CHAPTER 7. ROOT TREATMENT, REATTACHMENT, AND REPAIR

Section 1. Root 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.

HEALING BY A LONG JUNCTIONAL EPITHELIUM

Following surgery, the curetted root surface may be repopulated by 4 different types of cells: epithelial; gingival connective tissue; bone; and periodontal ligament cells. The cells which repopulate the root surface determine the nature of the attachment that will form. Periodontal wound healing following traditional surgical procedures results in the formation of a long junctional epithelium along the root surfaces, with no new connective tissue attachment. The epithelial downgrowth prevents the formation of a new connective tissue attachment by preventing repopulation of the root surface by cells derived from the periodontal ligament. However, the coverage of the root surface by an epithelial layer has a beneficial effect; i.e., the prevention of root resorption and ankylosis, which otherwise could be induced by gingival connective tissue and bone.

Waerhaug (1955) studied the healing following scaling and root planing in one dog with subgingival calculus on 4 cuspids. Two of the teeth were scaled and polished and 2 served as untreated controls. After the removal of calculus, the bleeding subsided and normal conditions were observed. It was concluded that a complete removal of subgingival calculus will, under favorable conditions, lead to a re-formation of a normal epithelial cuff in areas earlier covered with calculus, and it may result in a more or less complete disappearance of the inflammation caused by the calculus.

Caton and Zander (1976) studied the healing after surgical treatment. They created a periodontal pocket on 1 molar in a monkey. The pocket was treated by flap curettage, followed by plaque removal every other day for 1 year. Radiographs taken after 1 year showed increased radiodensity of the crestal bone. The histological sections showed a long junctional epithelium extending to the most apical point of root instrumentation. The connective tissue fibers between the junctional epithelium and the bone were oriented parallel to the long axis of the tooth. They concluded that repair of an osseous defect can occur opposite junctional epithelium on the root surface without new attachment of connective tissue.

Caton and Zander (1979) created 22 pairs of periodontal pocket in 2 monkeys. All teeth were scaled, then a plaque control program consisting of toothbrushing, flossing, and topical application of 2% chlorhexidine 3 times a week was initiated. On one side of the jaw, root planing and soft tissue curettage were performed and were repeated at 3, 6, and 9 months after initial therapy. The treatment resulted in the formation of a long junctional epithelium with no new connective tissue attachment. In 8 of the 22 pockets, the procedure produced discontinuities or "windows" of connective tissue attachment in the junctional epithelium. The resistance to probing following root planing and soft tissue curettage appears to result from the formation of a long junctional epithelium rather than new connective tissue attachment.

Caton et al. (1980) compared the healing after 4 different surgical procedures. Periodontal pockets were induced in 8 monkeys then treated by 1) modified Widman flap (MWF) without osseous surgery; 2) MWF without osseous surgery but with autogenous red marrow and cancellous bone; 3) MWF without osseous surgery but with beta tricalcium phosphate; and 4) periodic root planing and soft tissue curettage. Histometric measurements after 12 months of healing demonstrated that all treatment procedures resulted in the reformation of an epithelial lining (long junctional epithelium) with no difference between treatments. The most apical cells of the junctional epithelium were consistently located at or close to the level of the root surface which had been planed. Adjacent to the epithelial lining were fibers oriented parallel to the root surface. In a few specimens, principal fibers were inserted into new cementum and adjacent alveolar bone. This area could represent healing of the root surface injured during instrumentation.

Proye and Polson (1982) studied the effect of root surface alterations on periodontal healing. Three teeth in each of 4 monkeys were extracted and the coronal third of the root surfaces was planed to remove the attached periodontal fibers and cementum. The teeth were reimplanted into their sockets within 15 minutes. Histological examination showed a zone of fibrin containing erythrocytes and PMNs adjacent to the denuded root surface 1 day after reimplantation. Epithelium migrated rapidly along the denuded root, reached the alveolar crest at 3 days, and was within the ligament space at 7 days. At 21 days, the epithelium was at the apical limit of root instrumentation. There was no evidence of connective tissue attachment to any portion of a denuded root surface. It was concluded that the absence of fibers on the root surface results in apical migration of the epithelium, and precludes formation of new connective tissue attachment.

In a followup study, Polson and Caton (1983) evaluated the factors influencing periodontal repair and regeneration. In 2 monkeys, central incisors with reduced periodontium were transplanted into sockets of normal height, and central incisors with normal periodontium were transplanted into sockets of reduced height. After 40 days of healing, the normal roots transplanted into the reduced periodontium had connective tissue reattachment in the periodontal ligament and supracrestal regions. The exposed roots placed into the normal periodontium were lined with epithelium interposed between the root surface and the alveolar bone. The results indicated that root surface alterations, rather than the presence of a reduced periodontium, inhibit new connective tissue attachment.

Lindhe et al. (1984) studied the contribution of alveolar bone to connective tissue re-attachment following treatment. The maxillary and mandibular incisors in 3 monkeys were extracted and the buccal root surfaces of the incisors from the left side of the jaws were planed. In 2 of the monkeys, the buccal alveolar bone plate was removed. All teeth were reimplanted into their original sockets within 4 minutes. Histologic examination after 6 months showed that irrespective of the presence or absence of alveolar bone, connective tissue reattachment failed to form on that part of the tooth that had been root planed; instead a long junctional epithelium had formed. However, in non-root planed teeth a connective tissue reattachment had occurred. Alveolar bone located adjacent to a root surface may have limited influence on the biological conditions which determine whether periodontal healing results in connective tissue reattachment or new attachment.

Magnusson et al. (1983) evaluated the resistance of the long junctional epithelium to plaque infection in 4 monkeys. Eight test teeth with induced periodontitis were treated surgically. After 4 months of plaque control, plaque was allowed to accumulate for 6 months on 4 of the treated teeth and 3 control teeth. Ligatures were placed on the remaining 4 test teeth and on 3 control teeth to enhance subgingival plaque formation. The infiltrated connective tissue of the test teeth covered about 60% of the junctional epithelium while for the controls it was 90%. The inflammatory lesion in the connective tissue did not extend deeper into the periodontal tissues in sites with a long junctional epithelium than in gingival units of normal height. It was concluded that the barrier function of a long junctional epithelium against plaque infection is not inferior to that provided by a dentogingival epithelium of normal height.

The resistance of the long junctional epithelium was also studied by Beaumont et al. (1984). Inflammation by ligatures was induced in 6 dogs. Three of the dogs had induced periodontitis and were treated surgically which resulted in long junctional epithelium; the remaining 3 dogs had healthy periodontium. Healing was evaluated over periods ranging from 4 to 20 days. There were no instances of sulcular ulceration in the group with established long junctional epithelial attachment, but ulcerated sulcular epithelium was seen often in the earlier time periods of the previously healthy group. It was concluded that there was no appreciable difference in resistance to disease between a long junctional epithelium and a true connective tissue attachment.

The coverage of the root surface by an epithelial layer has a beneficial effect; i.e., the prevention of root resorption and ankylosis, which otherwise could be induced by gingival connective tissue and bone. Karring et al. (1984) studied the potential for root resorption during periodontal wound healing. In 2 monkeys, teeth with induced periodontitis were extracted, and the roots were planed. After crown resection, the roots were partially embedded into sockets prepared in the buccal surfaces of the jawbone. The coronal periodontitis affected the roots located in contact with the connective tissue of the mucosal flap after suturing. Healing was evaluated between 1 and 24 weeks. The parts of the coronal root surfaces which were covered with epithelium as a result of exposure exhibited no resorption or ankylosis. The root portions in contact with bone or gingival connective tissue regularly displayed root resorption. The results indicate that root resorption is a progressive process in roots exposed to bone and/or gingival connective tissue and that epithelial downgrowth exhibits a protective function to this process.

HEALING BY REATTACHMENT

During surgery, if healthy root surfaces are left undisturbed, healing will result in the reunion of the gingival connective tissues with the root surfaces and bone. This healing will be characterized by the reformation of the functionally oriented attachment apparatus that was present before surgery.

Karring et al. (1980) studied the healing following implantation of periodontitis-affected roots into bone tissue in 3 beagle dogs. Following crown resection of 12 teeth, the periodontitis-affected portion of the roots was scaled and root planed. The roots were extracted and implanted into bone cavities prepared in edentulous areas of the jaws so that epithelial migration into the wound and bacterial infection were prevented during healing. The results after 1, 2, and 3 months of healing demonstrated that new connective tissue attachment did not occur to periodontitis-affected root surfaces placed adjacent to bone tissue, but healing was characterized by repair phenomena; i.e., root resorption and ankylosis. In areas where periodontal ligament tissue was preserved, a functionally oriented attachment apparatus was reformed.

Nyman et al. (1980) in a similar experiment studied the healing following implantation of periodontitis-affected roots into gingival connective tissue. The study was performed on 28 teeth in 1 dog and 2 monkeys. Following root resection and scaling and root planing of the periodontitis-affected portion of the teeth, the extracted roots were implanted into grooves prepared in edentulous areas of the jaws so that the roots were embedded to half their circumference in bone, leaving the remaining part to be covered by the gingival connective tissue of the repositioned flap of the recipient site. Histologic examination after 2 and 3 months of healing disclosed that a new connective tissue attachment failed to form on the previously exposed root surface located in contact with gingival connective tissue. In addition, root resorption was seen on this portion of the roots, which indicated that gingival connective tissue does not possess the ability to form new connective attachment, and may induce resorption of the root. In areas where the periodontal ligament was preserved prior to transplantation, a fibrous reattachment occurred between the root and the adjacent gingival tissue. Resorption and ankylosis were seen in areas adjacent to bone.

HEALING BY NEW ATTACHMENT

Healing after treatment can be in the form of new attachment. This new attachment is characterized by the union of connective tissue or epithelium with the root surface that has been deprived of its original attachment apparatus. Several clinical and histological studies have confirmed that healing by new attachment is possible, and several techniques have been employed to achieve this type of healing.

Animal Studies

The healing of surgical wounds by new connective tissue attachment was studied by Listgarten et al. (1982). A surgical wound was created on the mesial surface of the left maxillary first molar of rats and the root surface curetted free of soft tissue and cementum. The rats were sacrificed between 10 days and 12 months after surgery. The junctional epithelium became re-established by migration of epithelium from the wound edge along the cut gingival surface facing the tooth, until contact was established near the apical border of the instrumented root surface. The entire epithelial attachment was displaced coronally, primarily at the expense of sulcus depth which decreased with time, and by replacement of the apical portion of the junctional epithelium by a connective tissue junction of increasing dimension.

New connective tissue attachment was also reported by Polson and Proye (1983) after citric acid root conditioning. Twenty-four (24) teeth in 4 monkeys were extracted, then reimplanted after either root planing the coronal one third or root planing the coronal one third followed by topical application of citric acid. Histological examinations were performed at 1, 3, 7, and 21 days after implantation. Epithelium migrated rapidly along the denuded, non-acid treated root surfaces reaching the level of root denudation at 21 days. Epithelium did not migrate apically along denuded root surfaces treated with citric acid. At 1 and 3 days, inflammatory cells were enmeshed in a fibrin network which appeared to be attached to the root surface by arcade-like structures. At 7 and 21 days, the region had repopulated with connective tissue cells, and collagen fibers had replaced the fibrin. It was concluded that collagen fiber attachment to the root surface was preceded by fibrin linkage, and that the linkage process occurred as an initial event in the wound healing response.

Karring et al. (1985) studied the formation of new connective tissue attachment in a submerged environment. Periodontitis was induced in 4 monkeys. Three months later, the teeth were root planed, the crowns resected, and the roots covered by a laterally displaced flap. The roots that remained covered had newly formed cementum with inserting collagen fibers on the instrumented root portions. New fibrous attachment was 1.0 ± 0.7 mm. The part of the roots coronal to the newly formed cementum exhibited resorption as the predominant feature. In sites with angular bony defects, regrowth of supporting bone had occurred in the bottom of the defect. The authors concluded that new connective tissue attachment forms on previously periodontitis-involved roots by coronal migration of cells originating from the periodontal ligament.

Blomlof et al. (1987) compared 5 different methods for new attachment formation. Four monkeys with induced periodontitis were treated by 1 of 5 methods: plaque control only; surgery with ultrasonics or hand instrumentation; or chemical treatment by cetylpyridinium chloride and sodium-n-lauroyl sarcosine with or without citric acid. Results of surgery with ultrasonic or hand instrumentation were very similar. Epithelium covered the denuded dentin surface and bone formation was minimal. Both chemically-treated groups resulted in a significant new attachment formation, with the citric acid group showing a slight tendency for more new attachment. The supracrestal fiber bundle was 2 to 3 times thicker in the chemically-treated groups than the mechanically-scaled roots.

Selvig et al. (1988) studied new connective tissue formation in fenestration wounds. Full thickness flaps were reflected over the maxillary incisors in 8 dogs. A fenestration was made labially over each root 3 to 5 mm from the alveolar crest. The flap was repositioned and sutured. After 7 days of healing, fibroblasts, macrophages, and a few leukocytes were present near the treated root surface. At 14 days, interdigitation of the newly-synthesized fibers and the fibrils of the demineralized dental matrix was pronounced.

At 21 days, collagen fibers attached to the cementum or dentin surface now contained fibrils of mature width. Initial reattachment to an instrumented, demineralized root surface included deposition of newly formed collagen fibrils in close approximation to, but not in direct continuity with exposed matrix fibrils. In areas of resorption, new fibrils may adhere to the surface of hard tissue without any fibrillar interdigitation.

Human Clinical Studies

Proye et al. (1982) monitored 128 pockets in 10 patients immediately before and 1, 2, 3, and 4 weeks after a single episode of subgingival root planing. Significant probing depth reduction (initial) occurred at 1 week and was associated with gingival recession, was reduced further (secondary) at 3 weeks, and was associated with gain in clinical attachment. It was concluded that substantial reduction in probing depth occurs within 3 weeks after a single episode of root planing owing to initial gingival recession and secondary gain in clinical attachment.

Nyman et al. (1988) evaluated the role of diseased cementum on new attachment formation. Eleven (11) patients were treated surgically using a split mouth design. In 2 quadrants (control), the teeth were scaled and root planed to remove all cementum. In the remaining quadrants (test), calculus was removed without removal of cementum and the teeth were polished. The patients were followed for 24 months. The results showed that the same degree of improvement was achieved following both types of treatment: there was some gain of probing attachment for both treatment modalities.

Human Histologic Studies

Nyman et al. (1982) reported on a case of a mandibular lateral incisor with attachment loss of 11 mm that was treated with a barrier membrane. A Millipore filter was placed between the flap and the tooth to prevent the epithelium and the gingival connective tissue from reaching contact with the curetted root surface. The tooth was removed en bloc after 3 months of healing. New cementum with inserting fibers was observed extending to a level 5 mm coronal to the alveolar bone crest. New bone had been formed within the angular bony defect. It was concluded that regeneration of cementum including fibrous attachment may be achieved by cells originating from the periodontal ligament, provided that epithelial cells and gingival connective tissue cells are prevented from occupying the wound area adjacent to the root during the initial phase of healing.

Lopez and Belvederessi (1983) implanted 26 root fragments without periodontal ligament and 18 root fragments with periodontal ligament in pouches created in the connective tissue under the mucosa of 44 patients. The implants together with the adjacent tissues were removed between the third and twenty-sixth week after implantation. The implants without periodontal ligament failed to form cementum or bone-like tissue, and in the twenty-sixth week they still showed resorption. Ten of the implants with periodontal ligament showed deposition of cementum with collagen fibers attached to it after the twelfth week. The formation of new attachment could be ascribed to the influence of cells of the remaining periodontal ligament on the implanted root fragments.

