on fibroblasts, smooth muscle cells, endothelial cells, and other mesenchymal cells. Secretion is enhanced if the macrophage is activated by lipopolysaccharide, concanavalin A, fibronectin, or phorbol esters.

Platelet-Derived Growth Factors (PDGF)

PDGF is a family of polypeptide growth factors consisting of a 2-chain polypeptide linked by disulfide bonds with a molecular mass ranging from 27,000 to 30,000 daltons. PDGF is derived from platelets, osteoblasts, activated macrophages, and some tumor cell lines of mesenchymal origin. It is found in serum and has been isolated from bone matrix. PDGF is known to stimulate bone DNA and protein synthesis as well as bone resorption. It serves as a powerful chemoattractant for smooth muscle cells, fibroblasts, and leukocytes and has major mitogenic effects in serum that are dependent upon the presence of other growth factors.

PDGF is stored in the alpha granules of platelets and is extravasated after injury and hemorrhage. Platelet activation and degranulation follow platelet exposure to thrombin or fibrillar collagen. Subsequently, PDGF directly recruits and activates neutrophils and monocytes, possibly in a concentration-gradient fashion. After initiation of this inflammatory phase of wound healing, it serves to activate mesenchymal cells essential to the proliferative phase, including endothelial cells and smooth muscle cells. In the remodeling phases of wound healing, PDGF stimulates secretion of the collagenase and extracellular matrix by associated fibroblasts.

Tumor Necrosis Factor α (TNF-α)

TNF-α is a typical cytokine with a wide range of cell regulatory, immune, and inflammatory properties. TNF-α also interacts and overlaps with other members of the cytokine network, inducing, enhancing, or inhibiting their action. It can stimulate the growth of various diploid fibroblasts and some tumor cell lines. TNF-α's mitogenic action is synergistic with epidermal growth factor (EGF), platelet-derived growth factor (PDGF), and insulin.

TNF-α is also cytotoxic for some cells independent of protein synthesis. Although the basis for susceptibility/resistance of cells to the cytotoxic action of TNF-α is unknown, it may be dependent on other cytokines or growth factors. TNF-α may be involved in the cytoxic action of lymphocytes and natural killer cells. TNF-α may also contribute to the host defense system by inducing a cellular antiviral state. It can protect cells from infection by both DNA and RNA viruses, but only a narrow spectrum of cells.

TNF-α is a powerful neutrophil activator which promotes adherence to endothelial cells or particulate matter, stimulating phagocytosis, respiratory burst activity, and degranulation. TNF-α also has immunoregulatory activity on T-cells and targets vascular endothelial cells promoting coagulation, inflammation, and immunity. It inhibits the activity of thrombomodulin, augments the secretion of inhibitors of plasminogen activators, and induces the synthesis and transient cell surface expression of tissue factor procoagulant activity. TNF-α greatly increases the expression of endothelial leukocyte adhesion molecules and Class I MHC antigens, and can alter the morphology of endothelial cells in vitro, changing their typical "cobblestone" to a more elongated form.

TNF-α's bone resorption potential is comparable to that of parathyroid hormone. It will also stimulate chondrocytes to degrade proteoglycans and will elicit the secretion of proteolytic enzymes, such as collagenase, from synovial cells and fibroblasts surrounding bone and cartilage. There is also evidence that sustained and/or systemic TNF-α production may contribute to the signs and symptoms of disease, including endotoxic shock and acute phase responses in infection and injury.

Tumor Necrosis Factor-β (TNF-β)

TNF-β is a lymphotoxin secreted by mitogen-stimulated lymphocytes with cytotoxic and cytolytic properties. Its biological activities are similar to those of TNF-α, stimulating the growth of non-transformed cells. TNF-β also stimulates bone resorption and bone cell replication.

Insulin-Like Growth Factor (IGF-I, also Somatomedin C and IGF-II)

IGF-I is a single chain polypeptide hormone weighing 7,500 daltons. It is synthesized and secreted in precursor form and is activated by proteolytic cleavage. IGF-I has a 47% homology with insulin, with 3 similar sulfide bridge

cross-links. Growth hormone stimulates the production of IGF-I by hepatic cells, fibroblasts, and fetal rat bone organ cultures. IGF-I stimulates cartilage growth, bone matrix formation, replication of pre-osteoblasts, and osteoblasts. It may also directly stimulate the cell which produces it (autocrine). IGF-I significantly increases alkaline phosphatase activity in osteoblastic cells, suggesting a role in stimulating cell differentiation. Both IGF-I and insulin are capable of similar effects reflecting cross-reactivity at the IGF-I and insulin receptors.

IGF-I transcripts have been reported in macrophages isolated from wounds suggesting IGF-I acts as a local messenger (paracrine factor) between cells in the wound environment. IGF-I alone has minimal effects on wound healing but in combination with PDGF can enhance the rate and quality of wound healing. Poorly controlled diabetics have increased levels of growth hormone but decreased levels of IGF-I, which may impact wound healing.

Fibroblast Growth Factor (FGF)

FGF is one of a group of similar growth factors which share an ability to bind heparin. They induce angiogenesis and mitogenesis of endothelial cells. Two subtypes, acidic fibroblast growth factor (aFGF), and basic fibroblast growth factor (bFGF) have been recognized. Each appears to be derived from a single gene with differences in the multiple similar growth factors within the same class resulting from post-translational processing. The mechanism of action of FGF is largely unknown, but it appears to be released from granules, where it may be stored in a preformed state.

Transforming Growth Factor-β (TGF-β)

TGF-β is a 2-chain polypeptide which is linked together by disulfide bonds. It has a molecular weight of 25,000 daltons. It exists as 3 different gene products: TGF-1, TGF-2, and TGF-3. TGF-β was originally identified because it could induce non-transforming cells to grow in soft agar, which is usually associated with anchorage-independent growth in malignant cells. TGF-1 is found in high concentrations in bone and in the alpha granules of platelets. It is secreted in a latent form by macrophages and activated in conditions such as the low pH of wound healing and bone resorptive environments. It is also present in high concentrations in endochondral growth plates, and at lower levels in diaphyses, epiphyses, and calvaria.

Generally, TGF-β has an inhibitory effect on cells of epithelial origin and usually stimulates cells of mesenchymal origin. TGF-β modulates extracellular matrix production and at the same time suppresses the matrix destruction by decreasing the amount of plasmin and collagenase produced. It may act by altering the cellular response to other growth factors, either at the receptor or postreceptor level. TGF-β can induce the expression of other growth factors, and stimulate the production of PDGF from mesenchymal cells.

Transforming Growth Factor-α (TGF-α)

TGF-α is a peptide with a molecular weight of 5,700 that acts synergistically to induce anchorage-independent growth of non-transformed NRK cells in vitro. It is not related to TGF-β, but is related to EGF and competes for the same receptors. The activation of macrophages may result in TGF-α gene expression and production. It is 42% homologous with EGF and stimulates fibroblasts, epithelial cells, and endothelial cells by binding to the EFG receptors, which mainly stimulate epithelium.

