An Evaluation of Healing Following Periodontal Osseous Surgery in Monkeys

The removal of bone in the treatment of periodontal disease was originally advocated on the assumption that it was necrotic and laden with bacteria. The necrotic portions were therefore removed so as to reach viable bone. Later knowledge that chronic inflammatory periodontal disease produced resorption rather than infected necrosis of the subjacent alveolar process altered the rationale offered by those who continued to advocate removal of bone. To permanently eliminate interproximal pocketing and aid oral hygiene procedures, A. D. Black introduced the concept that it was necessary to eliminate bony craters so as to create an even curve to the marginal soft tissue. However, many interpreted this evidence of resorption rather than necrosis to mean that the integrity of bone was inviolate. In 1933 Kronfeld asserted that the reference to "necrotic bone" in pyorrhea was erroneous, and the removal of bone is at best "superfluous." While the removal of bone was performed by Nodine, Ward, and Zemsky for architectural reasons, others interpreted Kronfeld's statements to mean that the integrity of bone was inviolate. Contemporary surgical techniques introduced to eliminate the osseous deformities resulting from periodontal disease have been based on the observation that soft tissue has a limited capacity to conform to the underlying osseous architecture. The basic principles of osseous surgery have their origin in the concepts presented by Schluger in 1949. Based on the clinical observation that "the pattern of behavior of the soft tissue is conditioned by the hard tissues with which it is in contact," Schluger suggested elimination of certain common osseous deformities in order to prevent "post-reduction regrowth of soft tissue beyond the crevicular depth regarded as normal." Friedman later stated, "The principle of osseous resection was conceived ... to overcome a serious short-comings in the existing periodontal surgical techniques ... This principle grew out of repeated failures to maintain the results achieved by gingivectomy. Accordingly, bone is removed and/or reshaped in order to obtain a more predictable and permanent gingival configuration.

With an increased awareness of problems associated with the mucogingival junction and inadequate vestibular depth, a variety of surgical procedures were introduced to accomplish the desired physiologic contour in hard and soft

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tissues, all based on the "principle of harmonious gingival and osseous architecture." Friedman described osteoplasty as a plastic procedure in which the periodontal pocket is eliminated and the bone resheathed in order to achieve a proper contour of the bone and the gingiva overlying it. In this procedure, tooth-supporting bone is not removed. Osteotomy, however, involves the removal of bone which is part of the attachment apparatus, "in order to eliminate a periodontal pocket and establish gingival contour that will be maintained."

Statements and concepts supporting osseous surgery may be found in publications by Pritchard, Ochsnerbein, Friedman, and Schlager. While it has been generally accepted that successful periodontal therapy requires elimination of the underlying osseous deformities either by resection and reshaping of the alveolar process or by reattachment procedures, there has been some question concerning the necessity and effectiveness of the various therapeutic procedures. A clinical study has demonstrated natural re-contouring of bone in some cases without artificial contouring. However, the possibility has been recognized that the surgical contouring is slow and that soft tissue maintenance becomes difficult before these changes take place.

As a result, this investigation was undertaken to determine the maintenance of surgically produced osseous contours in monkeys, and the influence of the resultant bony profile on overlying soft tissue morphology.

Reparation of periodontal structures

A series of studies on the repair of periodontal structures following the surgical removal of alveolar bone and periodontal membrane from dogs reported varying amounts of alveolar process regeneration and in some cases an almost complete regeneration of the alveolar crest. However, the experimentally produced defects were limited to individual teeth, and no discussion followed concerning the architecture of the re-generated alveolar process. A short-term investigation evidenced that the ultimate buccal contour is not formed by the reshaped bone. No wound healing investigations have been directed toward the effects of osseous reshaping procedures per se. At the time of this investigation, the maintenance of surgically produced osseous contour and its influence on overlying soft tissue morphology had not been investigated.

Boyns (1966) studied the histologic response of bone to sectioning by high- and low-speed rotary instruments in dogs. The response to either was necrosis at the surface of bone. New bone formation occurred consistently in the region of the defect cut at high speed, as opposed to those cut at low speed.

Coffesse et al reported on a study of the healing of reverse bevel flaps, in rhesus monkeys, when small amounts of bone were removed on the buccal aspect of the alveolar crest. They confirmed previous reports of healing without a significant loss of attachment following reverse bevel flap surgery. A more recent rhesus monkey study reported that the resection of osseous walls of inter-

Materials and methods

Three young adult Mucaca infrahydis monkeys with an erupted permanent dentition and clinically healthy gingiva were used in this study.

Three types of surgical procedures were performed in this experimental project to evaluate the maintenance of surgically produced bone contour and its influence on soft tissue morphology. The various quadrants and the surgical procedures carried out in each are listed in Table 1.

Radiographs and clinical photographs were taken prior to and after surgery.

The initial incision in all operated quadrants was the same (Fig 1a). The coronal third of attached gingiva was removed by connecting the unbeveled buccal and lingual horizontal incisions interdentally. The initial incisions extended from the distal aspect of the canine to the distal aspect of the last molar. Subsequent elevation of buccal and lingual mucoperiosteal flaps exposed the underlying alveolar process. Sufficient relaxation of the flap was gained by extending the initial incisions mesially and distally, without the use of vertical incisions.

As outlined in Table 1, one of three surgical procedures was performed following mucoperiosteal flap elevation.

Table 1: Plan of study: Quadrant distribution of surgical procedures

<table>
<thead>
<tr>
<th>Monkey</th>
<th>Control</th>
<th>Surgery Procedure</th>
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<tr>
<td>1</td>
<td>OR*</td>
<td>Unoperated control</td>
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<td>OR*</td>
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<td>Unoperated control</td>
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<td></td>
<td>1 Week</td>
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* Osseous reduction. Reduction of alveolar process approximately 2 mm following flap elevation.
* Mucoperiosteal flap. No osseous surgery performed.
* Interdental osteoplasty. Same as above, with the exception that the interdental bone was reshaped buccally and lingually.

Operated control. The roots were planed and the elevated buccal and lingual mucoperiosteal flaps were replaced (Fig 1b). No osseous surgery was performed. This would reveal the effect of flap elevation on the morphology of bone and soft tissue.