Bowers et al. (1989 A, B, and C) in a 3-part study evaluated the regeneration of periodontal tissues in a submerged and non-submerged environment with and without grafting material. In Part I, the formation of new attachment (new bone, new cementum, and an intervening periodontal ligament) was studied in 9 patients with 25 submerged and 22 non-submerged defects. Histologic evaluation after 6 months showed that a new attachment did form on pathologically exposed root surfaces in a submerged environment (0.75 mm). Complete regeneration was limited by the amount of bone and cementum formation. Periodontal ligament fibers were embedded in cementum and bone and were most frequently oriented parallel to the root. In Part II, new attachment was evaluated in grafted and non-grafted submerged defects in 10 patients. The results showed that after 6 months of healing, grafting with demineralized freeze-dried bone allograft (DFDBA) enhanced the amount and frequency of new attachment apparatus (1.76 mm versus 0.76 mm for non-grafted sites), new cementum (1.88 mm versus 1.48 mm for non-grafted sites), and new bone (1.96 mm versus 0.80 mm for non-grafted sites) in a submerged environment. In Part III, new attachment was evaluated in a non-submerged environment with and without bone grafts. Twelve patients had 32 defects treated with DFDBA and 25 defects treated with open debridement. Histometric evaluation after 6 months of healing demonstrated that grafted defects had a mean new attachment apparatus of 1.21 mm. There was a mean of 1.24 mm of new cementum formation, 0.13 mm of connective tissue attachment, and 1.75 mm of new bone formation. The junctional epithelium was located 1.36 mm coronal to the calculus reference notch. In non-grafted sites, a long junctional epithelium formed along the entire length of exposed root surfaces.

THE EFFECTS OF TREATMENT ON GINGIVAL FIBROBLASTS

In Vitro Studies

The cells in the healing site can only attach to a biologically acceptable root surface. Periodontal treatment should produce a root surface that will promote cell growth and attachment.

Aleo et al. (1975) studied in vitro the attachment of human fibroblasts to root surfaces. Untreated periodontally involved teeth were extracted and cut longitudinally. Three groups of 20 or more teeth were employed: 1) received no treatment; 2) endotoxin extracted with 45% phenol in water; 3) cementum was mechanically removed. Teeth were incubated with human gingival fibroblasts for 24 to 48 hours. Microscopic examination demonstrated uniform attachment to the uninvolved portion of the root surface whereas the involved portion of the root surface allowed only a few cells to attach. When the endotoxin was removed from the root surface by phenol extraction or by mechanical removal of the diseased cementum, the fibroblasts attached normally to the root surface.

Gilman and Maxey (1986) compared ultrasonics to ultrasonics plus air powder abrasive for their ability to remove endotoxin. Six teeth were extracted and sectioned into 12 specimens. Test specimens were instrumented with the ultrasonics or ultrasonics plus air powder abrasive. Four calculus-covered control specimens were not instrumented. Eight root specimens were placed in fibroblast tissue culture and were stained for determination of fibroblast viability after 48 hours. No fibroblast growth took place on calculus control specimens. Ultrasonics specimens showed light fibroblast growth and viability. Ultrasonics plus air powder abrasive specimens showed superior growth and vitality of fibroblasts.

THE EFFECT OF PLAQUE CONTROL ON HEALING FOLLOWING TREATMENT

Bacterial plaque is the main etiologic factor in periodontal disease. Studies have established that periodontal disease will not initiate or progress in the absence of plaque. Also, when healing is considered, numerous reports have demonstrated that the results of treatment will be compromised if bacterial plaque is not removed during the healing period, and that optimal healing can only be achieved in a plaque-free environment.

Human Clinical Studies

Rosling et al. (1976) treated 24 patients with modified Widman flap surgery. The test group was recalled once every 2 weeks and given professional tooth cleaning. Control patients were recalled once every 12 months for prophylaxis. All patients were re-examined 6, 12, and 24 months after surgery. There was a gain of attachment in the test group (3.0, 3.2, and 3.5 mm, at 6, 12, and 24 months, respectively), whereas in the control group there was a continuous loss of attachment following surgery. In the control patients, 58 of 62 2-walled and all 3-walled defects were present after 2 years. In the test group, both 2-walled and 3-walled defects had a "bone fill" of approximately 80%.

Polson and Heijl (1978) treated 15 defects in 9 patients by reverse bevel flaps. Patients were recalled once a week for 3 to 6 weeks. Re-entry procedure performed 6 to 8 months after initial surgery showed a bony morphology with the surface texture of alveolar bone adjacent to the tooth in the area of the defect. The results showed that after surgical debridement and establishment of optimal plaque control, the amount of coronal bone regeneration averaged 2.5 mm (77%) and the average amount of crestal resorption was 0.7 mm (18%). Assessment of tooth mobility showed a tendency of a given tooth to decrease by 1 degree of mobility. It was concluded that intrabony defects may predictably remodel after surgical debridement and establishment of optimal plaque control.

Human Histologic Studies

Waerhaug (1978A) treated 21 patients with a total of 39 teeth scheduled for extraction with root planing, some with flap access. Patients were instructed to carry out supragingival plaque control, and were observed for periods ranging from 15 days to 7 months. Teeth were then extracted and microscopic observations reported. It was found that reformation of a normal dento-epithelial junction invariably occurs when calculus, including plaque, is completely removed. If good supragingival plaque control is maintained, no further subgingival plaque will form and health can be maintained. Residual plaque may give rise to reformation of plaque within the pocket; however with excellent plaque control, the tissues may appear clinically healthy. Residual plaque progresses apically, with a loss of attachment occurring at the same speed (2 μm/day).

Waerhaug (1978B) treated 84 condemned teeth with probing depths of $\geq$ 3 mm by scaling and root planing, some with flap access. Thirty-one (31) teeth were extracted immediately, and 53 had healing times of up to 1 year before extraction. The results of this light microscopic study demonstrated that the distance from the plaque front to intact periodontal fibers is 0.5 mm to > 1.0 mm. It was concluded that the chances of removing all subgingival plaque are fairly good if probing depth is $\leq$ 3 mm; in the 3 to 5 mm range, chances of failure are greater than the chances of success, and if probing depth exceeds 5 mm the chance of failure dominates. If all subgingival plaque is removed, the junctional epithelium will be readapted to the plaque-free tooth surface. If new supragingival plaque is allowed to form or subgingival plaque is not removed, they will give rise to the reformation of subgingival plaque within the pocket. Surgical elimination of pathological pockets $\geq$ 3 mm is the most predictable method for attaining good subgingival plaque control.

REFERENCES

Aleo J, De Renzis F, Farber P. In vitro attachments of human gingival fibroblasts to root surfaces. *J Periodontol* 1975;46:639–645.

Beaumont R, O'Leary T, Kafrawy A. Relative resistance of long junctional epithelial adhesions and connective tissue attachments to plaque-induced inflammation. *J Periodontol* 1984;55:213–223.

Blomlof L, Lindskog S, Appelgren R, Jonsson B, Weintraub A, Hammarstrom L. New attachment in monkeys with experimental periodontitis with and without removal of the cementum. *J Clin Periodontol* 1987;14:136–143.

Bowers G, Chadroff B, Carnevale R, et al. Histologic evaluation of new attachment apparatus formation in humans. Part I. *J Periodontol* 1989A;60:664–674.

Bowers G, Chadroff B, Carnevale R, et al. Histologic evaluation of new attachment apparatus formation in humans. Part II. *J Periodontol* 1989B;60:675–682.

Bowers G, Chadroff B, Carnevale R, et al. Histologic evaluation of new attachment apparatus formation in humans. Part III. *J Periodontol* 1989C;60:683–693.

Caton J, Nyman S, Zander H. Histometric evaluation of periodontal surgery. II. Connective tissue attachment levels after four regenerative procedures. *J Clin Periodontol* 1980;7:224–231.

Caton J, Zander H. Osseous repair of an infrabony pocket without new attachment of connective tissue. *J Clin Periodontol* 1976;3:54–58.

Caton J, Zander H. The attachment between tooth and gingival tissues after periodic root planing and soft tissue curettage. *J Periodontol* 1979;50:462–466.

Gilman R, Maxey B. The effect of root detoxification on human gingival fibroblasts. *J Periodontol* 1986;57:436–440.

Karring T, Isidor F, Nyman S, Lindhe J. New attachment formation on teeth with a reduced but healthy periodontal ligament. *J Clin Periodontol* 1985;12:51–60.

Karring T, Nyman S, Lindhe J. Healing following implantation of periodontitis affected roots into bone tissue. *J Clin Periodontol* 1980;7:96–105.

Karring T, Nyman S, Lindhe J, Sirirat M. Potentials for root resorption during periodontal wound healing. *J Clin Periodontol* 1984;11:41–52.

Lindhe J, Nyman S, Karring T. Connective tissue reattachment as related to presence or absence of alveolar bone. *J Clin Periodontol* 1984;11:33–40.

Listgarten M, Rosenberg S, Lerner S. Progressive replacement of epithelial attachment by a connective tissue junction after experimental periodontal surgery in rats. *J Periodontol* 1982;53:659–670.

Lopez N, Belvederessi M. Healing following implantation of healthy roots, with and without periodontal ligament tissue, in the oral mucosa. *J Periodontol* 1983;54:283–290.

Magnusson I, Runstad L, Nyman S, Lindhe J. A long junctional epithelium — A locus minoris resistentiae in plaque infection? *J Clin Periodontol* 1983;10:333–340.

Nyman S, Karring T, Lindhe J, Planten S. Healing following implantation of periodontitis-affected roots into gingival connective tissue. *J Clin Periodontol* 1980;7:394–401.

Nyman S, Lindhe J, Karring T, Rylander H. New attachment following surgical treatment of human periodontal disease. *J Clin Periodontol* 1982;9:290–296.

Nyman S, Westfelt E, Sarhed G, Karring T. Role of "diseased" root cementum in healing following treatment of periodontal disease. A clinical study. *J Clin Periodontol* 1988;15:464–468.

Polson A, Caton J. Factors influencing periodontal repair and regeneration. *J Periodontol* 1983;53:617–625.

Polson A, Heijl L. Osseous repair in infrabony periodontal defects. *J Clin Periodontol* 1978;5:13–23.

Polson A, Proye M. Fibrin linkage: A precursor for new attachment. *J Periodontol* 1983;54:141–147.

Proye M, Caton J, Polson A. Initial healing of periodontal pockets after a single episode of root planing monitored by controlled probing forces. *J Periodontol* 1982;53:296–301.

Proye M, Polson A. Effect of root surface alterations on periodontal healing. I. Surface denudation. *J Clin Periodontol* 1982;9:428–440.

Rosling B, Nyman S, Lindhe J. The effect of systematic plaque control on bone regeneration in infrabony pockets. *J Clin Periodontol* 1976; 3:38–53.

Selvig G, Bogle G, Claffey N. Collagen linkage in periodontal connective tissue reattachment. *J Periodontol* 1988;59:758–768.

Waerhaug J. Microscopic demonstration of tissue reaction incident to removal of subgingival calculus. *J Periodontol* 1955;26:26–29.

Waerhaug J. Healing of the dento-epithelial junction following subgingival plaque control. I. As observed in human biopsy material. *J Periodontol* 1978A;49:1–8.

Waerhaug J. Healing of the dento-epithelial junction following subgingival plaque control. II. As observed on extracted teeth. *J Periodontol* 1978B;49:119–134.

Section 2. Scaling and Root Planing

ROOT SMOOTHNESS (HAND VERSUS ULTRASONICS)

Controversy still exists over the superiority of ultrasonics versus hand instruments in calculus removal, cementum removal, endotoxin removal, and root surface smoothness.

The smoothness of the root surface after instrumentation was studied by Kerry (1967). One hundred and eighty (180) anterior teeth from 43 patients were scaled and root planed using 5 different methods: curets; one of two ultrasonic units; curets followed by ultrasonics; and ultrasonics followed by curets. The teeth were extracted and the relative roughness was determined with a Profilometer. The smoothest roots were obtained by first using the ultrasonics and finishing with curets. Almost equally as smooth were the curetted only roots. In the middle range was the group of curets followed by ultrasonics. The roughest roots were produced by the ultrasonic tips. Hand curets produced smoother root surfaces than the ultrasonic instruments.

In a scanning electron microscopic (SEM) study Wilkinson and Maybury (1973) found that teeth root planed by curets were smooth and flat and no longer harbored small particles of calculus. The root surfaces treated by ultrasonics looked chipped and fractured with the appearance of irregular ridges. They concluded that both methods of instrumentation were equally effective in removing foreign matter from the tooth, but curets produced smoother surfaces than ultrasonics.

Jones et al. (1972) treated 54 teeth using tungsten carbide curets, scalers, or ultrasonics before extraction and examination under SEM. Twenty-six (26) teeth were completely free of calculus after treatment. No difference in the efficiency of calculus removal was found between the various instruments used; the ultrasonics caused least damage to the root surface, while scalers and curets caused slight damage.

Pameijer et al. (1972) using SEM found no difference in root topography when teeth were instrumented by ultrasonics or hand instruments. Hand instruments removed substantially more tooth structure than ultrasonics. Instrumentation of a polished dentinal surface by hand instruments, however, removed tooth structure and left a rough surface when compared to ultrasonic instruments.

Lie and Meyer (1977) using SEM showed that calculus removal was considerably more complete with the diamond point than with curets, ultrasonics, or Roto-Pro instrument. The ultrasonic instrument gave the least satisfactory cleaning of the tooth surface. When the loss of tooth substance was scored, only minor differences were found between the Roto-Pro, curets, and the ultrasonic instrument, while the diamond scored considerably higher than any of the other instruments.

Breininger et al. (1987) instrumented 30 molar and 30 non-molar teeth with either hand curets or ultrasonics. These treated teeth plus 20 untreated controls were extracted, stained with 0.5% toluidine blue, and examined under SEM for residual stainable material and calculus. The results showed that a large percentage of treated proximal root surfaces had stainable deposits, but these surfaces were often "unexpectedly" free of microbes. The majority of stained deposits was composed of adherent fibrin and instrumentation debris. When plaque was found, it was in small "mini-colonies" (< 0.55 mm diameter). Both instrumentation methods appeared to be effective in bacterial debridement but only partially effective in removing subgingival calculus.

The effect of root roughness on plaque accumulation and inflammation of the adjacent gingival tissues was studied by Rosenberg and Ash (1974). Fifty-eight (58) teeth were extracted 28 to 232 days after instrumentation. Using a Profilometer to measure root roughness, they found a statistically significant difference in mean roughness between curetted teeth (mean 9.51) and either teeth treated with ultrasonics (mean 17.21) or control teeth (18.30). No significant differences in mean plaque scores or mean inflammatory indices were observed between the 3 groups. It was concluded that root roughness was not significantly related to the mean inflammatory index of the adjacent gingival tissues or to supragingival plaque accumulation.

Khatiblou and Ghodssi (1983) studied the effects of root roughness on healing following surgical treatment. Eighteen (18) single rooted teeth in 12 patients with advanced periodontitis were divided into 2 groups. Modified Widman flaps were performed for both groups. In one group, shallow horizontal grooves were made on root surfaces to roughen them after root planing. Healing was evaluated 4 months after surgery. Results indicated that there were no significant differences between the two groups in terms of probing depth reduction and gain of attachment. Both groups showed a gain of attachment and reduced probing depth as a result of the surgical treatment. It was concluded that clinical healing is not affected by varying degrees of root surface roughness.

CALCULUS REMOVAL

Several studies evaluated the effectiveness of calculus removal using ultrasonics, hand curets, or a combination of ultrasonics and hand instruments.

