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A study of the histologic reaction of submerged root segments

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Vital and endodontically treated root segments of three monkeys were submerged and studied histologically after varying experimental periods. Vital root segments in all animals demonstrated less inflammatory reaction, had a better submersion success rate, and displayed the blending of pulpal tissues with the overlying connective tissue in all cases which were successfully submerged. Segments filled with gutta-percha were associated with a light foreign-body reaction when successfully submerged but were apparently harder to submerge successfully. No inflammatory infiltrates were associated with the vital successfully submerged segments.

The histologic reaction of intentionally submerged vital and endodontically treated root segments has not been reported. The submersion of endodontically treated root segments in a clinical study by Howell and his co-workers[1] is considered to be the factor responsible for maintaining the alveolar crest height. Healing of hard and soft tissues in periodontal defects was demonstrated by Björn in animals[2] and in human beings.[3] Boulger[4] implanted in the muscle tissue of white rats the apices of human normal vital teeth, successfully endodontically treated teeth, infected pulpless teeth, and unsuccessfully endodontically treated teeth. No inflammatory infiltrate was found around the normal vital teeth or

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the successfully endodontically treated teeth. The infected pulpless teeth produced large abscesses, and the unsuccessfully endodontically treated segments produced areas of chronic inflammation at the coronal and apical ends of the segments.

Claflin[5] and others[6-9] fractured and partially extracted teeth in animals so as to leave fragments of root in the alveolus. No attempt was made to obtain or maintain primary closure over these fractured roots. Epithelial proliferation and exfoliation of the more superficial fragments were consistent findings. These investigators also found that some root segments with vital pulps were maintained in the aveolus without an inflammatory reaction. Kronfeld[10] and others[11-13] removed asymptomatic retained root tips in human beings and studied them histologically. They concluded that such roots were not associated with any inflammatory infiltrates.

Sonnabend[14] removed 100 asymptomatic radiopaque areas from human jaws en bloc and these were studied histologically. Of the eighty-eight root tips, 42 per cent were encased in heathy bone, 42 per cent were associated with very little granulation tissue, 10 per cent were associated with an abundance of granulation tissue, and 6 per cent were associated with cysts.

Poe[15, 16] found that vital submerged root segments in dogs demonstrated histologically a blending of the pulpal and overlying connective tissues, apposition of a cementum-like tissue to the amputation site, and calcifications in the coronal extent of the root canals. There was an absence of any inflammatory exudate associated with the coronal or apical ends of all segments.

The objective of this study was to observe histologically the response of submerged root segments, both vital and endodontically treated.

MATERIALS AND METHODS

Three monkeys *(Cebus apellae)* were dewormed, tested for tuberculosis, and confined in an animal-care facility which maintained a constant relative humidity, temperature, and cycling of lights. The animals were fed and watered twice daily. The diet consisted of a softened commercial monkey chow twice daily and fresh fruit once a week.

Each monkey was radiographed and weighed upon arrival and before perfusion. All three monkeys either maintained their weight or gained slightly during the period of experimentation. Phencyclidine hydrochloride, a primate tranquilizer, was used to anesthetize the monkeys (subcutaneous injections of 2 mg. per kilogram of body weight).

One week prior to submersion of the anterior teeth of each animal, the two diagonally opposed anterior quadrants were treated endodontically. Each of the teeth was isolated, the pulps were removed, and the canals were cleansed and shaped. A solution of 95 per cent ethanol was the only irrigating solution used during instrumentation. Gutta-percha was laterally condensed in these canals with the use of Kloroperka cement. The endodontic access was sealed with Cavit. The teeth were radiographed after endodontic treatment.

Seven days after completion of this endodontic therapy on the two diagonally opposed anterior quadrants (experimental group A), all teeth were

submerged. Submersion of all anterior teeth produced experimental group B, which consisted of teeth with vital pulps covered by alveolar mucosa. The first premolars were used as controls.

Submersion of the radicular segments of experimental groups A and B was accomplished in the following manner: The anesthetized animal was wrapped tightly in sterile towels. Labial and lingual mucoperiosteal envelope flaps were reflected in the maxillary and mandibular arches; vertical relaxing incisions were made between the first and second premolars. The crowns of all anterior teeth were then notched at the height of the labial alveolar bone with a No. 2 low-speed bur. The coronal segments of the teeth were traumatically fractured with a surgical mallet and bibevel chisel at the level of the labial notch. The sharp intraseptal bony projections and sharp edges of root structure were removed by low-speed alveoloplasty diamond burs. Relaxing incisions through the periosteum at the depth of the flap were made from premolar to premolar. Blunt dissection of the lamina propria facilitated coronal repositioning and approximation of the labial and lingual flaps of each arch. A creviculectomy was intentionally not performed. An effort was made to provide secure closure of the labial and lingual submucosal layers with 4-0 black silk sutures. The surgical field was maintained by central aspiration and cotton gauze. An assistant helped with each endodontic and surgical procedure. Each animal was observed until recovery from the general anesthesia.