2. Interdental osteoplasty. With the aid of a rotary diamond stone adequately cooled with water, the interdental crestal bone was reshaped buccally and lingually. The osseous surgery was confined to the interdental areas without attempting to remove alveolar or radicular bone from the teeth adjaoming the interdental area. An attempt was made to produce a buccolingual peak in the interdental bone with the reshaping procedure, without reducing alveolar process height. This procedure was performed to determine the maintenance of a surgically produced profile and its effect on overlying soft tissue form. The resultant shape is illustrated in Fig 2.

3. Osseous resection. The height of the alveolar process was reduced by the removal of alveolar bone and radicular bone from vestibular and lingual surfaces. The amount of reduction was approximately 2 mm in radicular areas and slightly less than 2 mm in interdental areas. The bulk of the resection was carried out with chisels and rongeurs, and extended from a gradual ramp mesial to the first premolar to a gradual ramp buccally and lingually over the last molar (Fig 3). The resected alveolar process was reshaped at this reduced level with rotary diamond stones under water, the crestal bone tapered to a thin margin. As with the interdental osteoplastic procedure, an attempt was made to produce a buccolingual peak in the bone interdentally. The roots were debried and the mucoperiosteal flaps replaced. Subsequent study of these areas would reveal the effect this bone reduction had upon osseous and gingival contour.

The remaining quadrants were left untreated to act as unoperated control areas. Two months later the animals were anesthetized; any accumulated calcified deposits were removed with curettes. The teeth were then polished with pumice and rotary rubber disks.

Twice a week for the remaining 4 months each animal was removed from his cage and received oral hygiene procedures. One animal was killed 4 months following the twice weekly oral hygiene procedures, and the other after 6 months following surgery. The third monkey was killed 1 week following surgery to compare the surgically created osseous contour with the bone and soft tissue morphology in monkeys 1 and 2.

Buccolingual serial sections, 12 μm thick, were prepared and routinely stained with hematoxylin and eosin. Van Gieson's and Masson's tri-chrome staining procedures were employed to study connective tissue reattachment in selected areas. The prepared sections were studied at macroscopic and microscopic levels.

Macroscopic evaluation

1. Three-dimensional plexiglass reconstruction.
2. Wax model reconstruction.

In order to study the gross morphology of operated and control radicular and interdental areas, and to compare the relationship between various structures, representative interdental and radicular areas were selected for a three-dimensional plexiglass and wax model reconstruction. Fifth and tenth buccolingual sections were respectively projected on plexiglass and wax sheets at a magnification of X20. The drawn plexiglass sheets were then juxtaposed on a rack and spaced sufficiently to obtain a three-dimensional view. The wax selected was approximately 2 mm thick so as to obtain a reconstruction at X20 from the 12-μm thick sections.

Fig 1a. Amount of attached gingiva removed with initial incision. (AG) Attached gingiva, (AM) alveolar mucosa, (MG) marginal mucogingival junction, (---) initial incision.

Fig 1b. Palatal surface following replacement and suturing of mucoperiosteal flap. Note sutures placed in interdental areas.

Fig 2. Areas reshaped in the surgical procedure "interdental alveoplasty." The plastic procedure was confined to the cross-hatched areas. (AG) Attached gingiva of elevated flap, (AM) alveolar mucosa, (B) exposed bone.

Fig 3. Reduction of alveolar process height by removal of alveolar bone and rootal bone. The reduction extended from a greatest height buccally over the last molar. Cross-hatched areas interdentally were reshaped to produce a buccolingual peak in the bone. (AG) Attached gingiva, (AM) alveolar mucosa, (B) exposed bone.

Fig 4. Method of measurement. (A-A') Occlusal plane, connects dentinal cusp tips; (B-B') gingival plane, connects buccal and palatal gingival margins; (C-C') radicular plane; connects buccal and palatal bony crests. (D) denotes the most occlusal portion of the bone in the furcation areas.

Method of Measurement

Control

Operated

The prepared histologic sections were examined microscopically to aid in the interpretation of macroscopic findings. The histomorphology of bone in interdental and radicular areas was examined with specific reference to the relationship of osteons or haversian and longitudinal lamellae to an overlying more fibrous, cellular type bone.

Areas of new bone deposition, evidenced by the presence of osteoid and osteoblastic activity, were evaluated and compared with areas of resorption featuring Howship's lacunae and osteoclastic activity.

The relationship of radicular bone to the previous surgical level of reduction was evaluated by correlating its position at sacrifice to the curette mark produced at the time of surgery. In regions exhibiting regeneration of radicular bone, the amount of coronal reattachment was determined by correlating cementum formation with reattachment of collagen fibers.

Results

The results obtained with each surgical procedure will be described under the headings of (A) bone and (B) soft tissue.

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**Microscopic evaluation**

**A. Bone**

A description of the unoperated areas and the effect of each surgical procedure on interdental, radicular, and interradicular (bifurcation and trifurcation) areas will be presented in the following order:

1. **Maxillary interdental areas**
   a. Unoperated control
   b. Interalveolar osteoplasty: 6 months
   c. Osseous resection: 6 months
   d. Operated control: 1 week

2. **Mandibular interdental areas**
   a. Unoperated control
   b. Operated control: 6 months
   c. Interalveolar osteoplasty: 6 months
   d. Osseous resection: 6 months
   e. Osseous resection: 1 week
   f. Maxillary radicular areas
   a. Unoperated control
   b. Operated control: 6 months
   c. Osseous resection: 6 months
   d. Osseous resection: 1 week
   e. Mandibular radicular areas
   a. Premolar areas
   i. Unoperated control
   ii. Operated control: 6 months
   iii. Osseous resection: 6 months
   iv. Osseous resection: 1 week
   b. Molar areas
   i. Unoperated control
   ii. Operated control: 6 months
   iii. Osseous resection: 6 months
   iv. Osseous resection: 1 week
   v. Bifurcation and trifurcation areas

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Bone

Maxillary interdental areas

Unoperated control. The gross morphology of the unoperated interden tal alveolar crest of bone varies between premolar and molar regions and to some extent within each region (Figs 6 and 15) and is typical of the osseous contour in both maxillary and mandibular unoperated control premolar areas. The palatal cortical plate of bone terminates in a convexity (D) at the level of the interdental crest. This palatal convexity is continuous with a conical-shaped depression which runs to an eminence at C (Fig 15). The vertical buccal cortical plate A-B also exhibits a convexity at the level of the interdental crest which approaches the elevated area C (Fig 15).