Literature Review

Terranova et al. (1987) evaluated new in vitro assay systems to test the potential chemotactic and proliferative activity of various biological response modifiers to dentin. One assay, using human periodontal ligament cells (PDL), was for specific cell migration (AFSCM) to dentin (either preconditioned with tetracycline [TCN] or unconditioned) treated with fibronectin (FN) and laminin (LM). Another assay, using epithelial cells, evaluated the ability of dentin-bound chemoattractants to stimulate directed movement and proliferation on TCN preconditioned dentin surfaces. These surfaces were incubated with 100 μg of FN, washed and then varying concentrations of endothelial cell growth factor (ECGF) and LM were added. Migration distances were determined by photographs quantifying the stained leading front cells. The authors concluded that assays for specific cell migration were useful in selecting potential biological response modifiers capable of promoting healing at the dentin-soft tissue interface.

Terranova and Wikesjö (1987) reviewed extracellular matrices and polypeptide growth factors as mediators of function of periodontium cells. Fibroblasts exist in a fibrous matrix composed of types I and III collagen, chondroitin sulfate proteoglycan, and fibronectin. Fibronectin binds fibroblasts to the matrix, and also binds to many different collagen types, heparin sulfate, fibrin, and other glycoproteins. Chondrocyte matrix contains type II collagen, chondroitin sulfate proteoglycan, link protein, hyaluronic acid, and chondronectin, which binds chondrocytes to the matrix. Chondronectin also attaches to proteoglycan, collagen, and cell surface receptors. Epithelial cells abut on a matrix of basement membrane containing type IV collagen, and a large heparin sulfate proteoglycan and laminin. Heparin sulfate forms a charged barrier in the basement membrane which prevents passage of proteins, while laminin constitutes 30% to 50% of the total protein in basement membranes.

Fibroblasts, chondrocytes, and epithelial cells produce and use different cell specific attachment factors. Laminin will not support fibroblast attachment, and fibronectin will not support epithelial cell attachment, and may be protective mechanisms. Endothelial cells and hepatocytes can use both fibronectin and laminin for attachment in vitro, and these growth factors can affect the phenotype of the cells.

Polypeptide growth factors (PGF) are released continuously to diffuse to target cells. They may represent a large family of regulatory factors, contributing significantly to wound healing. PGFs, neural elements, proximal contacts with heterologous and homologous cells, and interactions with extracellular matrix material all contribute to stimulation and control of cell growth. PGFs also may contribute to evolving chemotactic responses in targeted cells.

Connective Tissue Attachment Regeneration

Citric acid (CA) conditioning of instrumented root surfaces may contribute to new attachment in animals and humans, with animal models exhibiting better results. CA leads to partial surface demineralization and exposed collagen fibrils. Semi-porous membranes beneath gingival tissues have been used to exclude epithelial cell migration along the root surface, allowing fibroblast proliferation. Whereas epithelial cells normally migrate 10 times faster than fibroblasts, CA treatment of root surfaces followed by exogenous fibronectin application reverses this pattern. Application of exogenous extracellular matrix material and appropriate PGFs to prepared root surfaces may confer a selective advantage to gingival fibroblasts, osteoblasts, and PDL cells.

Sporn and Roberts (1988) completed a review of the multi-functionality of peptide growth factors. Peptides are now known to have a wider range of action than originally thought, with a broader cell response to them than previously believed. Interleukins were first defined as signalling molecules which controlled activities of cells of the immune system. IL-2, originally T-cell growth factor, is now known to be an important factor for B-cells and to increase the cytotoxic activity of monocytes. IL-4, originally B-cell growth factor, has been shown to be a potent stimulant of T-lymphocytes, and to control the maturation of granulocytes and macrophages. IL-1, first described as a substance produced by macrophages which acted on lymphocytes, also is a potent stimulator of epidermal keratinocytes, chondrocytes, and fibroblasts. Peptides originally isolated from non-immune cells and defined by their actions on non-immune cells now have been found to have potent effects on the immune system. In a single cell type, growth-factor action may change according to other substances that are present. TGF-β stimulates growth of certain fibroblasts in vitro in the presence of platelet-derived growth factors, but inhibits their growth if epidermal growth factor is present. The cellular mechanisms responsible for the multiple actions of a peptide ligand are unknown. A possible mechanism is the ability of a receptor for a specific peptide to alter either the cellular distribution or the binding affinity of the receptor for a second peptide growth factor, which is independent of any direct cross-reactivity of the peptides themselves. Also, receptor molecules can be multi-functional, having separate binding sites for two distinct ligands in the same receptor.

Sporn and Roberts concluded that growth factors form part of a complex cellular signalling language, in which individual peptides are the equivalent of characters in an alphabet or code. The information resides in the pattern, or set of regulatory peptide molecules, to which a cell is exposed.

Canalis et al. (1988) evaluated the role of growth factors and the regulation of bone remodeling. Growth factors act primarily as local regulators of cell growth and have important effects on cell replication and differentiation. Effects include increasing osteoblast populations capable of synthesizing bone matrix, stimulating cell replication and differentiated function, or affecting the availability of a factor, and the binding to its receptor. Three categories of growth factors include those synthesized by skeletal muscles, those isolated from bone matrix, and those synthesized by cells from adjoining tissues. Growth factors synthesized by skeletal cells include TGF, bone-derived growth factors (BDGF), IGF, and PDGF. BDGF is found in serum or on the surface of most mammalian cells and stimulates bone collagen and DNA synthesis. BDGF (2m) and molecules of the major histocompatibility complex interact with the receptors for hormones and growth factors and may modulate binding of other growth factors or hormones to their receptor; therefore, it may not be a growth factor in the classic sense. Growth factors isolated from bone matrix include TGF-β, 2m, IGF-1, PDGF, acidic fibroblast growth factor (aFGF), and basic fibroblast growth factor (bFGF); aFGF and bFGF are members of a family of polypeptides that include endothelial cell growth factor (ECGF). They are synthesized by multiple tissues and affect endothelial cell replication and neo-vascularization, and stimulate DNA synthesis and cell replication. They result in an increased bone cell population capable of synthesizing collagen and non-collagen protein. They have no direct stimulatory effect on cell function, and sometimes directly inhibit osteoblastic function. They are available only after cell injury or death, and have no effect on bone resorption. Growth factors synthesized by cells from adjoining tissues include cartilage and blood cell-derived factors. Somatomedin and bFGF-like factors have been isolated from cartilage. Blood-derived factors include monokines and lymphokines.

Lynch et al. (1989A) reported preliminary findings of studies using a combination of PDGF and IGF-1 to enhance the regeneration of periodontal structures. Using beagle dogs with 30 to 80% naturally occurring periodontal disease, 5 teeth received growth factors while 7 teeth served as controls. Following flap surgery and root planing, test teeth received 75 μl of an inert gel containing 1 μg each of purified human PDGF and recombinant IGF-1, while control teeth received the gel only. Two weeks post-surgery, block sections were taken and processed for histometric analysis. Control sites had a long junctional epithelium with no new cementum, while growth factor treated sites exhibited significant amounts of new cementum and

bone. The experimental sites averaged 926 μm of crestal new bone apposition, while the control sites averaged 71 μm. These preliminary results suggest that in vivo application of a combination of PDGF and IGF-1 may enhance periodontal regeneration.