Rabbani et al. (1981) studied the influence of probing depth on the efficiency of calculus removal. Sixty-two (62) teeth were scaled and root planed with hand instruments, and 57 were left untreated and served as controls. The gingival margin was marked on the teeth. The teeth were then extracted, stained with 1% methylene blue, and viewed under a stereomicroscope. The results indicated a high correlation between probing depth and the remaining calculus after scaling. Sites with probing depths less than 3 mm were the easiest to scale and those deeper than 5 mm were the most difficult. Tooth type did not influence the results.

Stambaugh et al. (1981) scaled 42 sites on 7 teeth with an ultrasonic instrument followed one week later by hand curets. Teeth were extracted immediately after hand instrumentation. Measurements were taken before treatment, 1 week after ultrasonic instrumentation, and after extraction of the teeth. The average depth of pocket instrumented to a plaque and calculus free surface "curet efficiency" was 3.73 mm, and was not deeper than 4 mm (range 2.7 to 4.1 mm). The maximum mean probing depth at which evidence could be seen of instrumentation on the root surface was termed "instrument limit" and 6.21 mm, (range 2 to 10 mm). Instrumentation was more efficient on the distal and mesial than on the buccal and lingual surfaces. The results of the study support the surgical debridement and the reduction of pockets in areas of deep probing depth.

Gellin et al. (1986) compared the effectiveness of calculus removal using either a sonic scaler, hand curets, or a sonic scaler plus hand curets. Six-hundred-ninety (690) root surfaces in 11 patients with moderate to advanced periodontitis were studied. The results showed that the percentage of surfaces with residual calculus was: sonic scaler only (31.9%); curets only (26.8%); and sonic scaler plus curets (16.9%). The combination of sonic scaler and curets was more effective in the removal of subgingival calculus than either method used alone. As probing depth increased, the percentage of surfaces with residual calculus increased for all 3 methods.

Kepic et al. (1990) treated 31 teeth by closed scaling and root planing with either ultrasonic (14) or hand instruments (17). After a healing period of 4 to 8 weeks, the teeth were root planed again using the same instruments after flap reflection. The teeth were then extracted and prepared for light microscopic evaluation. Twelve of the 14 teeth treated by ultrasonics and 12 of the 17 teeth treated by hand instruments retained calculus. Hand instrumentation appeared to be more effective than ultrasonics in removing cementum from proximal surfaces. Five blocks were studied under a scanning electron microscope. All 5 specimens displayed residual calculus at either the light microscope, the SEM level, or both. The results indicate that complete removal of calculus from a periodontally diseased root surface is rare.

Sherman et al. (1990) instrumented 476 surfaces on 101 extracted teeth using ultrasonics and hand instruments. The teeth were then evaluated stereomicroscopically for the presence of calculus. The percent surface area with calculus was determined by computerized imaging analysis. Fifty-seven percent (57%) of all surfaces had residual microscopic calculus and the mean percent calculus per surface area was 3.1% (0 to 31.9%). The inter-examiner and intra-examiner clinical agreement in detecting calculus was low. There was a high false-negative response (77.4% of the surfaces with microscopic calculus were clinically scored as being free of calculus) and a low false-positive response (11.8% of the surfaces microscopically free of calculus were clinically determined to have calculus). This study indicates the difficulties in clinically determining the thoroughness of subgingival instrumentation.

Rateitschak et al. (1992) non-surgically scaled and root planed 10 single-rooted teeth in 4 patients with advanced periodontitis. The teeth were then extracted and examined under SEM. Twenty-nine (29) of the 40 curetted root surfaces were free of residues, if they were reached by the curet. On the remaining 11 surfaces, only small amounts of plaque and minute islands of calculus were detected, primarily at the line angles and also in grooves and depressions in the root surfaces. Instrumentation to the base of the pocket was not achieved completely on 75% of the treated root surfaces. Surfaces that can be reached by curets are usually free of plaque and calculus; however, in many cases the base of the pocket will not be reached. It is for this reason that deep periodontal pockets should be treated surgically.

OPEN VERSUS CLOSED APPROACH

Root instrumentation could be performed using either a closed (non-surgical) or an open (surgical) approach. It is generally agreed that open scaling and root planing gives a better access to the root surfaces and improves calculus removal using either ultrasonics or hand instruments. This is especially true in sites with greater probing depth.

The effectiveness of instrumentation with or without flap reflection was compared by Eaton et al. (1985). Periodontally-involved buccal root surfaces on the anterior teeth of 33 patients were instrumented either before or after the reflection of the flaps. The remaining deposits were stained, then photographed. The findings revealed that root planing under direct vision at the time of surgery was more effective than blind instrumentation. However, in no instance was any root surface found to be completely free of stainable deposits.

Caffesse et al. (1986) found that for 1 to 3 mm pockets S/RP alone and flap plus S/RP were equally effective in obtaining calculus-free surfaces (86%). For 4 to 6 mm pockets 43% of the surfaces were calculus-free when S/RP alone and 76% when flap plus S/RP was performed. In sites greater than 6 mm, S/RP alone obtained only 32% calculus-free surfaces while flap plus S/RP obtained 50% calculus-free surfaces. The extent of residual calculus was directly related to probing depth, was greater following S/RP alone, and was greatest at the CEJ or in association with grooves, fossae, or furcations.

Brayer et al. (1989) distributed 114 periodontally involved, single-rooted teeth among 4 operators of 2 experience levels for either an open or closed session of scaling and root planing. The results showed that there was no difference in scaling and root planing effectiveness for experience level or type of procedure in shallow (1 to 3 mm) pockets. However, in moderate (4 to 6 mm) and deep (≥ 6 mm) periodontal pockets, scaling and root planing combined with an open flap procedure was more effective than S/RP alone for both experience levels. Also, the more experienced operators produced a significantly greater number of calculus-free root surfaces than the less experienced operators in periodontal pockets with moderate and deep probing depths. Best calculus removal was accomplished by experienced operators employing an open procedure.

Parashis et al. (1993) treated 30 mandibular molars with furcation involvement using either a closed or an open approach, or with an open approach using rotary diamond. After extraction, the teeth were assessed under a stereomicroscope and the percentage of residual calculus was calculated on external and furcation surfaces. The percentage of residual calculus on the external surfaces was significantly higher after closed than open root planing. Probing depth influenced the effectiveness of scaling and root planing, with more residual calculus observed for depths equal to or greater than 7 mm for both groups. The most effective method was the combination of open root planing and rotary diamond.

Closed and open scaling and root planing were also compared by Wylam et al. (1993). Sixty (60) multi-rooted teeth were assigned to one of 3 groups: untreated controls, closed scaling and root planing, and open flap scaling and root planing. Following extraction, the mean percent stained surface area was 54.3% in the closed group compared to 33.0% in the open flap group. No difference was found between shallow sites (< 3 mm) and deeper sites ($>$ 3 mm). Examination of furcation regions demonstrated heavy residual stainable deposits for both treatment methods, with no significant differences between techniques.

FURCATION AND ROOT MORPHOLOGY

Root morphology plays a major role when root instrumentation is considered. Multi-rooted teeth with furcation invasion are harder to instrument than single-root teeth. Other anatomical variations such as root grooves, narrow furcation openings, or furcation ridges make complete calculus removal harder if not impossible, even when an open approach is used.

The effectiveness of instrumenting furcation areas was studied by Matia et al. (1986). Forty-eight (48) patients with 50 mandibular molars with severe periodontitis scheduled for extraction were selected. Twenty (20) teeth were instrumented with curets, 10 after surgical exposure (open) of the furcation, and 10 without surgical exposure (closed). Twenty (20) teeth were instrumented with an ultrasonic scaler, 10 teeth open and 10 teeth closed. The remaining 10 teeth were not instrumented and served as untreated controls. The teeth were extracted after instrumentation and the furcations were assessed under a stereomicroscope for residual calculus. The results indicated that calculus removal in the furcation area is more effective when a surgical flap is utilized, and that the ultrasonic scaler is more effective than the curet in removing calculus in the furcation area utilizing a surgical flap.

Fleischer et al. (1989) compared open and closed scaling and root planing on 50 molars designated for extraction. They found that calculus-free root surfaces were obtained significantly more often with flap access than with a non-surgical approach. Their results suggest that, although both surgical access and a more experienced operator significantly enhance calculus removal in molars with furcation invasion, total calculus removal in furcations utilizing conventional instrumentation may be limited.

The influence of root morphology on the effectiveness of calculus removal was studied by Fox and Bosworth (1987). The mesial and distal surfaces of 168 extracted teeth, representing all tooth types except third molars, were examined to document the presence or absence of proximal concavities. Results showed that teeth from nearly every tooth position, both maxillary and mandibular had concavities at or within 5 mm apical to their cemento-enamel junction (CEJ). It was concluded that proximal concavities are extremely common, the existence of which may complicate restorative and periodontal therapy as well as the patient's ability to maintain effective plaque control.

REMOVAL OF TOOTH STRUCTURE

An excessive amount of tooth structure can be removed during root planing. Special attention should be paid not to overinstrument the roots. Riffle (1953) found that it was impossible to distinguish between curetting cementum and curetting dentin. When dentin was removed a V-shaped ditch was created near the CEJ.

Borghetti et al. (1987) root planed 4 periodontally involved teeth with a curet from 1 to 4 repeated "firm" strokes per surface. Teeth were subsequently extracted, sectioned, and measured for cementum thickness. The results showed that the amount of cementum removed increases with the number of strokes with the curet. Except for coronal areas, cementum was never completely removed; at best was reduced by two-thirds. Root planing seems to be more effective in the coronal areas where the cementum is thinner than in the apical areas. It was concluded that total removal of cementum cannot be accomplished under routine clinical conditions with a curet.

The removal of tooth structure was also studied by Ritz et al. (1991). Three-hundred-sixty (360) sites on 90 extracted mandibular incisors were instrumented with 4 different instruments: hand curet, ultrasonic scaler, air-scaler, and fine grit diamond. Twelve strokes were used with clinically appropriate forces of application. The loss of tooth substance was measured with a device especially constructed for this investigation. Only a thin layer of root substance (11.6 μm) was removed by the ultrasonic scaler, compared to the much greater losses sustained with the air-scaler (93.5 μm), the curet (108.9 μm) and the diamond bur (118.7 μm). The ultrasonic scaler caused the least amount of substance loss while the diamond bur caused the most amount of loss.

Zappa et al. (1991) scaled and root planed 40 extracted teeth. Low forces (mean 3.04 N) were used in 30 teeth and high forces (mean 8.84 N) in 10 teeth. Root substance loss was measured after 5, 10, 20, and 40 working strokes. The results showed that the mean cumulative loss of root substance across 40 strokes was 148.7 μm at low forces, and 343.3 μm at high forces. The results suggest that high forces remove more root substance, and loss per stroke becomes less with increasing numbers of strokes.

ENDOTOXIN REMOVAL

One of the aims of root instrumentation is the removal of endotoxin from the periodontally involved root surface to make it biologically acceptable. Jones and O'Leary (1978) compared 296 root surfaces from 5 treatment groups for the presence of endotoxin. The groups were: subgingival root planing, supragingival root planing, untreated roots with disease, gross scaled roots in vitro, and healthy non-diseased root surfaces. Pooled samples had endotoxin extracted by water/phenol method and assayed for quantity of endotoxin by the limulus lysate test. It was found that the root planed groups (both supra- and subgingival) had far less endotoxin recovered than the gross scaled or untreated groups; the amounts were close to non-diseased tooth levels. It was concluded that root planing was able to render previously diseased root surfaces nearly free of endotoxin, to levels comparable to healthy root surfaces of unerupted teeth.

Nishimine and O'Leary (1979) compared endotoxin removal by hand curets and ultrasonics. Two groups of 46 teeth each were treated, one by curets and the other by ultrasonics, and were compared to 2 control groups, one of 46 untreated periodontally diseased teeth and the other of 31 unerupted healthy teeth. The results showed that thorough root planing with curets produces root surfaces nearly as endotoxin free (2.09 ng/ml) as the surfaces of unerupted healthy teeth (1.46 ng/ml), and that curets are more effective than ultrasonics in removing endotoxin from the periodontally involved root surfaces. Ultrasonics treated root surfaces had 16.8 ng/ml and untreated periodontally diseased surfaces had 169.5 ng/ml.

Gilman and Maxey (1986) compared ultrasonics to ultrasonics plus air powder abrasive for their ability to remove endotoxin. Six teeth were extracted and sectioned into 12 specimens. Test specimens were instrumented with the ultrasonics or ultrasonics plus air powder abrasive. Four calculus-covered control specimens were not instrumented. Eight root specimens were placed in fibroblast tissue culture and were stained for determination of fibroblast viability after 48 hours. No fibroblast growth took place on calculus control specimens. Ultrasonic specimens showed light fibroblast growth and viability. Ultrasonics plus air powder abrasive specimens showed superior growth and vitality of fibroblasts.

Assad et al. (1987) studied the chemical removal of endotoxin from the root surface. Twenty (20) extracted periodontally involved teeth were cut into halves bucco-lingually and sterilized. The control half of each tooth was rubbed with saline and the experimental half was rubbed with 2% sodium desoxycholate followed by human plasma. Both groups were then placed in separate petri dishes, with fibroblast cell suspension. The control tooth surfaces showed a mean of 307 ± 63 attached cells. The experimental surfaces exhibited a mean of 650 ± 130 attached cells. The findings suggest that the desoxycholate/plasma combination enhanced in vitro fibroblast attachment to diseased root surfaces.

Nyman et al. (1988) evaluated the effect of removing diseased cementum on healing following surgery. Eleven patients were treated surgically using a split mouth design. In 2 quadrants (control), the teeth were scaled and root planed to remove all cementum. In the remaining quadrants (test), calculus was removed without removal of cementum and the teeth were polished. The patients were followed for 24 months. The results showed that the same degree of improvement was achieved following both types of treatment. There was some gain of probing attachment for both treatment modalities.

HEALING RESPONSE AND THE EFFECT OF THERAPY

The primary goal of periodontal treatment is to arrest the progression of disease, which could be done using hand or ultrasonic instruments and employing a closed or an open approach. The best way to determine which technique is superior in achieving that goal is by evaluating the healing response following treatment.

Tagge et al. (1975) evaluated 3 matched sites in each of 22 patients for the effects of scaling and oral hygiene versus oral hygiene alone. One site served as control, the second received oral hygiene alone, and the third was treated by root planing and oral hygiene. Eight to 9 weeks after treatment, measurements were taken and biopsies were obtained. Microscopically and clinically, scaling and root planing with oral hygiene was shown to be more effective in reducing gingivitis scores, probing depths, and gain in attachment levels than oral hygiene alone.

Hughes and Caffesse (1978) treated 61 teeth in 15 patients by scaling and root planing. Clinical measurements and scores were taken at initial exam, 1 week, and 1 month after treatment. The findings indicated that thorough scaling and root planing of teeth with severe inflammation of the gingiva is commonly followed within 1 week to 1 month after scaling by a decrease in probing depth, gain in attachment, gingival recession, and a decrease in the width of the keratinized tissue. No change in the location of the mucogingival junction occurred after treatment.

Torfason et al. (1979) treated 51 pairs of single rooted teeth with 4 to 6 mm probing depth in 18 patients with either hand or ultrasonic instruments using a split-mouth design. Instrumentation was repeated after 4 weeks. Measurements taken after 8 weeks showed a gradual reduction of probing depth and the number of bleeding sites. There were no significant differences between the two groups except ultrasonic treatment required less time to treat. They concluded that for treatment of 4 to 6 mm probing depth, there is no significant difference between hand instrumentation and ultrasonic in terms of clinical improvement.

Badersten et al. (1981) also found no difference in the healing response following treatment using hand or ultrasonic instruments; 528 tooth surfaces of single-rooted teeth in 15 patients with moderate periodontitis were treated by hand and ultrasonic non-surgical therapy. Improvements in plaque scores, bleeding on probing, decreased probing and attachment levels were similar for both treatment methods. It was shown that shallower sites had a slight loss of attachment while deeper sites showed some improvement.