In molar regions, the prominence at C is not present. This results in either an interdental plateau area (Fig 7) or a crater between buccal and palatal cortical plates of bone (Fig 6). In the latter case the convexities of the cortical plates occupy a more coronal position than the interdental crest area.

Histologically, the buccal and palatal cortical plates in both molar and premolar areas consist of interstitial and longitudinal lamellae and haversion-type bone (Fig 10). As the cortical plates approach the interdental crestal area at B and D a more fibrillar, cellular type bone caps the longitudinal and haversion lamellae (Fig 11). Usually these areas are covered with a well-defined layer of osteoid and an intact active osteoblastic layer. Lamellated compact bone is also apparent overlying cancellous bone in the interdental crestal area (Figs 7 and 12).

Interdental osteoplasty. Six months after interdental reshaping procedures, the interdental areas from the unoperated control areas that the profile is generally more rhabdoid or convex (Fig 8). The greatest deviation from the relatively flat rootocapatal profile seen in unoperated control areas is found between second premolar and first molar.

Osseous resorption. The following morphological and histologic variations are observed in the interdental areas of osseous resection: In premolar regions, the buccal width of the unoperated interdental plateau or table has become narrowed (Fig 5). More posteriorly, the buccal and palatal cortical plates converge to form a definite peak (Fig 9). Histologically, the cortical plates at the level of the interdental crest consist of a more lamellated and fibrillar type bone than observed in the unoperated control and the interdental osteoplasty areas (Fig 13).

Operated control. One week following the evaluation and replacement of mucoperiosteal flaps, the osseous profile in premolar and molar areas is identical to that seen in the unoperated control quadrants. The pattern and direction of osteoclastic activity has not produced any significant morphologic variations in the interdental bone, the cortical plates and the interdental area intact (Fig 11). In some areas bone apposition is taking place within the marrow spaces.
Fig 5: Mesial roots juxtaposed on a root. Interdental region between first and second premolar in an unoperated patient. (A-B) Buccal cortical plate; (D-E) palatal cortical plate; (E-D) interdental crest area; (AF) alveolar process; (BP) buccal peak of soft tissue; (PP) palatal peak of soft tissue.

Fig 6: Wax model reconstruction of an interdental and adjacent radicular area in a mandibular molar unoperated control quadrant. (A-B) Buccal cortical plate; (D-E) palatal cortical plate. Note: (1) the tipping of buccal cortical plate at B; (2) the interdental crater between B and D; and (3) the position of bone in location with respect to buccal and palatal cortical plates B and D.

Fig 7: Mandibular interdental bone between first and second molar 6 months following interdental osteoplasty. (AB) Buccal cortical plate, (DE) interdental plateau area, (G) spongy bone, covered by lamellated compact bone. (H) connection of buccal and palatal soft tissue pedicels. (I) low magnification X1.5.

Fig 8: Mandibular interdental bone between first and second molar 6 months following interdental osteoplasty. (AB) Buccal cortical plate, (DE) palatal cortical plate, (S) spongy bone. Note the closer approximation of soft tissue pedicles and greater convexity of osseous profile than observed in Fig 7.
Mandibular interdental areas

Unoperated and operated control. The typical bony morphology in the mandibular unoperated control premolar region has been previously described (see maxillary interdental areas) (Fig. 15).

Six months following elevation and replacement of mucoperiosteal flaps (monkeys 1 and 2, operated control), the interdental bone of the premolar sites exhibits the variations in morphology illustrated in Figs 16 and 17. In one animal, the buccal plate terminates in a much more pronounced lip at the level of the interdental crest than seen in the unoperated control area (Fig 16). A further variation is in the interdental crestal area which is relatively flat between the buccal and lingual convexities at B and D. In another animal, the interdental profile is basically similar to the unoperated control (Fig 17). The only exception is that the slight tipping effect seen in the unoperated control at B is not present here.
Medially, the vestibular and buccal cortical plates in operated and unoperated control areas consist of unaltered lamellated bone and cementum systems. The slight thinning of the inner lamellae observable macroscopically in the operated control and the extent to observable in one of the operated control premolar regions was of a fibrous type bone. (Fig 11)

All of the above, the interdental area consists of lamellated bone with a secondary lamellar layer. Slight osteoclastic activity is present, however (Fig 19).

In the unoperated and operated interdental regions, the buccal and lingual cortical plates present a thin surface at the level of the interdental crest which is flat buccally (Figs 20 and 21).
Fig 15  Interdental area between first and second premolar. Unoperated control. (AB) Vestibular cortical plate; (DE) oral cortical plate. Note slight lip of bone between arrows. (Original magnification x4.)

Fig 16  Interdental area between first and second premolar. Operated control. (AB) Vestibular cortical plate; (DE) oral cortical plate. Note lip of bone between arrows. See Fig 17 for higher magnification. (Original magnification x4.)

Fig 17  Interdental area between first and second premolar. Operated control. (AB) Vestibular cortical plate; (DE) oral cortical plate. Note troughed cortical plate below arrow. See Fig 19 for higher magnification. (Original magnification x4.)

Fig 18  Higher magnification of an area similar to the one seen beneath the arrow in Fig 16. (Original magnification x40.)
Fig 20. Mandibular interdental area between first and second molar. Unoperated control. (AB) Vestibular cortical plate; (DE) oral cortical plate. (Original magnification x4.)

Fig 22. Mandibular interdental area between first and second premolars 6 months following interdental osteoplasty. (AB) Vestibular cortical plate; (DE) oral cortical plate. Note most coronal position of interdental bone at C. (Original magnification x4.)