In a study of skin wound healing in pigs where several growth factors were used, Lynch et al. (1989B) found that only the combination of recombinant PDGF-2 plus recombinant IGF-1 produced a dramatic increase in connective tissue regeneration and epithelialization in the absence of increased inflammation relative to the control. The optimal ratio for synergism between these 2 factors was 2:1 (by weight) respectively. Other factors evaluated included epidermal growth factor, TGF-α, TGF-β, and fibroblast growth factor. TGF-α was able to substitute for IGF-1 by acting synergistically with PDGF to promote collagen synthesis and fibroblast proliferation, resulting in a variable increase in epithelial thickness. TGF-β had the greatest individual effect, causing a significant increase in collagen synthesis and fibroblast proliferation. It also enhanced inflammation, abnormal epithelial differentiation, and decreased epithelial volume.

Early wound healing events of bone around press-fit titanium implants inserted with and without a combination of PDGF-β and IGF-1 were evaluated by Lynch et al. (1991A). Two female beagle dogs with edentulous quadrants received 2.0 mm × 6.0 mm sand-blasted titanium implants with 2 transverse 1.0 mm diameter holes in their apical sections. Twenty-four (24) implants were coated with methylcellulose gel containing 4 μg of both recombinant PDGF-β and recombinant IGF-1, while 8 implants received only the gel and 8 were untreated controls. Five quadrants with 20 implants were harvested at 7 and 21 days. At 7 days, the PDGF-β and IGF-1 treated sites had significantly increased percentages of bone-fill in contact with implant surfaces. At 21 days, the treated sites had significantly increased percentages of bone-fill in the peri-implant spaces.

Seyedin (1989) reported on the discovery and research associated with bone morphogenetic proteins (BMP). BMP are osteoinductive substances retained in a collagenous bone matrix and are responsible for the cascade of events leading to bone formation, which includes chemotaxis, proliferation, angiogenesis, bone formation, and differentiation. TGF-α and TGF-β in combination with osteoinductive factor (OIF) can induce massive amounts of ectopic endochondral bone development.

Graves and Cochran (1990) reviewed mesenchymal cell growth factors identifying them as multifunctional, affecting mitogenic activity, cell migration, and differentiation. Paracrine factors are those produced by 1 cell to stimulate another cell, while autocrine factors are those produced by a cell to stimulate itself. Competence growth factors are those that stimulate resting cells in G0 to enter the cell cycle at a point in G1 and enter the S phase. Progression factors are those needed to move the cell from G1 to S efficiently.

Lynch et al. (1991B) evaluated the short-term application of PDGF-β and IGF-1 as a means of enhancing periodontal regeneration. Using beagle dogs with naturally occurring periodontal disease with standardized osseous defects, clearance studies were completed. Teeth received either 10 ng of radiolabeled PDGF-β, 10 ng of radiolabeled IGF-1, or 3 μg of unlabeled recombinant-derived PDGF-β and IGF-1 in a methylcellulose gel carrier. The mean half-life was 3.0 hours for IGF-1 and 4.2 hours for PDGF-β. The clearance slowed after 10 hours but approximately 7% remained after 48 hours, and less than 4% remained after 96 hours, while no detectable label was found at 2 weeks. In vivo studies on the dogs evaluated periodontal wound healing, utilizing the application of a combination of 3 μg of recombinant PDGF-β and 3 μg of IGF-1 in a methylcellulose gel to the roots of diseased premolars. Contralateral roots received the gel alone, with sacrifice of the animals taking place at 2 and 5 weeks, followed by the completion of histologic evaluations. In the PDGF-β/IGF-1 treated sites, there was significantly increased bone height and area, and length of new cementum compared to controls at both 2 and 5 weeks. Mean height and area of new bone at 2 weeks were 0.96 mm and 1.57 mm^2, respectively, at growth-factor treated sites compared to 0.27 mm and 0.07 mm^2 for controls. The bone continued to increase in both height and area from 2 to 5 weeks. At 2 weeks, the length of new cementum was 0.04 mm and 0.82 mm for the control and growth-factor treated sites respectively. The mean percent defect fill was 6.9% in control sites and 40.6% in growth-factor treated sites. By 2 weeks in the growth-factor treated sites, osteoblast-like cells were present on the bone surface and surrounded by new bone matrix. At 5 weeks, numerous mitotic figures were present within the osteoblast-like cells. A normal PDL space was seen between new bone and cementum and there was no difference in ankylosis between the two groups.

Six dogs in the wound healing study received about 10 mCi of 99m-technetium MDP immediately prior to periodontal surgery, and at 2 and 4 weeks following surgery. Alveolar bone uptake around the teeth was compared to nuchal crest bone in each animal. The experimental sites exhibited bone-forming activity which was 2.0 times that of the controls at 2 weeks and 2.7 times the controls at 4 weeks.

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Section 12: Sutures—Materials and Methods

SUTURE MATERIALS

Types of Sutures

Properties of the ideal suture material should include handling ease, minimal tissue reaction, strength, and knot security. The material should also be absorbable, non-allergenic, non-electrolytic, non-carcinogenic, and withstand sterilization. Levin (1980) described the relative strengths and weaknesses of available suture materials as follows:

Braided Sutures. These (cotton, linen, polyester, and silk) are more pliable and flexible than monofilaments and have better knot security. Disadvantages include the tendency to collect bacteria, a "sawing" effect when pulled through tissue and fragmenting within the tissue (especially silk). This results histologically in a greater inflammatory reaction, though severe reactions are rarely seen within the first 10 days.

Monofilament Sutures. These sutures (steel, nylon, polypropylene) are generally stronger, more durable, and create less tissue reaction. Unfortunately, they are also more difficult to handle and have inferior knot-holding properties.

Absorbable Sutures. These materials are plain and chromic gut, plain and chromic collagen, polyglycolic acid, and polyglactin. Plain gut suture is probably the best choice when difficult or inconvenient removal is anticipated. It is more difficult to tie than silk, has inferior knot-holding properties, and forms a hard knot which may irritate tissues. Resorption usually occurs within 5 to 7 days as a result of slow hydrolysis. Chromic gut suture has chromic salts deposited on the outer surface or within the entire strand, providing greater resistance to absorption. It is difficult to handle and tie and does not rapidly resorb. Collagen, polyglycolic acid, and polyglactin sutures generally have less value in periodontal procedures due to delayed healing and handling difficulties (Table 1).

Silk (protein fiber) is the most commonly used multifilament suture material; this is attributed to its handling properties, strength, and minimal tissue irritation at 5 to 7 days (Meyer and Antonini, 1989A and 1989B). While surgical silk and nylon (ethilon) are generally considered to be non-absorbable suture materials, they, in fact, undergo very slow absorption. In response to local information, silk is completely absorbed in 1 to 2 years while nylon (amide polymer) is absorbed via slow hydrolysis.

Non-Absorbable Sutures. These include cotton, steel, polyester (mersilene, dacron), ethibond, propylene (prolene, surgilene), polyethylene and polybutester (elastic). These materials are primarily used in conjunction with general and vascular surgery (Meyer and Antonini, 1989A and 1989B).