Badersten et al. (1984A) evaluated the response of deep sites in 16 patients with advanced periodontal disease using hand or ultrasonic non-surgical therapy. Comparable results were obtained by both methods. It was shown that the deep probing depths could be successfully treated non-surgically. It was shown that shallower sites were at risk of losing attachment, while the deep sites were more likely to gain attachment. Deeper residual probing sites were more likely to bleed on probing.

Cercek et al. (1983) monitored 7 periodontitis patients during 3 phases of treatment: 1) toothbrushing and flossing; 2) Perio-Aid used sub-gingivally; and 3) sub-gingival debridement. The mean probing depth of 4.4 mm was reduced to 4.0 mm in phase I; no improvement in phase II; and reduced to 3.2 mm after instrumentation. Clinical attachment level showed a slight loss through phase II, but improved attachment levels were found after instrumentation. Minimal effect was derived from patient performed plaque control, whether supra- or subgingival. The bulk of the effect was derived from professional subgingival instrumentation (scaling and root planing). This is one of the few studies that examines the separate effects of plaque control and that of scaling and root planing on periodontal healing.

Badersten et al. (1985B) studied the incisors, canines, and premolars in 33 patients with generalized periodontal destruction for patterns of clinical attachment loss. Patients received supra- and subgingival debridement after oral hygiene instructions, and were followed for 24 months. Measurements were made every third month and 7 patterns of probing attachment were identified. Seventy-three percent (73%) of the sites showed a gradual loss of probing attachment. Seventeen percent (17%) showed an early loss followed by a stabilization in attachment level. Shallower sites showed a pattern of early loss followed by stabilization while deeper sites showed a gradual loss.

Claffey et al. (1988) treated 1,248 sites in 9 patients by a single episode of root debridement with ultrasonics. Probing depth and attachment level were measured by 3 different examiners before instrumentation and at 3, 6, and 12 months after treatment. Results showed an initial mean loss of probing attachment of 0.5 to 0.6 mm as a result of instrumentation. Only 5% of all sites lost ≥ 1 mm of attachment from pre-instrumentation to 12 months. Only 2% of all sites lost attachment from post-instrumentation to 12 months. The results suggest that the observed attachment loss was either directly attributable to instrumentation or to a remodeling process as a result of therapy rather than to progressive disease.

OPERATOR VARIABILITY

The effect of operator variability on healing following non-surgical therapy was evaluated by Badersten et al. (1985A). The incisors, canines, and premolars were studied in 20 patients with generalized severe periodontitis. The periodontal pockets were debrided using either hand and/or ultrasonic instruments under local anesthesia by a periodontist or by 1 of a group of 5 dental hygienists. A split-mouth design was used with measurements recorded at the initial examination and every third month. The results indicated that deep periodontal pockets in single-rooted teeth may be successfully treated by plaque control and 1 episode of instrumentation and that operator variability may be limited.

Brayer et al. (1989) found no difference in scaling and root planing effectiveness for experience level in shallow (1 to 3 mm) pockets. However, the more experienced operators produced a significantly greater number of calculus-free root surfaces than the less experienced operators in periodontal sites with moderate and deep probing depths. Fleischer et al. (1989) also found that operators with more experience achieved calculus-free root surfaces significantly more often than operators of lesser experience with both an open and closed procedure.

SINGLE VERSUS REPEATED INSTRUMENTATION

Badersten et al. (1984B) evaluated the effect of single versus repeated instrumentation on healing following non-surgical treatment. Incisors, canines, and premolars were studied in 13 patients with severe periodontitis. Teeth were instrumented using ultrasonic instruments. Instrumentation was repeated in one side of the jaw after 3 and 6 months. A gradual and marked improvement took place during the first 9 months. No differences in results could be observed when comparing the effects of a single versus repeated instrumentation. It was concluded that deep periodontal pockets in incisors, canines, and premolars may be treated by plaque control and one episode of instrumentation.

THE EFFECT OF SCALING AND ROOT PLANING ON THE DENTIN AND THE PULP

Fischer et al. (1991) evaluated the effect of instrumentation on the pulp in 11 patients with periodontally diseased mandibular incisors. The subjects were divided into 2 groups according to marginal bone loss. The pulp sensitivity was evaluated by an electric pulp test. Dentin sensitivity was evaluated with 2 forms of controlled stimulations (probe and air-jet) and with a questionnaire. No changes in pulp sensitivity were found after scaling, but a clinically significant increase in dentin sensitivity to probe and/or air stimuli was observed in 6 patients. A natural mechanism of desensitization seemed to have occurred 2 weeks after subgingival debridement.

Fogel and Pashley (1993) used unerupted third molars in their in vitro study. The crowns were removed and longitudinal slices cut. The hydraulic conductance of the root dentin was measured before and after root planing, acid etching, and potassium oxalate application using a fluid filtration method. The results showed that root planing creates a smear layer that reduces the permeability of the underlying dentin. However, this smear layer is acid labile. Thus, root planing may ultimately cause increased dentin permeability and the associated sequelae of sensitive dentin, bacterial invasion of tubules, reduced periodontal reattachment, and pulpal irritation.

REFERENCES

Assad D, Dunlap R, Weinberg S, Ahl D. Biologic preparation of diseased root surfaces. An in vitro study. *J Periodontol* 1987;58:30–33.

Badersten A, Nilveus R, Egelberg J. Effect of nonsurgical periodontal therapy. I. Moderately advanced periodontitis. *J Clin Periodontol* 1981;8:57–72.

Badersten A, Nilveus R, Egelberg J. Effect of nonsurgical periodontal therapy. II. Severely advanced periodontitis. *J Clin Periodontol* 1984A;11:63–76.

Badersten A, Nilveus R, Egelberg J. Effect of nonsurgical therapy. III. Single versus repeated instrumentation. *J Clin Periodontol* 1984B;11:114–124.

Badersten A, Nilveus R, Egelberg J. Effect of nonsurgical periodontal therapy. IV. Operator variability. *J Clin Periodontol* 1985A;12:190–200.

Badersten A, Nilveus R, Egelberg J. Effects of nonsurgical periodontal therapy. V. Patterns of probing attachment loss in non-responding sites. *J Clin Periodontol* 1985B;12:270–282.

Borghetti A, Mattout P, Mattout C. How much root planing is necessary to remove the cementum from the root surface? *Int J Periodontics Restorative Dent* 1987;7(4):23–29.

Brayer W, Mellonig J, Dunlap R, Marinak K, Carson R. Scaling and root planing effectiveness: The effect of root surface access and operator experience. *J Periodontol* 1989;60:67–72.

Breininger D, O'Leary T, Blumenshine R. Comparative effectiveness of ultrasonic and hand scaling for the removal of subgingival plaque and calculus. *J Periodontol* 1987;58:9–18.

Caffesse R, Sweeny P, Smith B. Scaling and root planing with and without periodontal flap surgery. *J Clin Periodontol* 1986;13:205–210.

Cercek J, Kiger J, Garrett S, Egelberg J. Relative effects of plaque control and instrumentation on the clinical parameters of human periodontal disease. *J Clin Periodontol* 1983;10:46–56.

Claffey N, Loos B, Gantes B, Martin M, Heins P, Egelberg J. The relative

effects of therapy and periodontal disease on loss of probing attachment after root debridement. *J Clin Periodontol* 1988;15:163–169.
Eaton K, Kieser J, Davies R. The removal of root surface deposits. *J Clin Periodontol* 1985;12:141–152.
Fischer C, Wennberg A, Fischer R, Attstrom R. Clinical evaluation of pulp and dentine sensitivity after supragingival and subgingival scaling. *Endod Dent Traumatol* 1991;7:259–265.
Fleischer H, Mellonig J, Brayer W, Gray J, Barnett J. Scaling and root planing efficacy in multirooted teeth. *J Periodontol* 1989;60:402–409.
Fogel H, Pashley D. Effect of periodontal root planing on dentin permeability. *J Clin Periodontol* 1993;20:673–677.
Fox S, Bosworth B. A morphological survey of proximal root concavities: A consideration in periodontal therapy. *J Am Dent Assoc* 1987;114:811–814.
Gellin R, Miller M, Javed T, Engler W, Mishkin D. The effectiveness of the titan-s-sonic scaler versus curets in the removal of subgingival calculus: A human surgical evaluation. *J Periodontol* 1986;57:672–680.
Gilman R, Maxey B. The effect of root detoxification on human gingival fibroblasts. *J Periodontol* 1986;57:436–440.
Hughes T, Caffesse R. Gingival changes following scaling, root planing and oral hygiene. A biometric evaluation. *J Periodontol* 1978;49:245–252.
Jones S, Lozdan J, Boyde A. Tooth surfaces treated in situ with periodontal instruments: Scanning electron microscopic studies. *Br Dent J* 1972;132:57–64.
Jones W, O'Leary T. The effectiveness of in vivo root planing in removing bacterial endotoxin from the roots of periodontally involved teeth. *J Periodontol* 1978;49:337–342.
Kepic T, O'Leary T, Kafrawy A. Total calculus removal: An attainable objective? *J Periodontol* 1990;61:16–20.
Kerry G. Roughness of root surfaces after use of ultrasonic instruments and hand curets. *J Periodontol* 1967;38:340–346.
Khatiblou F, Ghodssi A. Root surface smoothness or roughness in periodontal treatment. A clinical study. *J Periodontol* 1983;54:365–367.
Lie T, Meyer K. Calculus removal and loss of tooth substance in response to different periodontal instruments. A scanning electron microscope study. *J Clin Periodontol* 1977;4:250–262.
Matia J, Bissada N, Maybury J, Ricchetti P. Efficiency of scaling the molar furcation area with and without surgical access. *Int J Periodontics Restorative Dent* 1986;6(6):24–35.
Nishimine D, O'Leary T. Hand instrumentation versus ultrasonics in the removal of endotoxin from root surfaces. *J Periodontol* 1979;50:345–349.
Nyman S, Westfelt E, Sarhed G, Karring T. Role of "diseased" root cementum in healing following treatment of periodontal disease. A clinical study. *J Clin Periodontol* 1988;15:464–468.
Pameijer C, Stallard R, Hiep N. Surface characteristics of teeth following periodontal instrumentation: A scanning electron microscope study. *J Periodontol* 1972;43:628–633.
Parashis A, Anagnou V, Demetriou N. Calculus removal from multirooted teeth with and without surgical access. (I). Efficacy on external and furcation surfaces in relation to probing depth. *J Clin Periodontol* 1993;20:63–68.
Rabbani G, Ash M, Caffesse R. The effectiveness of subgingival scaling and root planing in calculus removal. *J Periodontol* 1981;52:119–123.
Rateitschak P, Schwarz J, Guggenheim R, Duggelin M, Rateitschak K. Non-surgical periodontal treatment: Where are the limits? An SEM study. *J Clin Periodontol* 1992;19:240–244.
Riffle A. The dentin: Its physical characteristics during curettage. *J Periodontol* 1953;24:232–241.
Ritz L, Hefti A, Rateitschak K. An in vitro investigation on the loss of root substance in scaling with various instruments. *J Clin Periodontol* 1991;18:643–647.
Rosenburg R, Ash M. The effect of root roughness on plaque accumulation and gingival inflammation. *J Periodontol* 1974;45:146–150.
Sherman P, Hutchens L, Jewson L, Moriarty J, Greco G, McFall W. The effectiveness of subgingival scaling and root planing. I. Clinical detection of residual calculus. *J Periodontol* 1990;61:3–8.
Stambaugh R, Dragoo M, Smith D, Carasali L. The limits of subgingival scaling. *Int J Periodontics Restorative Dent* 1981;1(5):30–41.
Tagge D, O'Leary T, El-Kafrawy A. The clinical and histologic response of periodontal pockets to root planing and oral hygiene. *J Periodontol* 1975;46:527–533.
Torfason T, Kiger R, Selvig N, Egelberg J. Clinical improvement of gingival conditions following ultrasonic versus hand instrumentation of periodontal pockets. *J Clin Periodontol* 1979;6:165–176.
Wilkinson R, Maybury J. Scanning electron microscopy of the root surface following instrumentation. *J Periodontol* 1973;44:559–563.
Wylam J, Mealey B, Mills M, Waldrop T, Moskowicz D. The clinical effectiveness of open versus closed scaling and root planing on multirooted teeth. *J Periodontol* 1993;64:1023–1028.
Zappa U, Smith B, Simona C, Graf H, Case D, Kim W. Root substance removal by scaling and root planing. *J Periodontol* 1991;62:750–754.

Section 3. Ultrasonics and Air Abrasives

DEFINITION

Ultrasonic Scaler: An instrument vibrating in the ultrasonic range (approximately 30,000 cps) which, accompanied by a stream of water, can be used to remove adherent deposits from teeth.

PRINCIPLES OF ULTRASONICS

Magnetostrictive units contain a generator that converts 60 HZ, 120-volt current into high-frequency current that continually alters the shape of the magnetostrictive bimetallic stack. As the stack vibrates, the scaler tip vibrates. Ferromagnetic metals (nickel-cobalt alloys) in the stack change length in accordance with alterations in polarity. The resulting 25,000 contractions and expansions per second produce the ultrasonic wave, moving the ultrasonic tip an amplitude of approximately 0.0015 cm. The greater the power setting on the unit, the greater the distance traveled by the tip. Water flow through the tip dissipates heat and produces a cavitational effect. Cavitation is almost an instantaneous release of energy resulting from alternating pressures of the water which is accompanied by rapidly expanding and contracting the air bubbles that collapse in the water. As the bubbles change size at the root surface, they dislodge and wash away debris.

Piezoelectric units produce ultrasonic energy with a crystal system which expands and contracts when an electric current is applied, creating a reciprocal rather than an elliptical motion. The low electromagnetic interference (EMI) level emitted by piezoelectric scalers is not hazardous to cardiac pacemakers; therefore, it is a safe alternative to magnetostrictive scalers (Brown et al., 1987).

Checchi et al. (1991) studied the effect of sharpening on the ultrasonic scaler tip movement. Physical behavior of the scaler was not significantly modified by changes in tip diameter, although the resonant frequency of the tip was changed.

ULTRASONICS VERSUS HAND INSTRUMENTS

Plaque

Thornton and Garnick (1982) compared removal of subgingival plaque by ultrasonic and hand instrumentation. Twenty-four (24) periodontally hopeless teeth were treated by: 1) scaling with hand instruments; 2) scaling with an ultrasonic unit; or as 3) uninstrumented controls. Following extraction and staining, plaque removal was assessed with a compensating polar planimeter. Residual plaque was present on 33% of the surfaces of hand scaled teeth and 34% of ultrasonically scaled teeth. Uninstrumented teeth exhibited 87% total root surface coverage with plaque. Walmsley (1990) showed increased plaque removal due to the cavitation during ultrasonic scaling as compared to ultrasonic scaling without water spray and water spray alone. Baehini et al. (1992) reported no difference in microscopic or cultural data between ultrasonic and sonic instrumentation.

Calculus

Jones et al. (1972) treated 54 teeth scheduled for extraction using curets, scalers, or ultrasonics and then exmined them under a scanning electron microscope (SEM). Twenty-six (26) of the teeth were completely free of calculus after treatment and no difference in the efficiency of calculus removal was observed between the various instruments. The ultrasonic unit caused least damage to the root surface, although scalers and curets caused little damage.