Interdental osteoplasty. The morphology of mandibular interdental bone 6 months after interdental osteoplasty is relatively similar in all areas. The mandibular interdental bone generally presents a more convex buccolingual profile than previously observed in unoperated and operated control areas (Fig 22).

Osseous resection: 6 months. Following osseous resection the greatest deviation from control morphology is observed posteriorly between the molars. The buccal cortical plate presents a more gradual ramp as it approaches the crestal area. The crestal area is generally more convex following osseous resection than it is in control areas (Figs 23 and 24).

Osseous resection: 1 week. The surgical procedure is seen to have established a longer and more gradual ramp to the buccal bone (Fig 25). The presence of a broad lingual shelf of bone, particularly in premolar segments, prevented attainment of similar osseous morphology buccally and lingually. The morphologic result is an interdental crestal area approached by buccal and lingual ramps with different slopes. While the histologic picture is dominated by osteoclastic activity (Fig 26) the pattern of resorption is primarily from the marrow spaces and haversian canals and does not appear to have altered the surgically created morphology at this time interval. As seen in Fig 25, the surgical procedure has not exposed the marrow spaces underlying the vestibular and oral cortical bone plates. Surface vascularity and cellular activity in these areas are minimal and the replaced soft tissue flaps are poorly if at all reattached.

In the crestal area however (Figs 25 and 26), the surgical procedure has exposed many of the underlying marrow spaces, and osteoclastic activity is apparent on the surface as well as from within the marrow spaces.

Maxillary radicular areas

Unoperated control: monkeys 1 and 2. The buccal cortical plate of bone is seen to terminate at a "lip" at its occlusal margin, the morphology and thickness of which vary in premolar and molar areas. The lip of bone is thickest in premolar and third molar radicular areas, and it is extremely thin on the first and second molar radicular areas, where some sections show the root to have perforated the buccal cortical plate of bone, producing a fenestration (Fig 27).

The morphology of the unoperated control palatal cortical bone (Fig 6) shows the palatal ramp D-E to terminate in a broad convexity in the radicular areas. The bone between the roots in the trifurcation areas F is located apical to the buccal and palatal bony crests.

Histologically, the compact buccal plate consists of longitudinal and haversian lamellae overlying distinct reversal lines in some areas. In this area a coarse fibillar bone overlies varying numbers of well-defined osteons exhibiting new bone opposition in the marrow cavities. The whole lip of bone and the apical buccal cortical plate are generally covered with osteoid tissue and an intact layer of osteoblasts (Fig 28). On the periodontal membrane side, the buccal cortical plate generally presents a scalloped appearance—one of the lucunae filled with osteoclasts and others exhibiting a layer of osteoid and osteoblastic activity.

The palatal cortical plate consists of longitudinal lamellae and haversian bone which overlies the trabecular spongy bone. Various amounts of aposition and resorption are observed on the spongy trabeculae.

Operated control: monkey 2. As previously noted in the section on materials and methods, the radicular bone was not altered when performing interdental osteoplasty. Therefore, the effect of flap elevation on these radicular areas can be determined by comparing them with the unoperated control radicular areas.

Six months following elevation and replacement of the mucoperiosteal flaps, the morphology of the maxillary buccal radicular bone appears thinner than in the unoperated control. However, the measurements taken to compare the relative heights of unoperated control and operated control radicular crestal bone indicate that they are at a similar level (Table 4). The only variation from the unoperated control is in the appearance of the bone overlying buccal and palatal crests, which is not as fibillar in this quadrant (maxillary right; see Table 1).
Fig 27 Radicular area overlying mesio-buccal root of first molar in maxillary unoperated control quadrant. (O) Direction of occlusal surface, (P) direction of tooth apex. (A) Tissue separation. (C) cementum. (D) dentin. (PM) periodontal membrane. Note osteoclastic activity on periodontal membrane surface of buccal cortical plate (arrow) and absence of radicular bone apical to I.

Fig 28 Maxillary molar radicular area; unoperated control. (MG) Mucogingival junction; (M) muscle fiber bundles. (PM) periodontal membrane. (AC) alveolar crest. (C) cementum. Note lip of bone extending from I to AC; and bulge of soft tissue, of uniform thickness, extending from the mucogingival junction to the level of the alveolar crest. (Original magnification x16.)

Fig 29 Maxillary molar radicular area 6 months following osseous resection. Note maintenance of surgically produced morphology and scalloped surface (S). (PM) Periodontal membrane. (O) osteoid tissue. (Original magnification x40)

Fig 30 Palatal radicular area 6 months following osseous resection. Regenerated alveolar crest (RAC) coronal to the surgical level of reduction (SR). (PRB) Palatal radicular bone. (EA) apical position of epithelial attachment. (Hematoxylin and eosin stain. x20)

Osseous resection: monkey 1. Six weeks following osseous resection, the buccal and palatal radicular perimortem maintained the surgically induced morphology (Fig 29). In these areas, the alveolar crest has regressed coronal to the previous surgical level of reduction (Fig 30) but remained in a more apical position than in the control (Tables 2 and 3).

The microscopic appearance of the regenerative process is similar to that seen in the control. Many of the narrow canals are lined with osteocytes and osteoblasts, indicating active bone apposition. The cells of the periosteum in the crestal area are greater in areas of osseous regeneration than in the control, and the formation of cortical plate 6 months following osseous resection is consistent with the morphology produced at the time of surgery (Figs 29 and 31).

MANDIBULAR RADICULAR AREAS

The gross and histomorphology of the mandibular bone in mandibular control and resected quadrants present variations that necessitate a separate description for the premolar and molar segments.

Premolar radicular areas: (1) Unresected control—monkey 3. In both the first and second premolar unresected radicular areas, the buccal alveolar crest is located apical to the mesiodistal junction, terminating in a slight lip which consists of a fibrous type bone overlying a cancellous alveolus. While the thickness of radial cortical plate increases in both alveolar and vestibular regions as the distal surfaces of the premolars approached, the morphology is basically similar in all areas in that
Fig. 33 Unoperated control premolar illustrating the buccal radicular lip of bone and broad lingual shelf of bone. (B) Buccal, (L) Lingual. (Original magnification x4.)