TISSUE REACTION TO SUTURE MATERIALS

Lilly (1968) compared the reactions of oral tissues to several suture materials. Nine 4–0 suture materials were placed in the buccal mucosa and tongues of adult mongrel dogs which were sacrificed in groups of 2 at 1, 2, 3, 4, 6, 8, and 10 days post-placement. Block sections were processed for light microscopy and tissue reactions graded as mild, moderate, or severe. Steel and nylon (monofilament) initiated the least tissue reaction. Plain gut created a mild-to-moderate reaction (suture was not present at 8 or 10 days) and braided materials (polyester, dermal, cotton, and silk) resulted in similar reactions (29% to 65% judged severe at 8 to 10 days). Tissue reaction to linen was the most severe of any material studied. The author suggests that the more severe tissue reaction to the braided (multifilament) materials is due to a "wicking" action that may transmit bacteria and fluids to the depths of the wound.

Rivera-Hildago et al. 1991 compared the reactions of the oral tissues in dogs to teflon sutures versus silk sutures at 1, 3, 5, and 7 days. The inflammatory infiltrate increased from day 1 through day 7 for both materials with the infiltrate close to the sutures appearing to be comparable, while the infiltrate some distance from the lumen was more intense with silk. Overall, silk induced a greater inflammatory response than the teflon.

SUTURE NEEDLES/WOUND CLOSURE

Suture needles are made from stainless steel wire and have distinctive shape, size, point, and method of suture attachment. Basic shapes include straight, three-eighths circle, half circle, and five-eighths circle. The immediate needle return from the tissue when using a curved needle is an advantage, and the half circle is easier to use in confined locations. The needle diameter should match the suture size to minimize tissue damage. Needle points may be tapered or cutting, the latter being more useful for thick resistant tissues. Conventional cutting needles are triangular in cross-section with a cutting edge on the inside of the curve. There

Table 1. EXAMPLES OF ABSORBABLE SUTURES

Suture	Material	Absorption	Strength
Plain gut	Submucosa sheep intestine; serosa beef intestine	Body enzymes/macrophages; complete at 70 d	4 to 10 d
Chromic gut	Chromic salts + gut	Complete at 90 d	10 to 14 d
Polyglactin	Co-polymer of glycolide and lactide	Slow hydrolysis; complete at 60 to 90 d	20 to 30 d
Dexon	Homopolymer of glycolic acid	Slow hydrolysis Complete at 60 to 120 d	14 to 21 d

is a greater potential for severing a wound edge with this design. The reverse cutting needle has the third cutting edge on the outside of the needle curvature, minimizing tissue laceration. Sutures may be threaded through the needle or attached in the non-cutting end (swagged). Swagged needles are more expensive, but less time-consuming, and cause less tissue damage on penetration. The most popular needle is the three-eighths circle with a reverse cutting point (Meyer and Antonini, 1989).

Cyanoacrylates were introduced for dental (wound closure) purposes in 1965. The butyl and isobutyl forms of cyanoacrylate are the most acceptable in the oral cavity; the methyl form (super glue) is toxic to tissues. Cyanoacrylates are capable of cementing living wet tissues and are exfoliated in 4 to 7 days. McGraw et al. (1979) reported biometric and histometric results following a cyanoacrylate flap fixation in monkeys. Clinically, cyanoacrylate reduced flap fixation time by 10 to 15 minutes per quadrant, providing firm fixation of the conservative flaps used in this study. However, it may not adequately secure flaps reflected past the MGJ or provide the strength needed to resist muscle pull. The authors suggest a combination of cyanoacrylate and sutures in such instances. The authors concluded that the use of cyanoacrylate appeared to have no effect on probing depth, recession, or attachment level. Levin (1980) reported no adverse tissue reaction to this material in a review of 872 periodontal procedures in 725 patients. McGraw and Caffesse (1978) reported no evidence of cyanoacrylate under the tissue flaps, and there appeared to be less inflammation in the early stages of healing when compared to sutures. The authors caution that because cyanoacrylate is irritating to respiratory and ocular tissues, extreme caution must be employed during its use. This material is not currently approved by the FDA for intra-oral use.

Human fibrin seal (HFS) contains fibrinogen, aprotinin, calcium chloride, fibronectin, fibrin, Factor XIII, thrombin, and platelet-derived growth factor. A dog study by Pini Prato et al. (1984) compared HFS to conventional silk sutures in the closure of periodontal flaps. Partial thickness flaps were reflected in 2 quadrants at healthy sites and immediately replaced and fixed with silk suture or HFS. Sutures were removed on the eighth postoperative day; block sections were obtained at 2 hours, and at 1, 3, 7, and 14 days. The authors state that flaps secured with HFS were more firmly adapted at 2 hours than the sutured flaps. Specimens from day 3 demonstrated absence of inflammation at the HFS side while the sutured side exhibited inflammation up to 7 days. At 14 days, the healing response was equal on both sides. In a subsequent study (Pini Prato et al., 1987), HFS was compared with sutures in humans receiving pedicle or free gingival grafts and modified Widman flap surgery. The authors reported more rapid tissue stabilization (30 seconds versus 4 to 5 minutes) and less hemorrhage at HFS sites. No differences among respective sites were observed at 14 to 22 days. Concerns include preparation time, expense, and "human" blood product derivation.

SUTURE TECHNIQUES

Dahlberg (1969) discussed 4 basic considerations of suturing: 1) use the smallest, least reactive material; 2) leave a minimum amount of suture under the flap; 3) maintain the suture close to the tissue; and 4) remove the suture as soon as possible (5 to 7 days). Regarding methodology, the interrupted suture should be used when tissue positioning is not a problem. The sling suture is used to position the flap at different levels around individual teeth. The continuous sling saves time in placement and the anchor suture is useful in positioning a single papilla. Finally, the vertical mattress suture is used when it is desirable to avoid suture placement beneath flap margins (e.g., osseous graft sites).

A study by Nelson et al. (1977) compared continuous sling and interrupted sutures for primary closure of mucoperiosteal flaps in 10 patients. Despite the authors' impression that interrupted sutures provided better flap adaptation, there was no difference between the 2 techniques with regard to attachment loss or recession.

Newell and Brunsvold (1985) described a vertical mattress suture for esthetic purposes in anterior regions of the mouth. If used with the "curtain procedure," a vertical mattress suture allows the palatal flap to adapt tightly to the underlying bone while retaining the facial papilla in its original position. According to the authors, long thin papillae are best treated with vertical mattress sutures while short wide papillae are best treated with horizontal mattress sutures.

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Section 13: Periodontal Dressings

DEFINITION

Periodontal Dressing (Pack): A protective material applied over the wound created by periodontal surgical procedures.

RATIONALE FOR USE

Reasons for using periodontal dressing include: 1) protect the surgical site from trauma; 2) enhance patient comfort by covering exposed bone and connective tissue; 3) keep debris out of the wound (does not prevent plaque formation); 4) can position and/or stabilize flaps and soft-tissue grafts; 5) prevent the proliferation of excess granulation tissue and exercise caution to avoid pushing the dressing in an apical direction resulting in an interproximal soft-tissue crater); 6) help retain osseous graft materials; and 7) aid in controlling post-operative bleeding in patients with coagulation disorders (Levin, 1980; Sachs et al., 1984).