Experimental observation periods began at surgical submersion and were carried out at 2 weeks, 5 weeks, and 25 weeks after surgical submersion. Some difficulty was encountered in the 2- and 5-week monkeys because the monkey biscuits denuded the alveolar mucosa. The problem was solved by softening the monkey chow in warm water for 5 minutes prior to feeding.

Block jaw sections of the three monkeys were perfused, decalcified, and prepared for histologic observation in serial sections of 7 to 10 microns. Alternate slides were stained with hematoxylin and eosin and Masson's trichrome for connective tissue. Selected sections from the 25-week animal were prepared with Bodian's silver stain for nerve fibers.

RESULTS

The results are presented in Tables I-VI. Classification of the microscopic findings of the examination of the submerged segments and the surrounding periodontium was made according to the following criteria:

0 = No reaction; no evidence of inflammation.
1+ = Mild reaction; characterized by a diffuse scattering of inflammatory cells in the prescribed area.
2+ = Moderate reaction; a mixed inflammatory infiltrate, not well localized, but associated with some cemental and dentinal resorption.
3+ = Severe reaction; characterized by a heavy inflammatory infiltrate and accompanied by resorption of bone and dentin.
4+ = Abscess formation; an area of suppuration having a central area of disintegrating polymorphonuclear leukocytes surrounded by viable

Table I. Results in 2-week monkey

Tooth No.	*Segment type*	*Submerged* +	*Submerged* -	*Evidence of inflammatory infiltrate* *Pulpal*	*Periapical*	*Pericoronal*
6	Gutta-percha		-	No pulp	0	2+
7	Gutta-percha		-	No pulp	0	2+
8	Gutta-percha	+		No pulp	1+	0
9	Vital	+		0	0	0
10	Vital	+		0	0	0
11	Vital	+		0	0	0
22	Gutta-percha		-	No pulp	1+	1+
23	Gutta-percha		-	No pulp	0	2+
24	Gutta-percha		-	No pulp	0	1+
25	Vital		-	2+	0	1+
26	Vital		-	2+	0	1+
27	Vital		-	3+	0	1+

Table II. Results in 5-week monkey

Tooth No.	*Segment type*	*Submerged* +	*Submerged* -	*Evidence of inflammatory infiltrate* *Pulpal*	*Periapical*	*Pericoronal*
6	Vital	+		0	0	0
7	Vital	+		0	0	0
8	Vital	+		0	0	0
9	Gutta-percha		-	No pulp	1+	1+
10	Gutta-percha		-	No pulp	0	2+
11	Gutta-percha		-	No pulp	1+	2+
22	Vital		-	4+	2+	3+
23	Vital		-	4+	3+	3+
24	Vital		-	4+	4+	3+
25	Gutta-percha		-	No pulp	0	3+
26	Gutta-percha		-	No pulp	0	3+
27	Gutta-percha		-	No pulp	2+	2+

leukocytes and a few lymphocytes. Fibroblastic cells formed a capsule around the area of suppuration.

"Segment type" referred to the root canal contents of the segments at the time of submersion:

+Submersion indicated that the coronal end of the segment and the oral fluids were separated entirely by alveolar mucosa.

–Submersion indicated that the coronal end of the segment had gained or maintained a patency with the oral fluids.

The location of the evidence of inflammatory infiltrate was divided into three areas: pulpal, periapical, and pericoronal. Pericoronal was defined as the area adjacent and lateral to the coronal extent of the segment.

Resorption of cementum and dentin was classified as pericoronal or periapical. These areas were used for the resorption evaluation columns.

0 = No resorption.
1+ = Resorption of cementum only.
2+ = Resorption of cementum and up to 1 mm. of dentin.
3+ = Resorption of cementum and from 1 to 3 mm. of dentin.
4+ = Rampant resorption of the root segment en toto.