Fig. 34 and 35 Operated control premolar buccal radicular area illustrating position of alveolar crest (AC) with respect to cementoenamel junction (CEJ). (D) Dentin, (ES) enamel space. (Original magnifications x12 and 40.)

Fig. 36 Mandibular molar radicular bone in an unoperated control quadrant. This figure is taken from the second molar area. Note the eroded appearance of the vestibular cortical plate (EC) apical to the cervical area (AC). (Original magnification x10.)

Figs 37 and 38  Mandibular first molar radicular area in an operated control quadrant. Note the thick layer of osteoid tissue and the extremely cellular periosteum of the crestal bone (AC). Compare with Fig 39. (Original magnifications x10 and 40.)

Figs 39 and 40  Mandibular second molar radicular area in operated control quadrant. Note the thin crestal margin (AC). The reversal line (R) indicates the extent of the previously notched cortical plate (NC). A thick layer of osteoid tissue (O) and an extremely cellular periosteum (P) covers the crestal area (Fig 40). New bone apposition has covered the previously notched cortical plate (Fig 39) and many recently incorporated osteocytes are visible in the thickened osteoid layer. (Original magnifications x10 and 40.)

the cortical plate terminates coronally in a lip. On the periodontal membrane side, in some areas the bundle bone presents the reverse lines, indicative of previous resorption and evidence of bone apposition. Lingually, the radicular bone presents a broad shelf at its occlusal margin (Fig. 33).

2. Operated control — monkey 2. Due to age differences in the animals used, there is some variation in mandibular premolar areas following mucoperiosteal flap elevation. In the younger animal (monkey 2), the radicular crestal bone is coronal to the cementoenamel junction (Fig. 34). The periosteal surface of the vestibular cortical plate is covered with osteoid tissue, and the periosteum presents a very cellular cambium layer which increases in thickness in the crestal area. On the periodontal membrane surface the cortical plate is eroded, exhibiting osteoclastic activity apically to the level of the cementoenamel junction (Figs 34 and 35). Further apically, the bundle bone is covered with osteoid tissue and a continuous intact layer of osteoblasts. In monkey 1 the radicular crestal bone is apical to the cementoenamel junction and is similar morphologically to the previously described unoperated control area.

The vestibular cortical plate of both animals presents a depression from previous resorptive activity. However, these areas are covered with a thick layer of osteoid tissue and an extremely cellular periosteum. Lingually, the gross morphology and histomorphology of both premolars are similar to the unoperated control with the exception that the shelf of bone is not as thick as in the unoperated control.

3. Osseous resection (6 months) — monkey 2. Following osseous resection the buccal alveolar crest overlying the first premolar is now apical to the cementoenamel junction in the quadrant opposite the operated control where the buccal crest was seen to be a considerable distance above the cementoenamel junction (Figs 34 and 35, Table 6). This is due to age differences in the animals used; monkey 2 was younger, and altered passive eruption must be considered as a factor. The measurements listed in Table 6 indicate the difference in the position of the alveolar crest in operated and control sections.

A thick layer of osteoid tissue covers the buccal cortical plate, particularly in the crestal region where it appears that many of the osteoblasts have been recently incorporated. The periosteum is extremely cellular, particularly at the crest, and bone apposition in this area is constant with the surgically created surface.

4. Osseous resection (1 week) — monkey 3. The crestal lip of fibrous bone observed in unoperated control areas has been eliminated with the surgical procedure. The resorptive/osteoclastic activity, primarily of marrow space origin, 1 week following osseous resection and replacement of mucoperiosteal flaps, does not appear to have altered the surgically produced morphology.

Molar radicular areas: (1) Unoperated control — monkey 2. The radicular alveolar crest generally tapers to a thin margin in all unoperated control mandibular molar radicular areas consisting of a fibrous type bone overlying lamellar bone. However, in some regions the more apical vestibular surface is scalloped and presents a depression from previous resorptive activity (Fig. 36). In some sections there was resorptive activity occurring at the time of sacrifice (Fig. 36).

(2) Operated control — monkeys 1 and 2. The response of vestibular and molar radicular bone to elevation and replacement of mucoperiosteal flaps varies in thickness in first and second molar areas (Figs 37 to 42). However, in all molar areas the apical vestibular cortical plate presents histologic evidence indicating a surface that was previously developed or eroded, similar to the operated control (Figs 39 and 40).

(3) Osseous resection (6 months) — monkey 2. As in the maxilla, regeneration of vestibular and molar radicular bone appears to be parallel and consistent with the surgically produced morphology (Figs 41 and 42). The crestal margin is generally located at the surgical level of reduction. Histologically, the fibrous crestal bone observed in control quadrants is not apparent here, its place taken by a more lamellated-type bone.

(4) Osseous resection (1 week) — monkey 3. The surgically produced morphology in molar radicular areas is illustrated in Fig. 36. Cellular activity in this segment is similar to that in the premolar areas 1 week following osseous resection and similarly does not appear to have altered the surgically produced morphology at this time interval.
Bifurcation and trifurcation areas (Figs 43 to 46)

In the mandible, the buccal cortical plate at B is seen to rise into the bifurcation with a more gradual ramp in the area of osseous resection (Fig 44). The morphology of the lingual cortical plate is similar in operated and control areas.

In the maxillary control quadrants (Fig 45) the convexity of the buccal cortical plate at B is continuous with a shell of bone extending into the furcation area. Following osseous resection, the buccal cortical plate approaches the furcation area with a more gradual ramp, with elimination of the shell of bone seen in control areas (Fig 46).

Soft tissue

Interdental areas

Unoperated control. A description of the unoperated sites evaluated in this study is necessary to provide a basis for evaluating the interdental soft tissue profile following surgery. Examination of individual buccolingual sections in unoperated segments reveals a saddle area between the buccal and lingual soft tissue peaks (Figs 7 and 47). The distance between the peaks and the depth of the saddle area is greater in molar than in premolar areas. Reconstruction of an interdental area demonstrates the mesial and distal slopes of the saddle or "col" region. The profile is markedly altered as tooth structure is approached (Fig 47).