PHYSICAL PROPERTIES

The original Ward's wonderpak consisted of zinc oxide-eugenol (ZOE) mixed with alcohol, pine oil, and asbestos fibers. Zinc oxide-eugenol dressings generally contain between 40 and 50% free-eugenol, which has been shown to cause tissue necrosis and delayed healing. ZOE dressings were popular due to their obtundent effect on sensitive dentin and connective tissue. Non-eugenol dressings may contain zinc oxide, various oils or fats, rosin, and bacteriostatic or fungicidal agents. ZOE dressings set with a hard, brittle consistency while non-eugenol dressings are more flexible. Tannic acid was originally added to dressings to facilitate hemostasis but has since been removed because of its associative potential for liver damage.

Barricaid is a visible light-cured periodontal dressing composed of polyetherurethane dimethacrylate resin, silanated silica, photo-initiator and accelerator, stabilizer, and colorant. The material is tinted pink, translucent, and tasteless and is packaged as a single component in a disposable syringe. It is highly viscous, easily positioned, and may be effectively handled following lubrication. The soft tissue and tooth surfaces should be dry to facilitate mechanical interlocking and adequate anchorage. While the cured material has adequate rigidity, it maintains enough flexibility to facilitate removal.

Cyanoacrylate has the advantage of eliminating sutures, providing immediate hemostasis, biodegradability, precise positioning of flaps, and protective barrier function. Delayed healing may occur if the material becomes embedded in tissue or beneath the flap. Despite short-term benefits, cyanoacrylate dressings apparently offer little advantage to long-term wound healing. Cyanoacrylate is not FDA approved for oral use.

All dressings are irritating to some degree with eugenol more irritating than non-eugenol dressings. Cell culture studies have demonstrated that cytotoxic components are found in all dressings. Cyanoacrylate appears better tolerated by tissues than conventional dressings and may speed early wound healing. This may be due to the reduction in plaque and debris accumulation when compared to conventional materials. The antimicrobial properties of dressings are of little therapeutic importance and potential drawbacks include sensitization, allergy, fungal overgrowth, and development of resistant strains (Levin, 1980; Sachs et al., 1984).

DRESSING VERSUS NO DRESSING

Dressings were used routinely in the past, especially during the era of gingivectomies and pushback procedures. With the advent of flap procedures and emphasis on post-surgical flap adaptation, dressing use has decreased. Jones and Cassingham (1979) compared healing following periodontal surgery (apically positioned flaps) with and without non-eugenol dressings in humans. Assessments of biopsies (inflammation), gingival crevicular fluid, gingival indices, and sulcular measurements revealed no difference between dressed and non-dressed sites. Postoperative pain was more severe with dressings. The authors imply no useful purpose of dressings following flap surgery. Using comparable assessments, Allen and Caffesse (1983) reported similar observations when comparing results following modified Widman surgery with and without surgical dressings. Sixty percent (60%) of patients preferred no dressing. Dressings contribute to plaque retention and may promote bacterial proliferation at the surgical site. It appears that the primary

concern should be flap adaptation, rather than the placement of a dressing.

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Section 14: Wound Healing

DEFINITIONS

Repair: Healing of a wound by tissue that does not fully restore the architecture or the function of the part.

Reattachment: To attach again. The reunion of epithelial and connective tissues with root surfaces and bone such as occurs after an incision or injury. Not to be confused with new attachment.

New Attachment: The union of connective tissue or epithelium with a root surface that has been deprived of its original attachment apparatus. This new attachment may be epithelial adhesion and/or connective tissue adaptation or attachment and may include new cementum.

Regeneration: Reproduction or reconstitution of a lost or injured part.

Guided Tissue Regeneration: Procedures attempting to regenerate lost periodontal structures through differential tissue responses. Barrier techniques, using materials such as expanded-polytetrafluoroethylene, polyglactin, polylactic acid, and collagen are employed in the hope of excluding epithelium and the gingival corium from the root surface in belief that they interfere with regeneration.

GENERAL

Wound healing involves many intricate mechanisms at the ultracellular and cellular level. However, the events which take place at the tissue level are of the utmost interest to the clinician and compose the main focus of this discussion

Epithelial Regeneration

Engler et al. (1966) studied the healing sequence of epithelialization following simple gingevectomy in monkeys using thymidine radiography. On a cellular level, mitosis within the basal cell and deep spinous layers of the epithelium provides cells for the process of epithelial migration. Notably, the replication rate for the junctional epithelium is about 5 days versus 10 days for gingival epithelium. Once the cells form, they are then expressed outward by a passive phenomenon. The source of epithelium required to cover a given wound is the epithelium peripheral to and adjacent to the wound site. Early in the healing process, epithelial cells begin to migrate (12 to 24 hours) over the wound by peaking at 24 to 36 hours. This movement proceeds at a rate of approximately 0.5 mm/day and takes place between the clot and the poly band which was established by 6 to 12 hours following surgery. Although the wounds were keratinized by 2 weeks, it took between 3 and 5 weeks for the new gingival sulcus to completely heal.

Connective Tissue

Collagen. In a radioautographic study of connective tissue healing following simple gingivectomy, Ramfjord et al. (1966) offered the following observations. Following clot formation and development of a PMN "poly band" at 13 hours, an acute inflammatory reaction (primarily macrophages) forms under the clot next to the poly band. This inflammatory reaction is responsible for the clearance of necrotic cells and provides an avenue for epithelial migration over the connective tissue and under the clot. Connective tissue matrix formation begins 1 to 2 days after surgery and peaks at 3 to 4 days. Collagenous maturation and functional orientation of the gingival CT required 3 to 5 weeks.

Bone. Wilderman (1964) reviewed the effects of bone exposure in periodontal surgery. Wound healing events accompanying temporary bone include presence of a fibrin clot beneath the flap and inflammation in the marrow spaces and Haversian canal. Granulation tissue was invading the clot at 4 days and bone resorption observed at days 4 to 8. Opposition of new bone occurred from days 10 to 21.

Cementum. Hiatt et al. (1968) studied repair following mucoperiosteal flap surgery and observed cementum formation as early as 3 weeks, which continued through the sixth month.

WOUND HEALING FOLLOWING NON-SURGICAL THERAPY

Following non-surgical therapy, the periodontium heals by formation of a long junctional epithelium. According to the most recent Glossary of Periodontal Terms (1992), this healing response represents new attachment which is a form of repair. Lindhe et al. (1978) characterized the effect of non-surgical therapy on gingival healing in beagle dogs. The junctional epithelium of healed tissues contained rete pegs and a much greater vascular density in the connective tissue subjacent to the junctional epithelium as compared to healthy gingiva which had not been inflamed. Caton and Zander (1979) used a ligature-induced periodontitis model in Rhesus monkeys to create periodontal defects which were then treated by scaling and root planing and soft tissue curettage. Healing was by the formation of a long junctional epithelium.

No new connective tissue attachment was observed.