Nishimine and O'Leary (1979) compared the effectiveness of hand instruments and ultrasonic scalers in removing calculus and endotoxin from proximal root surfaces treated before extraction. Visual inspection revealed that 30.4% of ultrasonically scaled teeth had residual calculus compared to 21.7% of teeth root planed with hand instruments. Hunter et al. (1984) compared hand and ultrasonic instrumentation during open flap root planing. Overall, hand-scaled root surfaces demonstrated less residual calculus (5.78%) than ultrasonically-treated surfaces (6.17%). Hand-scaled anterior teeth had less residual calculus (3.55%) on the available surface area than ultrasonically-scaled anterior teeth (5.49%). Conversely, posterior teeth had less residual calculus with ultrasonic scaling (6.87%) than hand-scaling (7.42%). Gellin (1986) evaluated the effect of hand versus sonic instrumentation on the removal of calculus by visually examining the root surfaces during periodontal flap surgery. The percentage of surfaces with residual calculus for each method of instrumentation was: 1) sonic scaler only (31.9%); 2) curets only (26.8%); and 3) sonic scaler and curets (16.9%). The authors concluded that: 1) there was no consistent difference between curets and the sonic scaler; 2) the combination of the sonic scaler and curet instrumentation was more effective than either method alone; 3) as the probing depth increased, the percentage of surfaces with residual calculus increased; and 4) subgingival calculus removal was more difficult in multi-rooted teeth and for proximal surfaces.

Kepic et al. (1990) treated 31 teeth by closed scaling and root planing with either an ultrasonic or hand instruments repeated the instrumentation 4 to 8 weeks later following flap reflection, and extracted the teeth. Light microscope (LM) evaluation indicated that 12 of the 14 teeth treated by ultrasound and 12 of the 17 treated by hand instruments retained calculus. In addition to LM, 5 blocks were evaluated by scanning electron microscope (SEM). All 5 specimens displayed residual calculus at either the light microscope, the SEM level, or both. The results indicate that complete removal of calculus from a periodontally diseased root surface is rare.

Microflora

Leon and Vogel (1987) compared the effectiveness of hand scaling and ultrasonic debridement in furcations. Before treatment, Class I furcations had more coccoid cells and fewer motile bacteria than Class III furcations. Class II furcations had percentages of bacteria between those of Class I and Class III furcations. In Class I furcations, hand scaling and ultrasonic debridement had equivalent effects on the flora with no significant differences between the 2 treatment modalities. When compared to baseline at 2 weeks, both treatments altered the microbiota and gingival crevicular fluid levels to one more consistent with health. In Class II and III furcations, both hand instrumentation and ultrasonics resulted in a bacterial form consistent with health at 2 weeks post-debridement. By 4 weeks, the microbial profile was returning to one consistent with disease. At all times, ultrasonic instrumentation provided greater improvement in microbial parameters than hand instrumentation in both Class II and Class III furcations. The authors suggested that this may be due to better access. Oosterwaal et al. (1987) treated single-rooted teeth and showed that hand scaling and ultrasonic treatment were equally effective in reducing probing depths; bleeding scores; and microscopic counts of rods, spirochetes, and motile forms. In addition, there was a reduction in total colony-forming units and numbers of *Bacteroides* and *Capnocytophaga*, resulting in a subgingival microbiota consistent with periodontal health.

Breininger et al. (1987) compared the effectiveness of ultrasonic and hand scaling in the removal of subgingival plaque and calculus. Both methods were only partially effective in removing subgingival calculus; however, both methods were "remarkably effective" at supragingival plaque removal. When plaque was present after instrumentation, it was usually found in "mini colonies" less than 0.5 mm in diameter. Cuticle-like substances were frequently found on ultrasonic but not hand-instrumented surfaces. Thilo and Baehni (1987) reported vibrations generated by an ultrasonic scaler have the potential to alter the composition of dental plaque and to kill spirochetes in vitro.

Wound Healing

Rosenberg and Ash (1974) studied 58 teeth from 20 prospective denture patients which were assigned to curets, ultrasound, or control groups. Twenty-eight (28) to 232 days after instrumentation and before extraction, plaque scores and labial biopsies were performed. After extraction, root surface roughness was determined with a Profilometer. A statistically significant difference in mean roughness was present between curetted teeth (mean 9.51) and either Cavitron (mean 17.21) and control teeth (18.30). No significant differences in mean plaque scores or mean inflammatory indices were observed between the 3 groups. Root roughness was not significantly related to the mean inflammatory index of the adjacent gingival tissues or to supragingival plaque accumulation.

In a study by Khatiblou and Ghodssi (1983), 18 single-rooted teeth in 12 patients with advanced periodontitis were divided into two groups and modified Widman flaps performed on both groups. In 1 group, shallow horizontal grooves created roughened root surfaces after root planing. The other group served as an unroughened control. Healing was evaluated 4 months after surgery, indicating no significant differences between the groups. Both groups showed attachment gain and reduced probing depth as a result of the surgical treatment. The authors concluded that clinical healing is not affected by varying degrees of root surface roughness.

Torfason et al. (1979) studied 51 pairs of single-rooted teeth with 4 to 6 mm pockets in 18 patients who were treated with either hand or ultrasonic instruments using a split-mouth design. Instrumentation was repeated after 4 weeks. Measurements taken after 8 weeks showed a gradual reduction of probing depth and the number of bleeding sites. For treatment of 4 to 6 mm pockets, there was no significant difference between hand instrumentation and ultrasonics in terms of clinical improvement, although ultrasonic instrumentation required less time.

Badersten et al. (1981) treated 528 tooth surfaces of incisors, canines, and premolars in 15 patients with severely advanced periodontal disease by hand and ultrasonic non-surgical therapy. Improvements in plaque scores, bleeding on probing, decreased probing depths, and attachment levels were similar for both treatment methods. Shallower sites had a slight loss of attachment while deeper sites showed some improvement.

Badersten et al. (1984A) treated 16 patients with severely advanced periodontal disease by hand or ultrasonic non-surgical therapy. Comparable results were obtained by both methods, indicating that the deep probing depths could be successfully treated non-surgically, based on probing depth, probing attachment levels, bleeding on probing, plaque, and gingival recession. Shallower sites were at a risk of losing attachment, while the deep sites were more likely to gain attachment. Deeper residual probing sites were more likely to bleed on probing.

Incisors, canines, and premolars in 33 patients with generalized periodontal destruction were studied by Badersten et al. (1985) for patterns of probing attachment loss. Patients received supra- and subgingival debridement after oral hygiene instruction and were followed for 24 months. Measurements were made after every third month and 7 patterns of probing attachment identified. Seventy-three percent (73%) of sites showed a gradual loss of probing attachment; 17% showed an early loss followed by a stabilization in attachment level. Shallower sites showed a pattern of early attachment loss followed by stabilization while deeper sites showed gradual loss.

Root Surface

Roughness. In a study by Kerry (1967), 180 anterior teeth from 43 patients were divided into 5 groups and the roots were scaled and root planed by curets; Cavitron EW.PP; Cavitron EW.P10; curets followed by ultrasonics; and ultrasonics followed by curets. Following extraction, the relative root roughness was determined with a Profilometer. The smoothest roots were obtained by ultrasonics followed by curets. The roughest roots were produced by the ultrasonic tips. Hand curets produced smoother root surfaces than the ultrasonic instruments.

Pameijer et al. (1972) studied 25 teeth scheduled for extraction and 10 freshly extracted teeth which were treated with either hand or ultrasonic instruments or were left untreated. The 10 extracted teeth were ground flat; polished and then treated with both previous methods. Replicas were made to duplicate the original morphology and topography of the specimens which were then studied utilizing scanning electron microscopy (SEM). No differences were observed in root topography, whether instrumented by ultrasonics or hand instruments. Hand instruments removed substantially more tooth structure than ultrasonics. Instrumentation of a polished dentinal surface by hand instruments, however, removed tooth structure and left a rough surface when compared to ultrasonic instruments.

Hunter et al. (1984) found that 81.2% of ultrasonically-treated teeth were rough (gouges or ripples 50 µm in depth), while only 43.4% of hand-scaled surfaces were graded as rough. Dragoo (1992) compared hand instruments to modified and unmodified Cavitron tips. He reported that the modified tips (reduced in size) produced smoother roots with less damage, better access to the bottom of the pocket, and better plaque and calculus removal than either hand scalers or ultrasonic scalers with unmodified inserts. Less operator time was required and less operator fatigue occurred with modified tips.

Endotoxin. Garrett (1977) suggested ultrasonics followed by hand instrumentation for superior endotoxin removal and production of a smoother root surface. Nishimine et al. (1979) compared effectiveness of hand instruments and ultrasonic scalers in removing endotoxin from root surfaces in vivo using Westphal (phenol-water) extraction and the limulus amebocyte lysate test. Endotoxin levels reported were: 1) healthy controls (unerupted third molars), 1.46 ng/ml; 2) teeth roots planed with hand instruments, 2.09 ng/ml; 3) ultrasonic-treated teeth, 16.8 ng/ml; and 4) untreated perio-diseased controls, 169.5 ng/ml. Checchi et al. (1988) showed no significant difference in in vitro fibroblast growth between periodontally involved root surfaces treated with curets or ultrasonic scalers. The authors concluded that both treatments resulted in the removal of endotoxin from diseased root surfaces. Chiew et al. (1991) confirmed the superficial location of bacterial toxic products associated with periodontally involved root surfaces. Smart et al. (1990) achieved root surface cleanliness (removal of endotoxin) with a Cavitron and light pressure (50 grams/force for 0.8 seconds/mm^2) on extracted roots with no clinically detectable calculus.

Cementum Removal. Hunter et al. (1984) reported approximately equal amounts of cementum removal by ultrasonics and hand instruments with neither method removing all cementum. Pameijer (1972) stated that ultrasonic instruments will not plane root surfaces while Wilkinson and Maybury (1988) indicated that ultrasonics could remove cementum, but only by producing root damage.

Nyman et al. (1988) treated 11 patients surgically using a split-mouth design. In 2 quadrants (control), the teeth were scaled and root planed to remove all cementum. In the remaining quadrants (test), calculus was removed without removal of cementum and the teeth polished. The patients were followed for 24 months. Results indicated that the same degree of improvement was achieved regardless of treatment and that some gain of probing attachment accompanied both treatment modalities.

Bone. Horton et al. (1975A) studied the effect of ultrasonic instrumentation on bone removal during periodontal surgery. Healing was uneventful with no post-operative complications and minimal patient discomfort. Histologically, no alterations in osteocytes, vascular channels, or underlying periodontal tissues were noted. In another report (Horton et al., 1975B), the authors showed faster healing of surgical defects in alveolar bone with ultrasonics than with rotary burs. Glick and Freeman (1980) found no significant difference in post-surgical bone loss in cats after full mucoperiosteal flap reflection and debridement with either hand instruments or ultrasonics. Three month re-entry surgery revealed 0.333 ± 0.077 mm mean bone loss with ultrasonic debridement versus 0.329 ± 0.075 mm mean bone loss with hand instrumentation.

Walmsley et al. (1990) evaluated the effect of cavitational action of the ultrasonic scaler on root surfaces . Using a gold ingot and extracted teeth, the ultrasonic tip was held against the surface and also away from the surface. Photomicrographs and scanning electron microscopy studies revealed that cavitational activity within the cooling water supply of the ultrasonic scaler results in superficial removal of root surface constituents.

Single Versus Repeated Instrumentation. Badersten et al. (1984B) studied incisors, canines, and premolars in 13 patients with severe periodontitis. Teeth were instrumented using ultrasonic instruments, and repeated instrumentation in one side of the jaw was performed after 3 and 6 months. A gradual and marked improvement took place during the first 9 months. No differences in results could be observed when comparing the effects of a single versus repeated instrumentation, suggesting that deep periodontal pockets in incisors, canines, and premolars may be treated by plaque control and 1 episode of instrumentation.

Antimicrobial Lavage. The penetration depth of the water from an ultrasonic instrument into the periodontal pocket was evaluated histologically by Nosal et al. (1991). Patients having teeth planned for extraction and exhibiting probing depths at least 3 mm in depth were used for study. Erythrosin dye was added to the coolant which was delivered to the apical extent of the pocket by vertical movement of the ultrasonic probe tip. After extraction of the tooth, the dye-stained root surface was observed along the full extent of the probe tip's penetration path. The findings indicate that the ultrasonic instrument may be an effective system for both removal of plaque and calculus while simultaneously delivering a chemotherapeutic agent. Limited dispersion of the erythrosin dye in a lateral direction indicates that thorough debridement of the root surface is necessary to adequately deliver chemical agents.

Single-rooted Versus Multi-rooted Teeth. Hunter et al. (1984) compared open flap root planing techniques and reported that hand instruments removed calculus better in anterior teeth, while the Cavitron was more effective in posterior teeth. Leon and Vogel (1987) showed that hand instruments and ultrasonics were equally effective in Grade I furcation; however, ultrasonics were more effective in Grade II and III furcations, based on differential darkfield microscopy and gingival crevicular fluid evaluation parameters. Loos et al. (1987) compared the clinical effectiveness of a single treatment with ultrasonic and sonic scalers using a split-mouth design in 10 patients. Similar changes in clinical parameters were observed for ultrasonic (3.3 minutes/tooth) and sonic scalers (4.0 minutes/tooth).

PREPROCEDURAL RINSING

Fine et al. (1992) reported that preprocedural rinsing with an antiseptic mouthwash (Listerine) can significantly reduce the microbial content of aerosols generated during ultrasonic scaling. Gross et al. (1992) showed no significant difference in mean combined total colony-forming units (CFU) per cubic foot (CF) for magnetostrictive, piezoelectric or air turbine sonic scalers. The magnetostrictive scaler generated the lowest CFU/CF at the deepest level of penetration, but there was no significant difference in level of a simulated lung penetration of the aerosol produced by any of the 3 instruments.

AIR ABRASIVES

Mechanism of Action. Abrasive particles propelled by high-speed air emerge from a point source at the tip of the handpiece. The abrasive powder is composed of sodium bicarbonate treated with 0.5 to 0.8% tricalcium phosphate to improve flow characteristics. The powder is converted into a slurry aerosol at the point source by turbulent mixing with 95 F water spray.

Advantages. Weaks (1984) evaluated an air abrasive unit (AAU) for effectiveness in removal of stain and plaque and its effect on the marginal gingiva, reporting complete removal of extensive stain and plaque in significantly less time (5.5 ± 3.6 minutes) than a rubber cup and pumice (13.4 ± 6.0 minutes).

Disadvantages. Weaks (1984) reported increased soft tissue trauma immediately following use of an air abrasive unit; however, this effect was not detected after 6 days. Finlayson and Stevens (1988) reported oral emphysema following use of an AAU during maintenance of deep periodontal pockets associated with teeth numbers 13 to 15. The complication resolved after 7 days (pen VK 500 mg QID).

Effects of AAU on Root Surfaces. Atkinson et al. (1984) noted that an AAU removed an average of 636.6 set µm (range, 470 to 856 µm) of root structure in 30 seconds of exposure. They also observed "partially obliterated" dental tubules, but found it impossible to distinguish occluded and open tubules. Horning et al. (1987) reported a mean of 80 µm of cementum removed after 40 seconds of exposure of extracted teeth to the air powder spray. The decreased cementum removal in this study may have been due to distribution of the spray over a surface area of 30 mm² versus 3/14 mm² in Atkinson's study.

Horning et al. (1987) studied 32 teeth scheduled for extraction using flap reflection, ultrasonic scaling, and either an AAU or manual root planing. The ultrasonic plus AAU and ultrasonic plus root planing techniques were similar in plaque, calculus, and cementum removal (both methods left some calculus but no plaque). The study showed no time advantage in using the AAU; however, it was less fatiguing than manual root planing. Clinically, the AAU showed more favorable (clean, white, and smooth) root surfaces including proximal flutings and furcal areas. Compared to hand instrumentation at 200× and 3000× magnification, the AAU-treated surfaces were smoother and had less debris. The AAU treated surfaces often exhibited tiny globular, crystalline particles, assumed to be tricalcium phosphate particles.