Operated control. In these segments, the soft tissue contour and the severity and distribution of inflammatory infiltrate is similar to the unoperated control.

Fig 43  Bilirubin area in an operated control mandibular molar. Buccolingual section. (B) Buccal cortical plate; (C) lingual cortical plate. (Original magnification ×4.)

Fig 44  Bilirubin in a mandibular molar 6 months following osseous resection. Buccolingual section. (B) Buccal cortical plate; (D) lingual cortical plate. (Original magnification ×4.)

Fig 45  Trilirubin area in an unoperated control maxillary molar. Buccopalatal section. (B) Buccal cortical plate; (P) palatal root. (Original magnification ×4.)

Fig 46  Trilirubin area in maxillary molar 6 months following osseous resection. Buccopalatal section taken from an area identical to that seen in Fig 45. (B) Buccal cortical plate; (P) palatal root. (Original magnification ×4.)

Fig 47  Wax model reconstruction separated in the interdental region to visualize soft tissue morphology. Unoperated control area; (B) buccal; (P) palatal; (ST) soft tissue; (T) tooth; (BP) buccal peak of soft tissue; (PP) palatal peak of soft tissue. Note depression between buccal and palatal soft tissue peaks. Arrowed outline represents the osseous profile (see Fig 7).

Fig 48  Wax model reconstruction separated in the interdental region to visualize soft tissue morphology. Area of osseous resection; (B) Buccal; (P) palatal; (ST) soft tissue; (T) tooth; (BP) buccal "papilla"; (PP) palatal peak of soft tissue. (See Fig 9.)

Interdental osteoplasty. In all maxillary and mandibular interdental areas the basic (two-peak) col morphology has not been altered by re-shaping the interdental bone. However, the soft tissue peaks are in closer proximity and are connected by a shallower saddle area (Fig 9). This slight morphologic deviation has neither altered the appearance of the overlying epithelium nor the severity and distribution of the inflammatory response.

Osseous resection. In all mandibular and in two maxillary interdental areas the alterations in soft tissue contour following osseous resection are similar to those described with interdental osteoplasty. However, a major deviation in soft tissue profile is observed between the mandibular premolars (Figs 5 and 49) and first and second molars (Figs 9, 48, and 50). In these regions the buccal peak of soft tissue is not present, and the interdental gingiva assumes the appearance of a “papilla” except for an area palatally associated with the enamel space (Fig 48). The epithelium overlying the papilla demonstrates zones of transition from a parakeratinized stratified squamous epithelium to a nonkeratinized epithelium of greater thickness (Figs 49 and 50). The latter zone exhibits irregular epithelial strands of varying thickness extending into the underlying connective tissue. However, the amount of inflammation in this area is relatively sparse.

Palatal to the tip of the papilla, the appearance of the epithelium becomes similar to that overlying the col in other segments, and the severity of the inflammatory response increases over that seen beneath the papilla. While the amount of inflam-
and in this zone is similar to that covering the saddle region in con-
tralateral areas the buccopalatal area
was smaller. Therefore, in two
contralateral areas osseous resection
was planned. The contour of the ging-
ival tissue, the overlying epithelium,
and the distribution of inflammatory
infiltrate


tissue areas


ecause the differences in soft tissue
areas are not immediately striking
when comparing operated and con-
tralateral segments there is a fun-
ctional dissimilarity worthy of men-
tion. As seen in Fig 28 a bulb of
soft tissue of uniform thickness, con-
tralateral to the crestal eminence of
bone observed in maxillary control
area. However, this soft-tissue form is
apparent following osseous sur-
face where the surgical procedure
eliminated this underlying osseous
profile. Furthermore, measurements
taken in an attempt to deter-
mine the relative amounts of soft tis-
ue avulsion control and resected
contralateral areas indicate that the gingi-
val tissue followed the osseous
profiles (Tables 3, 5, and 7).

Table 2  Distance from occlusal plane to buccal and palatal crestal bone

<table>
<thead>
<tr>
<th>Tooth</th>
<th>No. sections</th>
<th>Range mm (x20)</th>
<th>Average mm (x20)</th>
<th>Maintained bone reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd molar</td>
<td>15</td>
<td>(c) 82-103</td>
<td>94.6</td>
<td>1.1 mm</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>(a) 107-128</td>
<td>116.8</td>
<td></td>
</tr>
<tr>
<td>1st molar</td>
<td>18</td>
<td>(c) 83-95</td>
<td>88.0</td>
<td>1.3 mm</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>(c) 111-120</td>
<td>114.7</td>
<td></td>
</tr>
<tr>
<td>2nd premolar</td>
<td>7</td>
<td>(c) 85-111</td>
<td>95.7</td>
<td>0.9 mm</td>
</tr>
<tr>
<td>1st premolar</td>
<td>10</td>
<td>(c) 78-105</td>
<td>85.2</td>
<td>1.1 mm</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>(e) 108-112</td>
<td>108.3</td>
<td></td>
</tr>
<tr>
<td>3rd molar</td>
<td>14</td>
<td>(c) 60-97</td>
<td>77.6</td>
<td>0.6 mm</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>(a) 70-120</td>
<td>88.9</td>
<td></td>
</tr>
</tbody>
</table>

(c) Unoperated control.
(a) Osseous resection.

Table 3  Distance from occlusal plane to gingival margins (maxilla)

<table>
<thead>
<tr>
<th>Tooth</th>
<th>No. sections</th>
<th>Range mm (x20)</th>
<th>Average mm (x20)</th>
<th>Maintained soft tissue reduction*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd molar</td>
<td>15</td>
<td>(c) 35-69</td>
<td>58.7</td>
<td>1.0 mm</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>(a) 70-89</td>
<td>78.6</td>
<td></td>
</tr>
<tr>
<td>1st molar</td>
<td>18</td>
<td>(c) 23-55</td>
<td>40.7</td>
<td>1.4 mm</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>(c) 50-73</td>
<td>68.1</td>
<td></td>
</tr>
<tr>
<td>2nd premolar</td>
<td>7</td>
<td>(c) 32-62</td>
<td>50.2</td>
<td>1.1 mm</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>(a) 60-77</td>
<td>72.3</td>
<td></td>
</tr>
<tr>
<td>1st premolar</td>
<td>10</td>
<td>(c) 32-65</td>
<td>51.2</td>
<td>0.9 mm</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>(a) 62-72</td>
<td>68.2</td>
<td></td>
</tr>
<tr>
<td>3rd molar</td>
<td>14</td>
<td>(c) 25-34</td>
<td>28.4</td>
<td>0.2 mm</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>(a) 31-40</td>
<td>32.3</td>
<td></td>
</tr>
</tbody>
</table>

* Compare with maintained bone reduction in Table 2.
(c) Unoperated control.
(a) Osseous resection.