Waerhaug (1978A, and 1989B) examined 39 teeth which were treated by scaling and root planing and removed by block section at 15 days to 7 months after treatment. Healing occurred by formation of a long junctional epithelium. Based on 2 samples, it was estimated that the subgingival plaque front had advanced at 2 μm per day. Waerhaug (1978B) also investigated the condition of root surfaces following subgingival plaque control. Eighty-four (84) teeth were extracted at various time intervals after subgingival scaling and root planing (11 cases were completed with flap access). After staining with toluidine blue, stereoscopic examination revealed that in pockets less than 3 mm deep, subgingival plaque removal was successful 83% of the time. Successful subgingival plaque removal was much less in 3 to 5 mm (39%) and > 5 mm pockets (11%). The author felt that these findings supported pocket elimination therapy.

The effect of postsurgical plaque control on bone regeneration in periodontal defects has also been investigated. Rosling et al. (1976) demonstrated that professional plaque control every 2 weeks (after modified Widman flap surgery) resulted in 80% bone fill (as measured using standardized radiographs) as compared to no bone fill or deepening of intrabony defects in control patients who received professional plaque control every 12 months post-surgery. In a later study using a ligature-induced periodontitis model in squirrel monkeys, Kantor (1980) reported reduction of the inflammatory cell infiltrate from 68% to 14% and 50% increase in bone fill after 10 weeks of professional subgingival and supragingival plaque control administered 3 times per week.

In addition to plaque control, the condition of the root surface may also affect non-surgical wound healing. Aleo et al. (1975) used an in vitro system to show that periodontally-diseased root surfaces inhibited attachment of gingival fibroblasts. Conversely, root surfaces scaled to remove diseased cementum or treated by phenol extraction allowed cell attachment to take place. The researchers concluded that either chemical or mechanical removal of toxic substances from the root surface is necessary to allow fibroblast attachment to the root surface.

GENERAL WOUND HEALING WITH SURGICAL THERAPY

General wound healing considerations in surgical therapy have included the nature of the epithelial and connective tissue attachment, effect of flap reflection on the underlying alveolar bone, and the relative merits of full thickness and partial thickness flap designs.

Frank et al. (1972) addressed reformation of a junctional epithelium after surgical therapy by examining a block section of 4 anterior teeth and associated gingiva which was removed 4 months after flap curettage. Electron microscopy demonstrated that following open flap curettage, the epithelial attachment reforms with the presence of hemidesmosomes and a basal lamina. No difference was seen in the epithelial attachment to cementum or dentin. Using mongrel dogs, Hiatt et al. (1968) investigated the strength of the flap attachment after full thickness flap reflection. At 2 to 3 days postsurgery, flap adaptation was mediated by fibrin adhesion which was strong enough to prevent downgrowth of epithelium if the flap was well adapted. Using a suture through the flap, 225 grams of tension was required to remove the flap. At 1 week, 340 grams was required to displace the flap and by 2 weeks 1,700 grams of force could not displace the flap. Epithelial attachment was reformed by 1 week and increased in strength at 2 weeks such that flap traction resulted in microscopic flap tears within the epithelium with epithelial cells adhering to the root. By day 14, new connective tissue attachment was observed at the root surface. Osteoclastic activity was observed up to 3 weeks (maximum bone loss was 1 mm) while the earliest osteoblastic activity was noted at 2 weeks. Osteoblastic activity restored the lost bone. Cementum formation occurred over 1 to 6 months. Retained vital cementum appeared to accelerate connective tissue attachment. Dentin surfaces which had been denuded of cementum by root planing all underwent resorption prior to new cementum formation.

Crestal bone resorption has been addressed in studies comparing the merits of full and partial thickness flap reflection. Wood et al. (1972) compared apically positioned full and partial thickness flaps in 9 patients. Using clinical photographs, measurements, and surgical re-entry (7 patients), it was determined that healing was delayed at 1 and 2 weeks with partial thickness flaps but no differences were seen by 1 month. Mean crestal alveolar bone loss was 0.62 mm for full thickness flap and 0.98 mm in areas treated by partial thickness flaps. Use of the partial thickness flap in areas of thin gingiva resulted in a very thin non-protective layer of connective tissue and significant osteoclastic activity was seen. The authors concluded that loss of crestal alveolar bone depends on the pre-operative thickness of the radicular bone and overlying gingiva and mucosa. Thus, partial thickness flaps are not indicated in areas of thin connective tissue. In contrast, Staffileno et al. (1966) studied the histologic repair of the periodontium in dogs following resection of a split thickness flap. Results demonstrated that split thickness flaps with periosteal retention produced minimal tissue destruction, rapid repair, slight alteration of the dentogingival junction, and maximum preservation of the periodontal supporting structures.

Vascular healing is also of importance to wound healing in general. Cutright (1969) examined the rate and pattern of vascular regeneration after incisional wounds in dog gingiva. At day 1, withdrawal and blockage of cut ends of vessels were observed at the wound periphery. At day 2, new sprouts and club-shaped stubs were observed at the bottom of the wound where a fibrin clot was found. At days 3 to 5, short capillary loops from cut vessel ends formed anastomoses of vessels and were of normal length by day

11. Vascular healing proceeded in an apical-incisal direction.

WOUND HEALING WITH RESECTIVE SURGICAL THERAPY

Sabag et al. (1984) studied the reformation of the epithelial attachment after gingivectomy in an animal model (Donjou rats). At day 1, the wound was covered by a blood clot and many neutrophils. Epithelial migration began after day 2 and after 5 days covered the proliferating cells and fibers of the underlying connective tissue. After 7 to 8 days, a new junctional epithelium was seen with evidence of attachment to the root surface by 12 to 14 days. In a similar study, healing was reported by Novaes et al. (1969) after gingivectomy procedures in dogs. Re-epithelialization was complete at 7 days and the normal thickness of the junctional epithelium was restored by 16 days. Connective tissue healing was complete by 23 days. The gingiva exhibited a normal shape and healing was complete at 38 days. In humans, surgical excision of the entire zone of gingiva by gingivectomy procedure heals with the regeneration of a thin band (average of 2.05 mm) of keratinized tissue (Wennstrom, 1983).

The long-term healing following flap and osseous surgery was studied by Wilderman et al. (1960). The histologic repair of human tissue following mucogingival flap and osseous surgery indicated that osteoblastic activity was still present at 1 year postsurgery. The initial crestal bone loss of 1.2 mm (range: 0.14 to 4.47 mm) was followed by 0.4 mm (range: 0.14 to 1.15 mm) of new bone apposition which resulted in an average reduction in alveolar crest height of 0.8 mm (range: 0.11 to 3.1 mm). Bone thickness was an important factor determining the amount of postoperative bone loss. Thick bone with marrow spaces exhibited less resorption and greater repair than thin bone.