Resorption		*Calcifications*		*Attachment of connective tissue to dentin amputation site*
Pericoronal	*Periapical*	*Coronal bridging*	*Pulpal*	
2+	0	0	No pulp	0
2+	0	0	No pulp	0
1+	0	0	No pulp	0
2+	0	0	0	+
2+	0	0	0	0
2+	0	0	0	+
2+	0	0	No pulp	0
1+	0	0	No pulp	0
1+	0	0	No pulp	0
1+	0	0	0	0
1+	0	0	0	0
1+	0	0	0	0

Resorption		*Calcifications*		*Attachment of connective tissue to dentin amputation site*
Pericoronal	*Periapical*	*Coronal bridging*	*Pulpal*	
4+	0	+	+	+
3+	0	+	0	+
2+	0	+	0	+
1+	0	0	No pulp	0
1+	0	0	No pulp	0
2+	0	0	No pulp	0
2+	1+	0	0	0
2+	0	0	0	0
3+	+	0	0	0
2+	0	0	No pulp	0
2+	0	0	No pulp	0
2+	1+	0	No pulp	0

Califications were denoted as coronal bridging which appeared as cellular cementum or cementum-like tissues bridging across the coronal extent of the pulp chamber. Pulpal calcifications referred to dystrophic calcifications appearing in the pulpal tissues.

0 = No evidence of calcifications in either pulpal or coronal bridging.

+ = Positive evidence of calcifications.

Attachment of connective tissue to the dentin amputation site was recorded as:

0 = No evidence of attachment.

+ = Positive evidence of attachment.

Histologic observations on 2-week monkey

Four of twelve segments were successfully submerged in the 2-week monkey (Table I and Figs. 1 and 2). No pericoronal pulpal or periapical inflammation was seen in any of these segments, with one exception. This exception was found in the periapical tissues of the maxillary central incisor, which was overfilled 2 mm. with gutta-percha.

Resorptive changes were observed in the pericoronal tissues of these four

Table III. Results in 25-week monkey

Tooth No.	*Segment type*	*Submerged* +	*Submerged* -	*Evidence of inflammatory infiltrate* *Pulpal*	*Periapical*	*Pericorona*
6	Gutta-percha		-	No pulp	2+	3+
7	Vital	+		0	0	0
8	Gutta-percha		-	No pulp	2+	2+
9	Vital		-	2+	1+	3+
10	Vital	+		0	0	0
11	Vital	+		0	0	1+
22	Gutta-percha		-	No pulp	1+	3+
23	Gutta-percha	+		No pulp	0	1+
24	Gutta-percha	+		No pulp	0	1+
25	Vital	+		0	0	0
26	Vital	+		0	0	0
27	Vital	+		0	0	0

Table IV. Ratio of successful submersion

Type of segments	*2-Week*	*5-Week*	*25-Week*	*Totals of segment types*
Vital	3 of 6	3 of 6	6 of 7	12 of 19 = 63.2%
Gutta-percha	1 of 6	0 of 6	2 of 5	3 of 17 = 17.6%
Totals of each time period	4 of 12 or 33.3%	3 of 12 or 25%	8 of 12 or 66.7%	

successful submersions, but to no greater extent than in the unsuccessfully submerged segments. No calcifications, either pulpal or coronal bridging, were observed in the 2-week animal.

Pulpal tissues in the unsuccessfully submerged segments showed necrotic changes characteristic of the pulpal abscesses. These degenerative changes extended apically into the pulpal tissues from 3 to 7 mm. (Fig. 3). The segments which had larger root canals demonstrated a greater depth of necrotic tissue.

The four segments which were successfully submerged did not demonstrate a complete connective tissue attachment to the dentin amputation site. Two of the four segments exhibited a visible layer of new cementum, whereas the other two specimens exhibited questionable areas of fibrous attachment.

Coronal bridging was observed to such a small extent that it was not considered to be a positive finding.

Histologic observations on the 5-week monkey

Three of twelve segments were successfully submerged in the maxilla of the 5-week monkey (Table II). None of these three segments displayed any evidence of an inflammatory infiltrate pulpally, periapically, or pericoronally. Calcifications were seen in the maxillary right canine segments as dystrophic calcifications of the pulpal tissues and as secondary dentin bridging across the amputation site. Coronal bridging was found in the maxillary right lateral and central incisiors.