### Table 4  Distance from occlusal plane to buccal and palatal crest bone (maxilla)

<table>
<thead>
<tr>
<th>Tooth</th>
<th>No. sections</th>
<th>Range mm (×20)</th>
<th>Average mm (×20)</th>
<th>Actual difference in alveolar crest height</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd molar</td>
<td>25</td>
<td>(c) 67–104</td>
<td>84.0</td>
<td>0.11 mm</td>
</tr>
<tr>
<td>1st molar</td>
<td>34</td>
<td>(c) 65–100</td>
<td>85.4</td>
<td>0.71 mm</td>
</tr>
<tr>
<td>*</td>
<td>15</td>
<td>(c) 70–100</td>
<td>84.4</td>
<td>0.35 mm</td>
</tr>
<tr>
<td>1st premolar</td>
<td>5</td>
<td>(c) 101–109</td>
<td>105.0</td>
<td>0.08 mm</td>
</tr>
<tr>
<td>2nd premolar</td>
<td>5</td>
<td>(c) 100–111</td>
<td>106.5</td>
<td></td>
</tr>
</tbody>
</table>

(c) Unoperated control.
(o) Operated control.
* To avoid areas mesially and distally where radicular bone may have been inadvertently removed with interdental osteoplastics, 15 sections midway mesiodistally were measured separately.
* Loss of dentinal cusps tips with tissue preparation prevented evaluation of this area.

### Table 5  Distance from occlusal plane to gingival margins

<table>
<thead>
<tr>
<th>Tooth</th>
<th>No. sections</th>
<th>Range mm (×20)</th>
<th>Average mm (×20)</th>
<th>Actual difference in soft tissue height</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd molar</td>
<td>34</td>
<td>(c) 36–55</td>
<td>40.6</td>
<td>0.01 mm</td>
</tr>
<tr>
<td>1st molar</td>
<td>34</td>
<td>(c) 31–58</td>
<td>44.3</td>
<td>0.23 mm</td>
</tr>
<tr>
<td>1st premolar</td>
<td>5</td>
<td>(c) 4–46</td>
<td>43.8</td>
<td>0.22 mm</td>
</tr>
<tr>
<td>2nd premolar</td>
<td>5</td>
<td>(c) 39–45</td>
<td>39.5</td>
<td></td>
</tr>
</tbody>
</table>

(c) Unoperated control.
(o) Operated control.
* Compare with actual difference in alveolar crest height, Table 4.
* Greater amount of soft tissue over unoperated control first premolar radicular area than over operated control area.
* Loss of dentinal cusp tips with tissue preparation prevented evaluation of this area.

### Table 6  Distance from occlusal plane to buccal and lingual crest bone

<table>
<thead>
<tr>
<th>Type</th>
<th>No. sections</th>
<th>Range mm (×20)</th>
<th>Average mm (×20)</th>
<th>Maintained reduction of alveolar crest height</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 molar</td>
<td>12</td>
<td>(c) 65–105</td>
<td>83.5</td>
<td>0.63 mm</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>(a) 68–128</td>
<td>96.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>(c) 64–93</td>
<td>72.7</td>
<td>0.14 mm</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>(a) 63–88</td>
<td>70.0</td>
<td></td>
</tr>
<tr>
<td>#2 molar</td>
<td>23</td>
<td>(c) 70–92</td>
<td>83.4</td>
<td>1.70 mm</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>(a) 88–141</td>
<td>116.4</td>
<td></td>
</tr>
<tr>
<td>#1 premolar</td>
<td>20</td>
<td>(c) 73–128</td>
<td>100.0</td>
<td>0.60 mm</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>(a) 80–138</td>
<td>112.0</td>
<td></td>
</tr>
</tbody>
</table>

- Operated control.
- Distal control.
- As stated in materials and methods, the surgical reduction was terminated approximately midway mesiodistally over the last molar. Therefore, 12 sections were measured in the mesial radicular area and 11 sections in the distal radicular area.

### Table 7  Distance from occlusal plane to gingival margins (mandible)

<table>
<thead>
<tr>
<th>Type</th>
<th>No. sections</th>
<th>Range mm (×20)</th>
<th>Average mm (×20)</th>
<th>Actual difference in soft tissue height*</th>
</tr>
</thead>
<tbody>
<tr>
<td>#3 molar</td>
<td>23</td>
<td>(c) 36–54</td>
<td>41.3</td>
<td>0.16 mm</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>(a) 40–51</td>
<td>44.5</td>
<td></td>
</tr>
<tr>
<td>#4 molar</td>
<td>23</td>
<td>(c) 31–44</td>
<td>35.2</td>
<td>0.37 mm</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>(a) 34–55</td>
<td>42.5</td>
<td></td>
</tr>
<tr>
<td>#1 premolar</td>
<td>20</td>
<td>(c) 33–56</td>
<td>45.5</td>
<td>0.10 mm</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>(a) 34–59</td>
<td>43.9</td>
<td></td>
</tr>
</tbody>
</table>

- Operated control.
- Distal control.
- *Sections with maintained reduction of alveolar crest height in Table 6.

Discussion

The results of this investigation have demonstrated that the alveolar process is capable of maintaining surgically produced contour and that the soft tissue form is a reflection of this contour. Furthermore, our methods of evaluation indicate that there has been regeneration of attachment apparatus coronal to the surgical level of reduction. These findings are contrary to the view that surgical reshaping of bone leads to a further and permanent reduction in bone height.