Effects of AAU on Wound Healing After Surgery. Pippin (1988) investigated the effects of an AAU on wound healing after periodontal flap surgery in dogs, including abrasive spray on tissue and roots and abrasive powder on bone to study the effect of abrasive spray on tissue. No effort was made to shield the connective tissue side of the flap from overspray and no rinsing was performed, leaving residual material on tooth and tissue surfaces. The flaps in 3 dogs were intentionally sprayed for 5 seconds at a distance of 6 mm. After 2 and 4 days, a fibrinopurulent exudate was associated with the sulcus and bone. Moderate inflammation of bone resolved by 7 and 14 days postoperatively. The effect of the abrasive spray on the root surfaces was evaluated following a 20-second sweeping spray of the buccal surfaces with the handpiece tip held 4 to 6 mm from the root surface. The AAU treated and control sides healed equally well, and no significant difference was observed in inflammatory response. Inflammation was greatest at days 2 and 4, lessened by day 7, with little inflammation present at 14 days post-operatively. To study the effect of AAU powder on bone, each dog also had a separate flap reflected and a 40 mg bolus of dry powder placed directly on the bone. The flap was replaced and sutured. At 2 and 4 days, there was clinical ulceration and partial necrosis of the flap immediately overlying the powder. Histologically, there was acute inflammation and active bone resorption. At 7 and 14 days in general, the inflammatory response to the powder had subsided and few osteoclastic lacunae were present.

REFERENCES

Atkinson DR, Cobb C, Killoy W. The effect of an air-powder abrasive system on in-vitro root surfaces. *J Periodontol* 1984;55:13–18.

Badersten A, Nilveus R, Egelberg J. Effect of nonsurgical periodontal therapy. I. Moderately advanced periodontitis. *J Clin Periodontol* 1981;8:57–72.

Badersten A, Nilveus R, Egelberg J. Effect of nonsurgical periodontal therapy. II. Severely advanced periodontitis. *J Clin Periodontol* 1984A;11:63–76.

Badersten A, Nilveus R, Egelberg J. Effect of nonsurgical therapy. III. Single versus repeated instrumentation. *J Clin Periodontol* 1984B;11: 114–124.

Badersten A, Nilveus R, Egelberg J. Effects of nonsurgical periodontal therapy. V. Patterns of probing attachment loss in non-responding sites. *J Clin Periodontol* 1985;12:270–282.

Baehni P, Thilo B, Chapuis B, Pernet D. Effects of ultrasonic and sonic scalers on dental plaque microflora in vitro and in vivo. *J Clin Periodontol* 1992;19:455–459.

Breininger D, O'Leary T, Blumenshine R. Comparative effectiveness of ultrasonic and hand scaling for removal of subgingival plaque and calculus. *J Periodontol* 1987;58:9–18.

Brown F, Lubow R, Cooley R. Applied ultrasonics in periodontal therapy. *J West Soc Periodontol Periodont Abstr* 1987;35:53–60.

Chapple I, Walmsley A, Saxby M, Moscrop H. Effect of subgingival irrigation with chlorhexidine during ultrasonic scaling. *J Periodontol* 1992;63:812–816.

Checchi L, Pelliccioni G, D'Achille C. Sharpening of ultrasonic scalers. *J Clin Periodontol* 1991;18:505–507.

Chiew S, Wilson M, Davies E, Kieser J. Assessment of ultrasonic debridement of calculus-associated periodontally-involved root surfaces by the limulus amoebocyte lysate assay. An in vitro study. *J Clin Periodontol* 1991;18:240–244.

Dragoo M. A clinical evaluation of hand and ultrasonic instruments on subgingival debridement. Part I. With unmodified and modified ultrasonic inserts. *Int J Periodontics Restorative Dent* 1992;12:311–13.

Fine D, Mendieta C, Barnett M, et al. Efficacy of pre-procedural rinsing with an antiseptic in reducing viable bacteria in dental aerosols. *J Periodontol* 1992;63:821–824.

Finlayson R, Stevens F. Subcutaneous facial emphysema secondary to use of the Cavi-Jet. *J Periodontol* 1983;59:315–317.

Garrett J. Root planing: A perspective. *J Periodontol* 1977;48:553–557.
Gellin R. The effectiveness of the Titan-S sonic scaler versus curettes in the removal of subgingival calculus. A human evaluation. *J Periodontol* 1986;57:672–680.
Glick D, Freeman E. Post surgical bone loss following root planing by ultrasonic and hand instruments. *J Periodontol* 1980;51:510–512.
Gross K, Overman PK, Cobb C, Brockmann S. Aerosol generation by two ultrasonic scalers and one sonic scaler. A comparative study. *J Dent Hyg* 1992;66:314–318.
Horning GM, Cobb CM, Killoy WJ. Effect of an air-powder abrasive system on root surfaces in periodontal surgery. *J Clin Periodontol* 1987;14:213–220.
Horton JE, Tarpley TM Jr, Jacoway JR. Clinical applications of ultrasonic instrumentation in the surgical removal of bone. *Oral Surg Oral Med Oral Pathol* 1975A;39:236–242.
Horton J, Tarpley T, Wood L. The healing of surgical defects in alveolar bone produced with ultrasonic instrumentation and rotary bur. *Oral Surg Oral Med Oral Pathol* 1975B;39:536–546.
Hunter R, O'Leary T, Kafrawy A. The effectiveness of hand versus instrumentation in open-flap root planing. *J Periodontol* 1984;55:697–703.
Jones S, Lozdan J, Boyde A. Tooth surfaces treated in site with periodontal instruments: Scanning electron microscope study. *Br Dent J* 1972;132:57–64.
Kepic T, O'Leary T, Kafrawy A. Total calculus removal: An attainable objective? *J Periodontol* 1990;61:16–20.
Kerry G. Roughness of root surfaces after use of ultrasonic instruments and hand curettes. *J Periodontol* 1967;38:340–346.
Khatiblou F, Ghodssi A. Root surface smoothness or roughness in periodontal treatment. A clinical study. *J Periodontol* 1983;54:365–367.
Leon L, Vogel R. A Comparison of the effectiveness of hand scaling and ultrasonic debridement in furcations as evaluated with dark-field microscopy. *J Periodontol* 1987;58:86–94.
Loos B, Kiger R, Egelberg J. An evaluation of basic periodontal therapy using sonic and ultrasonic scalers. *J Clin Periodontol* 1987;14:29–33.
Nishimine D, O'Leary T. Hand instrumentation versus ultrasonics in the removal of endotoxins from root surfaces. *J Periodontol* 1979;50:345–349.
Nosal G, Sheidt M, O'Neal R, Van Dyke T. The penetration of lavage solution into the periodontal pocket during ultrasonic instrumentation. *J Periodontol* 1991;62:554–557.
Nyman S, Westfelt E, Sarhed G, Karring T. Role of "diseased" root cementum in healing following treatment of periodontal disease. A clinical study. *J Clin Periodontol* 1988;15:464–468.
Oosterwaal P, et al. The effect of subgingival debridement with hand and ultrasonic instruments on the subgingival flora. *J Clin Periodontol* 1987;14:528–533.
Pameijer C. Surface characteristics of teeth following periodontal instrumentation. *J Periodontol* 1972;43:628–633.
Pippin DJ, et al.: Effects of an air-powered device used during periodontal flap surgery on dogs. *J Periodontol* 1988;59:584–588.
Rosenburg R, Ash M. The effect of root roughness on plaque accumulation and gingival inflammation. *J Periodontol* 1974;45:146–150.
Smart G, Wilson M, Davies E, Kieser J. The assessment of ultrasonic root surface debridement by determination of residual endotoxin levels. *J Clin Periodontol* 1990;17:174–178.
Thilo B, Baehni P. Effect of ultrasonic instrumentation on dental plaque microflora in vitro. *J Periodontol Res* 1987;22:518–521.
Thornton S, Garnick J. Comparison of ultrasonic to hand instruments in the removal of subgingival plaque. *J Periodontol* 1982;53:35–37.
Torfason T, Kiger R, Selvig N, Egelberg J. Clinical improvement of gingival conditions following ultrasonic versus hand instrumentation of periodontal pockets. *J Clin Periodontol* 1979;6:165–176.
Walmsley A, Walsh T, Laird W, Williams A. Effects of cavitational activity on the root surface of teeth during ultrasonic scaling. *J Clin Periodontol* 1990;17:306–311.
Weaks LM, Lescher NB, Barnes CM, et al.: Clinical evaluation of the Prophy Jet as an instrument for routing removal of tooth stain and plaque. *J Periodontol* 1984;55:486–488.
Wilkinson R, Maybury J. Scanning electron microscopy of the root surface following instrumentation. *J Periodontol* 1973;44:559–563.

Section 4. Root Conditioning

A primary goal of periodontal therapy is to treat the diseased root surface making it biologically compatible with a healthy periodontium. This includes removing the endotoxins, bacteria, and other antigens found in the cementum of the root surface. A prerequisite for this root preparation is scaling and root planing which was shown by Jones and O'Leary (1978) to remove nearly all detectable levels of bacterial endotoxins. Another form of root conditioning used to help achieve this goal and facilitate new attachment is root surface demineralization. In a review article, Holden and Smith (1983) state that root conditioning was performed as early as 1883 when Marshall placed aromatic sulfuric acid on root surfaces, Younger used lactic acid in 1897, and in 1899 when Stewart decalcified the root surface with pure hydrochloric or sulfuric acid.

CITRIC ACID: HISTOLOGIC RESULTS

Register and Burdick (1975) studied several demineralizing agents for optimum concentration and time of application in gaining reattachment with cementogenesis. Dogs and cats were used as the experimental model and agents tested included hydrochloric, lactic, citric, phosphoric, trichloroacetic, and formic acids and a proprietary demineralizer RDO. Citric and lactic acids and RDO produced slightly wider bands of cementum deposition while trichloroacetic and formic acids stimulated more dentin resorption before cementum deposition. It was determined that citric acid at pH 1 for 2 to 3 minutes would be the best agent. They later showed the formation of cementum pins (perpendicularly extending fiber bundles seen in the tubules at 3 weeks, which appear continuous with and inseparable from the induced cementum at 6 weeks) extending into dentin tubules widened by demineralization when denuded root surfaces in dogs were treated by citric acid pH 1 for 2 minutes.

Garrett et al. (1978) used scanning and transmission electron microscopes to examine the morphological effects of citric acid on periodontally diseased root surfaces. Scanning microscopy showed acid decreased the surface characteristics of non-root planed teeth. Non-etched root planed surfaces were smooth and flat. Acid-etched root planed surfaces were flat with frequent depressions and numerous fiber-like structures. Transmission microscopy revealed root planed and acid-etched surfaces produced a zone of demineralization of 4 μm wide. This zone was dominated by exposed collagen fibrils. Lasho et al. (1983) also showed numerous collagen fibers exposed by the application of saturated citric acid, EDTA, or NaOCl followed by rinsing with 5% citric acid.

Polson et al. (1984) showed by SEM evaluation that root planing leaves an amorphous layer 2 to 15 μm thick which consists of organic and inorganic material. When these surfaces were treated by citric acid (pH 1 for 3 minutes) this smear layer was removed. The result was a fibrous mat-like structure with a fibrillar texture having numerous funnel-shaped depressions corresponding to open dentinal tubules. Similarly, Sterrett and Murphy (1989) used SEM photographs to evaluate extracted periodontally diseased-root surfaces that had been scaled and root planed, stored in formalin, and then treated with a 5-minute cotton pellet application of either passively placed or burnished citric acid. They examined the dentinal surfaces for root roughness and maximal exposure of the collagen surface. The smear layer was removed by both treatments. The burnished specimens were found to have patent dentinal tubules and an intertubular area with a very distinct "shag carpet" appearance of deeply tufted collagen fibrils. The passively placed citric acid specimen exhibited open dentinal tubules with a matted collagen surface. They proposed that the burnishing application removed more inorganic material through a combined mechanical/chemical process while fluffing and separating the entangled fixed dentin collagen.

Hanes et al. (1988) evaluated the initial wound healing response to demineralization in the same model as the previous study. They showed that acid-treated teeth had a fibrillar zone 3 to 8 μm thick consisting of collagenous fibrils of the dentin exposed during acid treatment. There appeared to be a layer of cells in dynamic activity and distinct attachment to dentin with cells migrating over the root surface. In the controls, there were large areas devoid of cells and other connective tissue components. This suggests that citric acid treatment may result in fibrin clot stabilization and initiate wound healing that results in new connective tissue attachment.

Fardal and Lowenberg (1990) evaluated in vitro citric acid conditioning compared to EDTA conditioning on fibroblasts cultured on sections of human periodontally involved teeth on migration, attachment and orientation. They found that: 1) root planing improves diseased roots and that root planing followed by citric acid demineralization improves diseased roots to a level comparable to non-diseased roots; 2) citric acid demineralization alone improves diseased roots to a level comparable to root planed diseased roots; and 3) acid demineralization results in both collagen fiber exposure and a more hospitable environment.

Different methods of citric acid application and time have been proposed. Codelli et al. (1991) evaluated citric acid effects upon extracted previously diseased human teeth relative to the duration and method of application. They found that passive applications for 5 minutes and burnished applications for 3 minutes both produced seemingly optimal surface characteristics consisting of a fine, fibrillar network of exposed collagen and a reduced or eliminated smear layer.

Wen et al. (1992) compared different application techniques for citric acid demineralization using scanning electron microscopy. Citric acid pH 1 was applied to dentin surfaces prepared from extracted teeth by 1) immersion; 2) placement of saturated cotton pellets; 3) burnishing with cotton pellets; or 4) camel hair brush. Immersion demonstrated tufting of intertubular dentin fibrils and wide open dentinal orifices. Pellet placement revealed a more matted surface and some debris inside the orifices. Burnishing resulted in a variation of characteristics. Two of 8 slabs showed tufting with widened tubular openings, while 6 of 8 showed surface smearing with complete obturation of the tubules. The camel hair brush resulted in surface characteristics close to those treated by immersion (tufting with widened tubules). Immersion resulted in the greatest number of openings followed by cotton pellet placement and camel hair brush.

Sterrett et al. (1993) examined the effects of citric acid concentration and application time on dentin demineralization. The measurements of calcium parts per million released for citric acid concentrations of 0, 10, 20, 25, 30, 35, 40, and 65% were determined at 1, 2, and 3 minutes. The peak demineralization for 1 minute was 30% (pH 1.55), for 2 minutes was 25% (pH 1.62), and for 3 minutes was 25%. For all concentrations, demineralization was time dependent.

WOUND HEALING AND ATTACHMENT EFFECTS

Animal Histology: Positive Effects

Register and Burdick (1976) examined reattachment with cementogenesis in dogs. Citric acid pH 1 was applied with cotton tip applicators for 2 minutes. Denuded root surfaces healed with cementogenesis with a secure fiber attachment at 6 weeks. However, circumferential and bifurcation defects only healed with approximately 10% reattachment.

Crigger et al. (1978) also studied the effect of citric acid in the dog model. Through and through furcation defects were created and allowed to accumulate plaque for 42 days. The denuded roots were treated with citric acid pH 1 for 3 minutes. These were compared histologically to non-acid treated roots. The controls healed by long junctional epithelium leaving a patent furcation. Thirteen of 23 acid-treated furcations demonstrated complete new attachment; 8 were incomplete and 2 remained patent.