WOUND HEALING IN MUCOGINGIVAL SURGERY

Denudation Procedures

Using a monkey model, Karring et al. (1975) studied the wound healing events of periosteal retention and denudation procedures designed to increase the zone of gingiva. Following both procedures, granulation tissue was observed to originate from residual periosteal connective tissue, PDL, bone marrow spaces, and the adjacent gingiva and alveolar mucosa. Bone resorption was generally more severe with the denudation procedure; however, greater amounts of loss were occasionally seen following periosteal retention. The transitional point between keratinized and non-keratinized epithelium corresponded to the junction between the connective tissue with and without regenerated elastic fibers, demonstrating the inductive influence of connective tissue on the overlying epithelium.

In a similar study of the denudation procedure, Wilderman et al. (1960) studied histologic wound healing of exposed alveolar bone in dogs. Differences in the anatomy of interdental and radicular bone appeared responsible for varying degrees of osteoclastic resorption seen. Where adequate marrow spaces remained interdentally, there was complete restoration of bone. In contrast, radicular areas showed 50% bone restoration, demonstrating functional repair with twice the fibrous attachment on new gingiva as compared to the original condition of epithelial attachment located more apically compared to interdental sites. The osteoclastic phase was present from 2 to 10 days while osteoblastic activity lasted for 10 to 28 days and peaked at 21 to 28 days.

Free Soft Tissue Autograft

Studies by James and McFall (1978) and Caffesse et al. (1979) have compared the healing of free soft tissue autografts placed on periosteum and denuded bone. Clinically, success rates were similar for the 2 types of recipient beds. Caffesse et al. (1979) reported delayed remodeling at grafts placed on bone while James and McFall (1978A) reported less shrinkage of grafts placed on bone (25% versus 50% on periosteum). James et al. (1978) performed a histologic comparison of wound healing between the 2 types of recipient sites. More marrow space to soft tissue communication occurred at "graft-to-bone" sites. Epithelial thickness was greater over free grafts placed on bone until 12 weeks, by which time no difference was seen. Grafts placed on bone exhibited less post-operative swelling, but there was no difference in the degree of inflammation. Bone resorption at the graft-to-bone sites allowed sufficient blood supply from the underlying marrow spaces.

Pedicle Grafts

Pedicle grafts have the advantage of a blood supply from the base of flap which can aid in wound healing by providing nourishment until the re-establishment of a vascular union with the recipient site. Sugarman (1969) reported 3 cases with human histologic evidence of the healing obtained with pedicle grafts and free soft tissue autografts. The full thickness, laterally positioned flap healed by new attachment consisting of junctional epithelium (1.0 to 1.6 mm), connective tissue attachment (0.1 to 3.2 mm), and areas of new cementum. Wilderman and Wentz (1965) presented the wound healing events of pedicle flaps in dogs. Four stages of healing were reported: 1) adaptation stage (0 to 4 days) when a fibrin clot containing neutrophils was present between the flap and the crestal bone; 2) proliferation stage (4 to 21 days) when granulation tissue invaded the fibrin clot, fibroblasts were present on the root surface (6 to 10 days), epithelium migrated apically (10 to 14 days), and an average of 1 mm of crestal bone was resorbed; 3) attachment stage (21 to 28 days) when collagen formation was visible, cementum formation occurred, and osteoblastic activity reached its peak; 4) maturation stage (28 to 180 days) showed new PDL fibers oriented perpendicularly to the root surface. New attachment consisted of a combina-

tion of long junctional epithelium (2.0 mm) and connective tissue attachment (2.1 mm).

Becker et al. (1986) investigated the repair of intrabony defects. Open debridement was performed, hard tissue measurements taken, and flaps were apically positioned to leave the margins of the flaps open adjacent to the treated sites. Re-entries were performed at an average of 14 months and results indicated that 34 of the 36 intrabony defects treated exhibited significant amounts of bone fill. Mean defect fill was 54.25% (2.55 mm) and defect resolution was due to the combination of crestal resorption and fill from the defect base and surrounding osseous walls.

Similar results were reported by Polson and Heijl (1978) following their treatment of intrabony defects; however, unlike Prichard (1983) and Becker et al. (1986), flaps were replaced with their margins at the pre-surgical level following open flap debridement. Re-entry at 6-8 months revealed defect remodeling consisting of 77% bone regeneration and 18% bone resorption. Osseous defect mean bone regeneration at re-entry was 2.5 mm. Two-and three- walled defects exhibited the same potential for osseous regeneration and initial mobility did not affect the regeneration potential.

Ellegaard et al. (1974) described a technique for attaining new periodontal attachment using free palatal or gingival grafts to retard epithelium migration in intrabony defects. The defect was exposed and debrided, a recipient bed for a free soft tissue graft prepared, a cancellous bone autograft placed, and the soft tissue graft inserted over the treated intrabony defect. The authors reported on 88 lesions treated with this procedure and evaluated at 3 and 6 months with clinical measurements and radiographs. The amount of new attachment was markedly greater with the soft tissue grafting technique than with a traditional flap procedure. Sixty percent (60%) of the defects treated using the soft tissue grafting technique exhibited 60% of the defects to fill completely, compared to 40% of defects showing some new attachment with conventional flap design. The practicality of this technique may be the reason for its lack of popularity as it requires a minimum of 3 different surgical sites.

Caton et al. (1980), using Rhesus monkeys, performed a histometric comparison of the following procedures: 1) modified Widman flap; 2) modified Widman flap with frozen autogenous red marrow and cancellous bone graft; 3) modified Widman flap and tricalcium phosphate; and 4) periodic root planing and soft tissue curettage. Animals were sacrificed after 1 year. All procedures resulted in healing by a long junctional epithelium with no new connective tissue attachment.

Although true regeneration was not achieved by any of the procedures compared in the study by Caton et al. (1980), studies have suggested that a long junctional epithelium may be as resistant to periodontal insult as connective tissue. Magnusson et al. (1983) used monkeys to compare histologically the effect of ligature-induced periodontitis on teeth with a known long junctional epithelial attachment and on teeth with a normal junctional epithelium. Results after 6 months demonstrated that a gingival unit with a long junctional epithelium responded to plaque infection in a manner similar to normal junctional epithelium. Similarly, in a shorter study (up to 20 days) Beaumont et al. (1984) reported that long junctional epithelial attachment formed in beagle dogs after flap surgery was no less resistant to plaque and its products than true connective tissue attachment. Although the study was relatively short, the authors noticed a trend toward replacement of the long junctional epithelium by connective tissue at longer time intervals.

Regeneration of lost periodontium is a process which is influenced by several different factors. Egelberg (1987) reviewed several clinical and laboratory studies which have investigated the role of factors such as the diseased root surface, the effect of various clinical regenerative techniques, supracrestal wound healing and healing of the periodontal ligament, and root resorption. Polson and Caton (1982) designed a study to evaluate the relative significance of a reduced periodontium and a diseased root surface in the formation of new bone, cementum, and periodontal ligament. The regenerative capacity of the reduced periodontium was evaluated by transplanting a tooth with a non-diseased surface into the reduced periodontium. The regenerative potential for the tooth with the diseased root surface was evaluated by transplanting it into the normal periodontium. Results revealed that the diseased root surface that had been placed into the normal periodontium was lined with epithelium interposed between root surface and alveolar bone. The normal root surface that had been placed into the reduced periodontium had connective tissue reattachment in the periodontal ligament and supracrestal region. It appeared that root surface alterations inhibited the potential for new connective tissue attachment and that the connective tissue in areas of a reduced periodontium possessed the progenitor cell populations necessary for this attachment formation.