Our findings are also contrary to the view that reshaping procedures do not influence the final osseous contour. The observation that the greatest amount of crestal regeneration and reattachment occurred in maxillary premolar vestibular areas and on palatal surfaces of all teeth is consistent with the observations of others that the postoperative level of the alveolar crest is determined to a large extent by the amount of supporting bone between cortical plate and alveolar bone.

The apparent contradictions resulting from these results and those of another investigation were similar to that reported by Lotene and Glickman in that an attempt was made to evaluate the response of the alveolar process to surgical reshaping procedures. The differences, however, outnumber the similarities. The most obvious differences are the animals used, the experimental period, and the surgical procedures per se.

Our choice of the monkey instead of the dog was based on observations that the denition of the monkey more closely resembles that of humans. Furthermore, our study was primarily concerned with maintenance of surgically produced morphology and alveolar crest height. Therefore, we chose an experimental period of 6 months rather than 28 days.

The differences in surgical procedures employed must also be a primary consideration. For example, our contouring procedures did not call for reducing the thickness of the existing buccal radicular bone at its original height. Instead, we reduced the height of the alveolar process initially and then created an acceptable osseous contour. The inherent danger in reducing the thickness of buccal bone in experimental animal's is that the buccal radicular bone is initially the thickness desired. However, with periodontal disease the crestal margin generally exhibits an undesirable thickness. Therefore, a reduction of marginal width in an animal free of periodontal disease produces an unusually thin margin of bone that is very susceptible to postoperative resorption. This appears to be an important consideration because one would expect maintenance of surgically produced morphology and regeneration of alveolar crest height to be more difficult where large amounts of bone had been removed, as was done in our study. This was not the case.

Another important consideration is the actual manipulation of tissues during the surgical procedure. This gives rise to variations in different studies which are difficult to evaluate.

A further observation that merits comment concerns the appearance of mandibular vestibular or buccal bone. It was previously noted that the vestibular cortical plate (Figs 33 to 36) occasionally presented a scalloped or eroded surface indicative of previous resorptive activity. It should be stressed that this pattern was observed in both operated and unoperated areas. It is also important to note that the scalloping was not localized to any particular area, premolar or molar, nor was it more apparent in areas of surgical intervention than in unoperated areas. Furthermore, this pattern of an eroded cortical plate was never observed in maxillary quadrants. This seems to indicate that the scalloped surface is not the result of the surgical procedures. The factors responsible for the resorptive pattern in the mandible are subject to conjecture. Whether it is due to functional forces, the lingual inclination of mandibular teeth, or remodeling associated with mandibular growth cannot be determined by the scope of this study. Regardless of the responsible mechanism, one must be cautious when interpreting material of this nature and not conclude that an eroded or thinned cortical plate is the result of a surgical procedure.

The interproximal space apical to the contact area is further reduced in some areas by the divergence and proximity of the roots.

The morphology of the monkey dentition makes it virtually impossible to produce an interdental area completely free of tooth structure unless tooth structure is removed and reshaped. This indicates that a more desirable soft tissue contour might be expected in a dentition exhibiting greater interproximal space and where optimum oral hygiene is possible. While our material demonstrates a definite relationship between tooth form and soft tissue profile, it provides no information concerning the effects of specific tooth forms on soft tissue contour.

In radicular areas it is significant that our measurements indicate that similar amounts of soft tissue overlie operated and control areas. This supports the concept that the form which the gingiva takes is conditioned by the architecture of the underlying bone. However, to draw conclusions from our material concerning the specific influence of radicular bone on marginal soft tissue morphology is difficult because of the manner in which the soft tissue flaps were replaced and sutured.

However, it was noted that the soft tissue overlying the marginal lip of bone in unoperated control areas presented a bulge of uniform thickness (Fig 28). This soft tissue bulge was noticeably absent following osseous resection and elimination of the bony lip, indicating a relationship between radicular bone contour and soft tissue profile.

Summary and conclusions

This investigation was undertaken in an attempt to evaluate the morphologic and histologic response of bone and soft tissue to osseous surgery. The following surgical procedures were performed on young adult Macaca rhesus monkeys: (1) flap elevation, (2) interdental osteoplasty, and (3) osseous resection.

Following sacrifice at intervals of 1 week and 6 months, the tissues were processed for histologic study and evaluated macroscopically and microscopically. Macroscopic evaluations, accomplished at a magnification of x20, consisted of three-dimensional reconstruction of interdental osseous and gingival morphology, wax model reconstructions of representative interdental and radicular areas, and measurements. The following conclusions were drawn:

Radicular areas

1. The postoperative position of the alveolar crest is dependent on the amount of supporting bone between cortical plate and alveolar bone. The greatest amount of alveolar crest regeneration and reattachment following osseous resection occurred in maxillary premolar vestibular areas and in all anterior areas. In these regions new bone was consistently observed coronal to the previous surgical level of reduction.

2. The surgically produced osseous morphology has been maintained in every radicular area regardless of the position of the alveolar crest. Bone opposition at the 6-month interval is parallel and co-

sistent with the contoured alveolar process.

3. Elevation and replacement of mucoperiosteal flaps does not appear to significantly alter the 6-month postoperative level of the alveolar crest. However, the radicular bone does appear thinner in these areas.

4. Similar amounts of soft tissue, exhibiting morphologic differences, overlie resected and control radicular areas, indicating a relationship between radicular bone contour and soft tissue profile.

Interdental areas

1. The surgically produced osseous morphology is maintained in interdental areas. However, osseous resection, in conjunction with resurfacing procedures, appears to be more effective in maintaining surgical contour than interdental osteoplasty alone.

2. Interdental osteoplasty has not altered the col morphology of the interdental soft tissue. However, the buccal and lingual peaks of the col are closer together and the col is shallower.

3. Following osseous resection, the interdental soft tissues reflect the underlying osseous contour when sufficient interproximal space exists between the contact area and the level of the alveolar process. As this space decreases, the influence of tooth form on soft tissue contour increases.

References