Polson and Proye (1982) also studied the effects of citric acid conditioning in the monkey. Twelve teeth in 4 monkeys were extracted and the coronal third was planed to remove the fibers and cementum. The root surfaces were then treated with citric acid for 3 minutes and then re-implanted into their sockets. They were histologically examined at 1, 3, 7, and 21 days. At days 1 and 3, a fibrin linkage was shown between the periodontal ligament and the root surface. A new connective tissue attachment was present at 21 days with no cementum formation. Extensive root resorption had occurred with some new bone formation.

This led Polson and Proye (1983) to determine the healing sequence related to the fibrin clot and its interaction with collagen. Twenty-four (24) teeth in 4 monkeys were extracted and root planed and 12 teeth treated with citric acid pH 1. They were reimplanted and then biopsied at 1, 3, 7, and 21 days. At 1 and 3 days there was a fibrin network which appeared to be attached to the root surface. Teeth not treated with citric acid had epithelium migrating apically, reaching the crest by day 3, and by day 21 had reached the apical extent of root planing. Those teeth treated with citric acid had collagen fibers replacing the fibrin network by days 7 and 21. The epithelium was located at the CEJ. They concluded that the fibrin network was the initial stage in healing and precedes the collagen attachment.

The importance of the fibrin linkage was also shown by Woodyard et al. (1984). They studied the effects of citric acid on root coverage with pedicle flap procedures in the monkey model. Healing was studied histologically at 0, 3, 7, 14, 21, 28, and 42 days after treatment. Test teeth were treated by citric acid application. They showed the citric acid-treated teeth had a fibrin network while the controls did not. Controls displayed proliferation of the epithelium apical to the notch. Although citric acid treatment did not show enhanced root coverage, it did result in greater amounts of new connective tissue attachment.

Polson et al. (1986) evaluated the cellular, connective tissue, and epithelial response of demineralization on periodontitis affected dentin surfaces. Dentin specimens were obtained from root surfaces covered by calculus. Experimental specimens were immersed in citric acid pH 1 for 3 minutes. All specimens were then implanted into the necks of rats with 1 mm protruding through the skin. Biopsies were prepared at 1, 3, 5, and 10 days for histological examination. Healing of those specimens treated with citric acid occurred by inflammatory cells and fibroblasts in a fibrin network and attached fibers oriented obliquely and perpendicular to the root surface. The non-acid treated specimens showed fewer attached cells with epithelial migration to the apical portion resulting in extrusion. In a similar follow-up study, Polson and Hanes (1987) compared non-periodontitis affected specimens to periodontitis-affected root. Specimens were treated with citric acid pH 1 for 3 minutes and then implanted transcutaneously in the neck of rats. Healing was initiated by a fibrin network which prevented the apical migration of epithelium, allowing fiber attachment in the periodontitis affected specimens. In non-periodontitis specimens healing resulted in a similar attachment. In a follow-up study Hanes et al. (1988) evaluated the initial wound healing response to demineralization in the same model as the previous study. They showed acid treated teeth had a fibrillar zone 3 to 8 μm thick consisting of collagenous fibrils of the dentin exposed during acid treatment. There appeared to be a layer of cells in dynamic activity and distinct attachment to dentin with cells migrating over the root surface. In the controls there were large areas devoid of cells and other connective tissue components. They suggest that citric acid treatment may result in fibrin clot stabilization and initiate wound healing that results in new connective tissue attachment.

Steinberg et al. (1986) studied the effect of various root surface alterations on thrombogenicity and the morphological appearance of initial clot formation. Periodontally-involved human teeth were extracted, sectioned, and reimplanted. One section was immediately removed while the other was removed 1 minute later and examined by scanning electron microscopy. Platelet attachment conditions were examined: 1) intact fibers; 2) periodontitis, no treatment; 3) root planed; 4) root planed plus citric acid; and 5) root planed, citric acid, and collagenase incubation. Platelet attachment was greatest when the intact fiber was present. Citric acid enhanced platelet attachment in the diseased surfaces.

Selvig et al. (1988) also studied the development of attachment on citric acid treated teeth. Eight beagle dogs had fenestration defects created which were treated with citric acid pH 1 for 3 minutes. Biopsies were obtained at 7, 14, and 21 days. They concluded that initial reattachment to an instrumented, demineralized root surface generally takes place by interdigitation between newly synthesized collagen fibrils of the cementum or dentin matrix. In areas of resorption, new fibrils may adhere to the surface of hard tissue without any fibrillar interdigitation.

Wikesjö et al. (1991) studied the effect of citric acid treatment on root resorption. Surgically-created defects were treated in 6 beagle dogs with citric acid or stannous fluoride and the flaps replaced to cover the tooth to the level of the cusp tips. After 12 weeks, histology showed 45% of the defect in the saline treated controls healed by long junctional epithelium; 78% of the defects in stannous fluoride healed by long junctional epithelium, while only 17% of the defects healed by long junctional epithelium in citric acid treated specimens. Control and acid-treated teeth showed similar amounts of root resorption, suggesting citric acid does not enhance or prevent resorption.

Animal Histology: No Effect

Nyman et al. (1981) studied the potential for new attachment in the monkey model using citric acid. Experimental periodontitis was treated by flap and citric acid pH 1 for 3 minutes. The monkeys were sacrificed 6 months after surgery. Root planed alone (controls) and acid-treated teeth resulted in healing by long junctional epithelium. It was determined that citric acid application did not promote formation of new cementum and connective tissue.

Bogle et al. (1981) also provided evidence that citric acid conditioning might not be significant. Citric acid-root conditioning was used in naturally occurring furcation defects in dogs. They found epithelialization of the furcation fornix in 17/26 defects. Complete new attachment occurred in 2 and incomplete new attachment in 7 defects.

Isidor et al. (1985) failed to demonstrate a difference for citric acid conditioning in the monkey model with orthodontic elastic-induced periodontitis. Histologic sections showed 1.0 mm of newly formed connective tissue for the non-acid treated controls and 1.1 mm for the acid-treated test teeth.

Nyman et al. (1985) also studied the effects of citric acid on root planed teeth that were re-implanted. Five adult monkeys were used, forming 3 groups. Group 1 had teeth extracted and immediately re-implanted; group 2 was root planed and then re-implanted; and group 3 was root planed, treated with citric acid pH 1, and re-implanted. Six months later animals were examined histologically. Immediately re-implanted teeth showed connective tissue reattachment to a level 1 mm apical to the CEJ. Root planed teeth demonstrated apical migration of the epithelium to areas of resorption were ankylosis was present. Teeth root planed and treated with citric acid were similar to the root planed only group. They concluded citric acid had no effect on the healing of reimplanted teeth.

Aukhil and Pettersson (1987) studied the effect of citric acid on cell density. Maxillary canines in 6 dogs were used. Experimental roots were conditioned with citric acid pH 1 for 3 minutes and the dogs were sacrificed after 10 days. They found fibroblast cell density to be less on the acid treated surfaces when compared to controls. It was suggested that citric acid conditioning may result in low cell density during the early stages of healing.

Dyer et al. (1993) used the beagle dog to study the effects of demineralization during guided tissue regeneration. Teeth in 12 quadrants were treated, 4 by citric acid, 4 by tetracycline, and 4 by membrane alone. Histometric analysis demonstrated that root conditioning by either agent did not enhance the amount of connective tissue and bone gained by membrane alone. These results are substantiated by Parashis and Mitsis (1993).

Human Histology: Positive Effects

Cole et al. (1980) examined specimens histologically to determine if new attachment to periodontally-diseased root surfaces could be achieved by topical application of citric acid. Teeth treated by flap procedures had citric acid applied for 5 minutes. Four months later block sections were recovered. In all 10 specimens, connective tissue forming a periodontal ligament extended 1.2 to 2.6 mm coronal from the reference notch.

Albair et al. (1982) also histologically examined the effects of citric acid on formation of new connective tissue attachment. Eight patients requiring extractions for prosthetic reasons were treated by flaps with vigorous root planing. Experimental teeth were treated with citric acid for 5 minutes while contralateral teeth served as non-acid treated controls. Six to 15 weeks later the teeth were extracted and examined by scanning and light microscopy. Six of 9 acid-treated teeth displayed connective tissue coronal to the notch with fibers generally exhibiting a functional orientation. The control displayed a junctional epithelium.

Common and McFall (1983) compared treatment of experimentally-induced human recession using laterally positioned pedicle flap surgery with and without citric acid conditioning. Block sections were obtained at 1, 2, 4, 12, and 20 weeks to observe healing. Citric acid (pH 1) was rubbed onto the prepared root surface for 2 minutes. Control teeth exhibited a long junctional epithelium with no cementogenesis. The citric acid-treated pedicles had a connective tissue attachment to new cementum and, at 1 month postsurgery, did not separate from the teeth as easily as the controls.

Frank et al. (1983) made observations with electron microscopy on teeth treated with citric acid. After treatment by flap procedures, roots were conditioned with citric acid pH 1 for 3 minutes. Sixty-seven (67) days after the surgery the teeth were removed. They determined that two types of connective tissue reattachment occurred. One was splicing of the newly secreted collagen fibrils by mineralization of the decalcified dentin band, while the second involved cementum formation on top of the dentin surface.

Lopez (1984) studied connective tissue healing of periodontally-involved teeth treated by citric acid pH 1 for 5 minutes. Experimental teeth were extracted, cementum removed, treated by citric acid, and then placed in a pouch under the mucosa. They were recovered at 2, 6, 12, 18, 20, and 24 weeks for histological evaluation. At various time intervals they showed resorption, connective tissue attachment to old cementum, and dentin and fibers attached perpendicular to the root surface. They concluded that a new connective tissue attachment could form, even in the absence of periodontal ligament cells.

Human Histology: No Effect

Stahl and Froum (1977) evaluated the effects of citric acid on pocket closure both clinically and histologically. Seven extracted teeth from 2 patients were examined. Root surfaces were treated with citric acid and measurements were repeated at 4, 8, 12, and 16 weeks. Block sections were performed at the 16-week visit. In 5 of 6 citric acid-treated teeth, no evidence was observed of accelerated cementogenesis or functional connective tissue attachment.

Kashani et al. (1984) obtained human histology on citric acid-treated teeth extracted 3 months after surgery. Maxillary anterior teeth planned for extraction were treated with citric acid pH for 1 to 5 minutes. There was no difference on pocket closure between citric acid treated and non-acid treated teeth, which was by long junctional epithelium.

Cogen et al. (1984) compared root planing alone, citric acid alone, and a combination of root planing plus citric acid on fibroblast attachment to diseased roots. Human gingival fibroblasts adhered and grew on root planed surfaces but not on surfaces treated by citric acid alone. Addition of citric acid treatment after root planing offered no additional fibroblastic attachment compared to root planing alone.

CITRIC ACID: CLINICAL RESULTS

Human Studies: Positive Effects

Cole et al. (1981) examined the effects of citric acid in a pilot study after replaced flap surgery. A split mouth design was used in 12 patients with advanced periodontitis who were treated with citric acid pH 1 for 3 to 5 minutes on the experimental side. A probing attachment level gain of 2.1 mm for the acid-treated teeth resulted, compared to 1.5 mm for controls (60% of the acid-treated areas gained 2 mm of attachment while about 40% of the controls gained 2 mm). The clinical results cannot reveal if improvement is from gain in connective tissue attachment or improved adaptation of the junctional epithelium.

This was followed by a similar study by Renvert and Egelberg (1981) where 13 periodontally involved patients had intraosseous defects treated with citric acid pH 1 for 3 minutes. Six months after surgery, final measurements of probing depth, attachment level, and bone level were carried out. For acid treated teeth there was a gain in probing attachment level of 2.0 mm while the non-acid treated controls showed a gain of 1.2 to 1.3 mm. In 19 of 26 acid-treated teeth gain in probing attachment was 2 mm or more.

Caffesse et al. (1988) treated two sextants in each of 29 subjects with modified Widman flap surgery while another two sextants received the same treatment supplemented with citric acid and fibronectin application. While citric acid/fibronectin application improved probing depth and probing attachment levels to a statistically significant degree, the difference was clinically insignificant (a matter of 0.2 to 0.3 mm).

Human Studies: No Effect

Parodi and Esper (1984) tested the ability of citric acid to promote new attachment and induce bone formation in alveolar defects in humans. Twenty (20) lower molars with Class II and III furcation defects were used. The experimental group was treated with citric acid pH 1 for 3 minutes. At 6 months a re-entry was done to repeat measurements. Results showed a reduction in probing depth (2 to 3 mm) gain in attachment (1 to 1.5 mm), and a gain in bone level (1 mm) for both groups. The results show no difference between acid and non-acid treated teeth.

Renvert et al. (1985) also evaluated the relationship between citric acid conditioning and osseous grafts. They treated 19 patients by mucoperiosteal flaps, debridement, root planing, and citric acid with or without autogenous osseous grafts. They found that osseous grafting did not enhance the results achieved by citric acid conditioning alone and provided results similar to that expected with surgical debridement alone.

Marks and Mehta (1986) evaluated citric acid conditioning (pH 1 for 3 minutes) on 3 patients involving 72 teeth with moderate periodontitis. Results at 12 months showed citric acid did not enhance new connective tissue attachment as measured clinically.

Smith et al. (1986) used a split mouth design to study the effects of citric acid on new attachment during surgery. Experimental sites were treated with citric acid pH 1 for 3 minutes. Clinical attachment levels were evaluated at 3 and 6 months after surgery. There was no difference between acid treated and non-acid treated teeth.

Moore et al. (1987) clinically evaluated the results of citric acid treatment during replaced flap surgery. In a split mouth design, 12 patients had the experimental teeth treated with citric acid pH 0.6 for 3 minutes. Measurements were made from a fixed stent at 3 and 9 months after surgery. They showed that both controls and acid-treated teeth demonstrated gain in attachment levels, but there was no difference between them.

CITRIC ACID EFFECTS ON OTHER TISSUES

Nilveus and Selvig (1983) studied the effects of citric acid on the dental pulp after topical application using 6 beagle dogs. After removal of the alveolar plate, the surfaces were root planed and treated with citric acid or without. Biopsies were obtained after 1 and 15 weeks. It was determined that reparative dentin formed but did not cause inflammatory reactions in the pulp.

Crigger et al. (1983) evaluated the effects of citric acid on exposed connective tissue after flap procedures. Buccal and lingual flaps were raised in 4 dogs. On the test side, citric acid was applied to the inner flap for 3 minutes while the control side was treated with saline. Histology was performed at 3, 7, 14, and 21 days. They demonstrated no irreversible effects resulted on the exposed soft tissues or underlying alveolar bone at any time point.

Ryan et al. (1984) showed a different pulpal response to citric acid treatment while studying cats. Nine cats each provided 1 negative and 1 positive control and 2 experimental canine teeth. Positive controls were treated by surgery only while the experimental teeth received surgery with citric acid conditioning. Positive controls showed mild to moderate short-term and mild to no pulpal reactions long-term. Five experimental teeth became abscessed or necrotic, although 4 teeth were relatively non-inflamed.

Valenza et al. (1987) examined histologically the effects of citric acid on the gingival epithelium. Nine patients had citric acid pH 1 applied locally to the gingiva for 5 to 10 minutes. Gingival biopsies were taken before and after application. Citric acid resulted in edema of the prickle cell layer with disarrangement of the tonofilaments and karyolysis of the nucleus. It was suggested that the alterations may contribute to the prevention of the formation of a long junctional epithelium.

CITRIC ACID: ANTIBACTERIAL EFFECTS

Daly (1982) reported on the antibacterial effects of citric acid. Twenty (20) human teeth affected by periodontal disease were extracted. Ten (10) teeth were immersed in citric acid pH 1 for 3 minutes. Samples from the surfaces were plated on a culture dish. Citric acid treated teeth reduced both aerobic and anaerobic numbers, while there was no difference in numbers before and after saline treatment in the control teeth.