Root surface alterations were again shown to inhibit connective tissue attachment in an investigation by Lindhe et al. (1984). The authors designed a study to examine if alveolar bone, located adjacent to a root surface deprived of its periodontal ligament and cementum layer, could stimulate the reformation of a connective tissue attachment. Using reimplanted incisors in monkeys, a histometric comparison of root planed teeth with either reduced buccal alveolar bone or normal bone and non-root planed teeth with reduced or normal bone was accomplished. A 6-month evaluation demonstrated that, irrespective of the presence or absence of alveolar bone, a fibrous reattachment failed to form on that part of the reimplanted teeth which had been deprived of their periodontal ligament. In those teeth where periodontal ligament and cementum were preserved, reattachment of connective tissue (CT) fibers occurred whether or not ad-

TABLE 1. WOUND HEALING

Study	Begin Migration	Epithelium Re-epithelialize	Reform JE	Connective Tissue Fibroblast Activity Began	Fibroblast Activity End	Bone Osteoclastic Phase	Osteoblastic Phase	Cementum Formation
Wilderman, 1960 (dogs), denudation procedure	2 days, granulated tissue from PDL, gingiva	Complete at 21 days			New CT covering at 14 days	2-10 days, undermining resorption peak 4 to 6 days	10-28 days, peak 21 to 28 days	
Staffileno, 1966, periosteal *retention*	2 days fibrin, clot, and PMN	Complete at 7 days	Complete at 14 days	4 days		Peak at 4 days over at 7 days	Begins at 7 days, *new bone at* 21 days	
Hiatt, 1968, mucoperiosteal flap			Complete at 7 days	Fibrin clot 2 to 3 days	14 days new CT at root surface	Up to 3 weeks	Begins at 14 days	1 to 6 months
Wood, 1972 full vs. PT flap						Crest reduction; full-0.62 mm PT-0.98 *mm*		
Novaes, 1969 (dogs) gingvectomy	Clot, first epithelial migration, 2 days	Complete at 7 days	16 days normal thickness	New CT at 7 days	Complete at 23 days			
Wilderman, 1965 pedicle flap	Clot, 2 to 4 days	Greatest rate 10 to 15 days		New CT at 4 days, cover root at 10 days	Increase CT formation at 28 days; *collagen* bundles from flap to root at 90 days	Present at 4 days, subsides by 14 days	Greatest at 21 to 28 days	Cementoid covered entire root surface at 28 days
Caffesse, 1979 FGG (Rhesus monkey)	At 7 days	Complete at 14 days		Periosteal bed 2 to 4 days Denuded bone none till 7 days				
James and McFall, 1978, on FGG* denuded bone bed		Epithelial variable thickness at 1 week		Capillary ingrowth from bone at 14 days	6 weeks-collagen fibers trapped in new osteoid	Resorption at 1 week, open marrow spaces	Thinner bone found at 2 to 4 weeks	

*Free gingival graft

jacent bone was present. It was concluded that alveolar bone adjacent to a root surface may have little influence on the biological conditions which determine whether periodontal healing results in CT reattachment or new attachment.

In a series of articles by Bowers et al. (1989A, B, and C), the relative influence of several factors on the regeneration of a new attachment apparatus (bone, cementum, and a functional periodontal ligament) in humans was evaluated. Teeth with advanced periodontal disease were treated, extracted after 6 months, and subjected to histologic examination. In Part I of the study, formation of new attachment was evaluated in two groups of teeth: 1) those treated by open debridement, crown removal, and submersion of the vital roots below the oral mucosa and 2) those treated by open debridement but not submerged. Results showed that a new attachment apparatus (mean 0.75 mm) was found in submerged defects and no evidence of a new attachment apparatus was seen in the non-submerged defects (long junctional epithelium only). In Part II, similar comparison was made by 2 different groups: 1) teeth treated using open debridement and placement of decalcified freeze-dried bone allograft (DFDBA) in a submerged environment and 2) teeth treated using open debridement and no DFDBA but also in a submerged environment. When results from these 2 groups were compared, it was determined that a significant difference was found in the amount of new attachment apparatus formation for grafted versus non-grafted sites (1.76 mm versus 0.76 mm) in a submerged environment. Finally, in Part III, only non-submerged teeth were evaluated and placed in 1 of 2 groups: 1) those teeth

TABLE 2. SEQUENTIAL WOUND HEALING EVENTS

Vascular regeneration Cutright, 1969 (incisional wound in dogs)	Day 1 Vessel contraction no cell labeling	Day 2 New vascular sprouts, club shaped ends	Day 3 Short capillary loops from anastomes of cut ends	Day 5 Increased capillary loops, dilitation of one end-venous differentiation	Day 7 Capillary loops reformed at wound edges	Day 9 Capillary loops about as high as normal gingiva, but not as dense	Day 11 Increased maturation of normal vasculature
Epithelial regeneration Sabag, 1984 (gingivectomy in rats)	Day 2 Migration of oral epithelium seen	Day 5 Epithelium covers cut CT, crevicular epithelium reformed	Days 7-8 JE stratification present	Days 9-11 JE thicker	Days 12 to 14 apical third of new JE joined to cemental surface, new epithelial attachment		
Granulation tissue Karring, 1975 (Rhesus monkeys)	Exposure of periosteum (periosteal retention procedure)	Days 1-2 Clot and PMN infiltrate	Days 4-5 granulation tissue formed from PDL space	1-3 weeks osteoclastic activity gingiva regenerated by 3 weeks	3-6 weeks osteoclastic activity subsided, epithelium thickened, well developed rate ridges	2 to 12 months variable amounts of alveolar crest resorption found	
Same	Exposure of bone (denudation procedure)	Thin fibrin clot over bone, many PMN, surface of bone necrotic	Some granulation tissue from PDL space bone resorption, especially at alveolar crest	Undermining resorption seen on PDL side of bone, granulation tissue extends from open marrow spaces	Osteoclastic activity subsided, new bone formation seen, thin epithelial covering over wound	Bone formation subsided, keratinized epithelium present, variable amounts of alveolar crest resorption	
Osseous surgery Wilderman, 1970	1 week CT proliferation	2 weeks continued CT proliferation, apical migration of epithelium	Crestal resorption averaged 1.2 mm, crestal apposition of 0.4 mm	Average bone loss 0.8 mm	2 months CT embedded into bone	3 months periosteum formed	

which were treated with open debridement and DFDBA and 2) those teeth which were treated with open debridement alone. Results revealed that grafted, non-submerged sites demonstrated 1.21 mm of new attachment apparatus while non-grafted, non-submerged sites healed by long junctional epithelium only. Free gingival grafts were used to enhance wound coverage and retard epithelial migration for both groups in Part III but these did not appear to enhance regeneration of a new attachment apparatus, new cementum, new connective tissue, or new bone in sites which were not treated using bone grafts. The role of free gingival grafts in DFDBA grafted sites could not be determined in this study.

Tables 1 and 2 summarize general wound healing events.

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