Sarbinoff et al. (1983) also studied the effect chemical treatments had upon endotoxin levels. They found that antiformin alone or in combination with citric acid neutralization resulted in endotoxin levels of less than 1 ng/gm, approaching levels found in undiseased roots. Citric acid alone did not remove endotoxin. Besides the effects upon the root, citric acid may also affect the flora.

Forgas and Gound (1987) compared the effects on darkfield microscopic parameters of root planing alone versus root planing plus antiformin-citric acid application. Both treatments resulted in decreased proportions of spirochetes and motile rods, with no differences between treatments. Microscopic parameters returned to baseline at 12 weeks in both groups.

Tanaka et al. (1989) studied the effects of citric acid on retained plaque and calculus after instrumentation. Five extracted teeth were sectioned longitudinally, and 1 segment was treated with citric acid pH 1 for 3 minutes. Controls showed surface debris and large amounts of bacteria on the retained calculus. Acid treated teeth showed little debris with virtually no bacteria. The surface morphology varied from layered-like to honeycombed.

Corley and Killoy (1982) studied the stability of citric acid solutions used for root conditioning. A solution of citric acid pH 1 achieved by 61 grams of citric acid crystals in 100 ml of distilled water was tested for the effects of light, time, and air exposure. A stable pH was maintained for a 5 month period. They showed that the solution was not affected by time, light, or air exposure.

TETRACYCLINE

Wikesjö et al. (1986) evaluated the effects of tetracycline conditioning on dentin surfaces. Dentin slabs were prepared from extracted bovine teeth. They were immersed in various concentrations of tetracycline solutions for 5 minutes. Morphological effects were compared to slabs treated with saline and inhibition of bacterial growth was tested by inoculating pretreated slabs. Immersion of the slabs removed the smear layer and exposed a regular pattern of open dentin tubules. Maximum binding of tetracycline was greatest with concentrations greater than 50 mg/ml. Maximal bacterial inhibition was achieved at 11 and 33 μm/ml tetracycline.

Terranova et al. (1986) studied the effects of tetracycline root conditioning on cell adhesion, migration, and proliferation. Assays using human gingival epithelial and connective tissue cells were done on dentin blocks prepared from bovine teeth. Tetracycline (TTC) and non-TTC treated slabs were incubated with fibronectin. Maximal binding of fibronectin occurred when slabs were immersed in 100 mg/ml and above of TTC, which varied in a dose dependent manner. TTC also reversed the greater binding of laminin in control specimens. When slabs were treated with TTC and fibronectin there was a 4-fold increase in the attachment of fibroblastic cells. TTC bound 3 times more cells than citric acid and 7 times more than controls.

Alger et al. (1990) used 22 human non-molar teeth with moderate to advanced periodontitis to compare root surface treatments of root planing versus a 3 minute burnished application of tetracycline-hydrochloride (TCN). They also added a 5-minute application of fibronectin (10 mg/ml) to the TCN treatment in a third group. The teeth were removed in block sections at 90 days and examined histologically. New attachment was not found in any of the specimens. TCN was found to result in small amounts of reattachment, which the addition of fibronectin generally inhibited.

Demirel et al. (1991) evaluated the substantivity of doxycycline on disease-affected cementum and dentin by treating prepared root surfaces with 3-minute applications of aqueous solutions of doxycycline HCl in concentrations of 1, 10, 50, and 100 mg/ml. The specimens were then rinsed and incubated for either 10 minutes, or 7 or 14 days in seeded agar containing either *A. viscosus, Actinobacillus actinomycetemcomitans* (Aa) or *Porphyromonas gingivalis* (Pg), with substantivity determined by agar diffusion inhibition assay. Doxycycline substantivity was found to be similar on both dentin and cementum at all concentrations and time intervals. Only the 100 mg/ml concentration of doxycycline produced zones of inhibition in all test organisms at all time intervals, while the 50 mg/ml concentration was effective at all times, except on day 14 with Aa. Aa was found to be most resistant to doxycycline, while Pg was found to be most sensitive. They concluded that cementum and dentin may be capable of acting as reservoirs for doxycycline with its slow release taking place for several days.

Stabholz et al. (1993) assessed in vitro the substantivity of tetracycline. Fifty-one extracted teeth were root planed and then immersed in 10 or 50 mg/ml solutions for 1, 3, and 5 minutes. The 10 mg/ml concentration of TCN showed antimicrobial activity for 4 days while the 50 mg/ml concentration demonstrated antimicrobial activity up to 14 days. Chlorhexidine was also tested (0.12 and 0.2%) and showed activity for only 24 hours.

Parashis and Mitsis (1993) studied the effect of tetracycline (TCN) root conditioning in conjunction with guided tissue regeneration. Controls were treated by expanded polytetrafluoroethylene membranes alone while test teeth were treated with TCN plus membrane. The change in vertical attachment was 1.7 mm for test teeth and 1.6 mm for controls. The horizontal changes were 4.7 mm for test teeth and 4.8 mm for controls, indicating there was no advantage to TCN when compared to membrane alone.

Lafferty et al. (1993) compared the surface effects of tetracycline and citric acid on periodontally diseased teeth which were extracted and root planed. SEM evaluation demonstrated both agents to be equally effective in removing the smear layer resulting in a similar surface morphology. All specimens demonstrated opened dentinal tubules and a fibrillar matrix with a matted appearance.

REFERENCES

Albair W, Cobb C, Killoy W. Connective tissue attachment to periodontally diseased roots after citric acid demineralization. *J Periodontol* 1982;53:515–526.

Alger F, Solt C, Vuddhakanok S, Miles K. The histologic evaluation of new attachment in periodontally diseased human roots treated with tetracycline-hydrochloride and fibronectin. *J Periodontol* 1990;61:447–455.

Aukhil I, Pettersson E. Effect of citric acid conditioning on fibroblast cell density in periodontal wounds. *J Clin Periodontol* 1987;14:80–84.

Bogle G, Adams D, Crigger M, Klinge P, Egelberg J. New attachment of the surgical treatment and acid conditioning of roots in naturally occurring periodontal disease in dogs. *J Periodont Res* 1981;16:130–133.

Caffesse R, Kerry G, Chaves E, et al. Clinical evaluation of the use of citric acid and autologous fibronectin in periodontal surgery. *J Periodontol* 1988;59:565–569.

Codelli G, Fry H, Davis J. Burnished versus nonburnished application of citric acid to human diseased root surfaces: the effect of time and method of application. *Quintessence Int* 1991;22:277–283.

Cogen R, Al-Jaburi W, Gantt D, Denys F. Effect of various root surface treatments on the attachment of human gingival fibroblasts: histologic and scanning electron microscopic evaluation. *J Clin Periodontol* 1984;11:531–539.

Cole R, Crigger M, Bogle G, Egelberg J, Selvig K. Connective tissue regeneration to periodontally diseased teeth. A histologic study. *J Periodont Res* 1980;15:1–9.

Cole R, Nilveus R, Ainamo J, Bogle G, Crigger M, Egelberg J. Pilot clinic studies of the effect of topical citric acid application on healing after replaced periodontal flap surgery. *J Periodont Res* 1981;16:117–122.

Common J, McFall W. The effects of citric acid on attachment of laterally positioned flaps. *J Periodontol* 1983;54:9–18.

Corley J, Killoy W. Stability of citric acid solutions during a five-month period. *J Periodontol* 1982;53:390–392.

Crigger M, Bogle G, Nilveus R, Egelberg J, Selvig K. The effect of topical citric acid application on the healing of experimental furcation defects in dogs. *J Periodont Res* 1978;13:538–549.

Crigger M, Renvert S, Bogle G. The effect of citric acid application on surgically exposed periodontal attachment. *J Periodont Res* 1983;18:303–305.

Daly C. Antibacterial effect of citric acid treatment of periodontally diseased root surfaces in vitro. *J Clin Periodontol* 1982;9:386–392.

Demirel K, Baer P, McNamara T. Topical application of doxycycline on periodontally involved root surfaces in vitro: Comparative analysis of substantivity on cementum and dentin. *J Periodontol* 1991;62:312–316.

Dyer B, Caffesse R, Nasjleti C, Morrison E. Guided tissue regeneration with dentin biomodification. *J Periodontol* 1993;64:1052–1060.

Fardal O, Lowenberg B. A quantitative analysis of the migration, attachment, and orientation of human gingival fibroblasts to human dental root surfaces in vitro. *J Periodontol* 1990;61:529–535.

Forgas L, Gound S. The effects of antiformin-citric acid chemical curettage on the microbial flora of the periodontal pocket. *J Periodontol* 1987;58:153–158.

Frank R, Fiore-Donno G, Cimasoni G. Cementogenesis and soft tissue attachment after citric acid treatment in a human. *J Periodontol* 1983;54:389–401.

Garrett J, Crigger M, Egelberg J. Effects of citric acid on diseased root surfaces. *J Periodont Res* 1978;3:155–163.

Hanes P, Polson A, Frederick G. Initial wound healing attachments to demineralized dentin. *J Periodontol* 1988;59:176–183.

Holden M, Smith B. Citric acid and fibronectin in periodontal therapy. *J West Soc Periodontol Periodont Abstr* 1983;31:45–56.

Isidor F, Karring T, Nyman S, Lindhe J. New attachment formation on citric acid treated roots. *J Periodont Res* 1985;20:421–430.

Jones W, O'Leary T. The effectiveness of in vivo root planing in removing bacterial endotoxin from the roots of periodontally involved teeth. *J Periodontol* 1978;49:337–342.

Kashani H, Magner A, Stahl S. The effect of root planing and citric acid applications of flap healing in humans. A histologic evaluation. *J Periodontol* 1984;55:679–683.

Lafferty T, Gher M, Gray J. Comparative SEM study on the effect of acid etching with tetracycline HCl or citric acid on instrumented periodontally involved human root surfaces. *J Periodontol* 1993;64:689–693.

Lasho D, O'Leary T, Kafrawy A. A scanning electron microscope study of the effects of various agents on instrumented periodontally involved root surfaces. *J Periodontol* 1983;54:210–220.

Lopez N. Connective tissue regeneration to periodontally diseased roots, planed and conditioned with citric acid and implanted into the oral mucosa. *J Periodontol* 1984;55:381–390.

Marks S, Mehta N. Lack of effect of citric acid treatment of root surfaces on the formation of new connective tissue attachment. *J Clin Periodontol* 1986;13:109–116.

Moore J, Ashly F, Waterman C. The effect on healing of the application of citric acid during replaced flap surgery. *J Clin Periodontol* 1987;14:130–135.

Nilveus R, Selvig K. Pulpal reactions of the application of citric acid to root-planed dentin in beagles. *J Periodont Res* 1983;18:420–428.

Nyman S, Lindhe J, Karring T. Healing following surgical treatment and root demineralization in monkeys with periodontal disease. *J Clin Periodontol* 1981;8:249–258.

Nyman S, Houston F, Sarhed G, Lindhe J, Karring T. Healing following reimplantation of teeth subjected to root planing and citric acid treatment. *J Clin Periodontol* 1985;12:294–305.

Parashis A, Mitsis F. Clinical evaluation of the effect of tetracycline root preparation on guided tissue regeneration in the treatment of class II furcation defects. *J Periodontol* 1993;64:133–136.

Parodi R, Esper M. Effect of topical application of citric acid in the treatment of furcation involvement in human lower molars. *J Clin Periodontol* 1984;11:644–651.

Polson A, Proye M. Effect of root surface alterations on periodontal healing. II Citric acid treatment of the denuded root surface. *J Clin Periodontol* 1982;9:441–454.

Polson A, Proye M. Fibrin linkage: A precursor for new attachment. *J Periodontol* 1983;54:141–147.

Polson A, Frederick G, Ladenheim S, Hanes P. The production of a root surface smear layer by instrumentation and its removal by citric acid. *J Periodontol* 1984;54:443–446.

Polson A, Ladenheim S, Hanes P. Cell and fiber attachment to demineralized dentin from periodontitis-affected root surfaces. *J Periodontol* 1986;57:235–246.

Polson A, Hanes P. Cell and fiber attachment to demineralized dentin. A comparison between normal and periodontitis-affected root surfaces. *J Clin Periodontol* 1987;14:357–365.

Register A, Burdick F. Accelerated reattachment with cementogenesis to dentin, demineralized in situ. I. Optimum range. *J Periodontol* 1975;46:646–655.

Register A, Burdick F. Accelerated reattachment with cementogenesis to dentin, demineralized in situ. II. Defect repair. *J Periodontol* 1976;47: 497–505.

Renvert S, Egelberg J. Healing after treatment of periodontal intraosseous defects. II. Effect of citric acid conditioning of the root surface. *J Clin Periodontol* 1981;8:459–473.

Renvert S, Garrett S, Schallhorn R, Egelberg J. Healing after treatment of periodontal intraosseous defects. III. Effects of osseous grafting and citric acid conditioning. *J Clin Periodontol* 1985;12:441–455.

Ryan P, Newcomb G, Seymour J, Powell R. The pulpal response to citric acid in cats. *J Clin Periodontol* 1984;11:633–643.

Sarbinoff T, O'Leary T, Kafrawy A. The comparative effectiveness of various agents in detoxifying diseased root surfaces. *J Periodontol* 1983;54:77–80.

Selvig K, Bogle G, Claffey N. Collagen linkage in periodontal connective tissue reattachment. *J Periodontol* 1988;59:758–768.

Smith B, Mason W, Morrison E, Caffesse R. The effectiveness of citric acid as an adjunct to surgical reattachment procedures in humans. *J Clin Periodontol* 1986;13:701–708.

Stabholz A, Kettering J, Aprecio R, Zimmerman G, Baker P, Wikesjö U. Antimicrobial properties of human dentin impregnated with tetracycline HCl or chlorhexidine. *J Clin Periodontol* 1993;20:557–562.

Stahl S, Froum S. Human clinical and histological repair responses following the use of citric acid in periodontal therapy. *J Periodontol* 1977;48:261–266.

Steinberg A, LeBreton G, Willey R, Mukherjee S, Lipwoski J. Extravascular clot formation and platelet activation on variously treated root surfaces. *J Periodontol* 1986;57:516–522.

Sterrett J, Bankey T, Murphy H. Dentin demineralization. The effects of citric acid concentration and application time. *J Clin Periodontol* 1993; 20:366–370.

Sterrett J, Murphy H. Citric acid burnishing of dentinal root surfaces. A scanning electron microscopy report. *J Clin Periodontol* 1989;16:98–104.

Tanaka K, O'Leary T, Kafrawy A. The effect of citric acid on retained plaque and calculus. A short communication. *J Periodontol* 1989;60: 81–83.

Terranova V, Franzetti L, Hic S, et al. A biochemical approach to periodontal regeneration: Tetracycline treatment of dentin promotes fibroblast adhesion and growth. *J Periodont Res* 1986;21:330–337.

Valenza V, D'Angelo M, Farina-Lipari E, Farina F, Margiotta V. Effects of citric acid on human gingival epithelium. *J Periodontol* 1987;58: 794–795.

Wen C, Caffesse R, Morrison E, Nasjleti C, Parikh U. In vitro effects of citric acid application techniques on dentin surfaces. *J Periodontol* 1992;63:883–889.

Wikesjö UME, Baker P, Christersson L, et al. A biomedical approach to periodontal regeneration: Tetracycline treatment conditions dentin surfaces. *J Periodont Res* 1986;21:322–329.

Wikesjö UME, Claffey N, Nilveus R, Egelberg J. Periodontal repair in dogs: Effect of root surface treatment with stannous fluoride or citric acid on root resorption. *J Periodontol* 1991;62:180–184.

Woodyard S, Snyder A, Henley G, O'Neal R. A histometric evaluation of the effect of citric acid preparation upon healing of coronally positioned flaps in non-human primates. *J Periodontol* 1984;55:203–212.