Attachment of connective tissue to the dentin of the amputation site was seen in all three successfully submerged specimens, although the canine and

Resorption		*Calcifications*		*Attachment of connective tissue to dentine amputation site*
Pericoronal	*Periapical*	*Coronal bridging*	*Pulpal*	
1+	1+	0	No pulp	0
1+	0	+	0	+
2+	0	0	No pulp	0
3+	0	0	0	0
1+	0	+	0	+
2+	0	+	0	+
3+	1+	0	No pulp	0
1+	0	0	No pulp	+
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1+	0	+	0	+
1+	0	+	0	+
1+	0	+	0	+

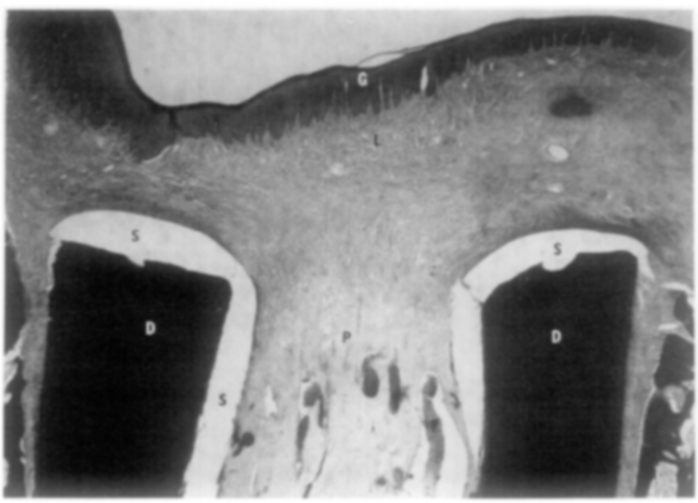

Fig. 1. A vital canine in the 2-week monkey, successfully submerged. Note the blending of the lamina propria *(L)* and the pulp *(P)*. *D*, Dentin. *G*, Gingival epithelium. *S*, Shrinkage. (Hematoxylin and eosin stain. Magnification, ×10.)

lateral incisors had been fractured into several pieces during the traumatic amputation (Fig. 4). Resorption of pericoronal dentin was more pronounced in the segments which exhibited fragments of dentin close to the occlusal end of the submerged segment. Pericoronal resorption was a common finding in the operated segments.

The three successfully submerged segments were the only specimens to show connective tissue attachment to the dentin amputation site. An interphase of cellular cementum was found between the dentin and connective tissue in all sections.

The pulps in the segments of the mandibular left quadrant demonstrated frank necrosis to the apical foramina. These unsuccessfully submerged segments also had periapical inflammatory changes which were characterized by

Fig. 2. The apical and periapical areas of the canine in Fig. 1. Note the absence of any inflammatory infiltrate. *B,* Bone. *D,* Dentin. *P,* Pulp. (Hematoxylin and eosin stain. Magnification, ×10.)

polymorphonuclear leukocytes walled off by connective tissue elements. The canine segments demonstrated the most severe periapical inflammatory response.

Histologic observations on the 25-week monkey

Eight segments were successfully submerged in the 25-week-monkey (Table III and Figs. 5-7). No pericoronal or periapical inflammatory reactions were seen in these eight segments, with three exceptions. Mild periapical inflammatory responses were seen in three segments which had overextended gutta-percha points. Six of the eight successfully submerged segments had vital pulpal tissues which exhibited no inflammatory cells.

Seven segments (No. 6, 7, 8, 9, 11, 22, and 25) had single or multiple dentinal fractures in the coronal half of the segment. Three of these seven fractured specimens were successfully submerged and demonstrated less significantly inflammation and resorption than did the fractured segments which were open to the oral fluids. The three successfully submerged fractured segments had a connective tissue attachment surrounding the fragments.

One vital root segment was not successfully submerged. The pulpal tissues exhibited a predominantly polymorphonuclear leukocytic infiltrate with some lymphocytes. The degenerative changes were evident in the coronal half of the pulpal tissues, leaving the apical half hyperemic.

Fig. 3. An endodontically treated mandibular incisor, in the 2-week monkey, which was unsuccessfully submerged. Arrows delineate the area of acute inflammatory infiltrate and abscess. (Hematoxylin and eosin stain. Magnification, ×25.)

Periapical resorption was found in two specimens, both of which were open to the oral fluids, were fractured, and had root canal fillings.

A 100 per cent correlation existed between successfully submerged vital segments and coronal bridging by secondary dentin or cellular cementum. The amount of coronal bridging varied from specimen to specimen. One of the canine segments had the new growth of dentin continuing apically in the canal to the junction of the coronal and apical halves. The majority of the vital segments demonstrated coronal bridging as a circumferential closure of the coronal rim of the pulp canal. There were two examples of gutta-percha–filled segments which were successfully submerged. These two specimens failed to demonstrate the coronal bridging, although they did have a cellular cementum interphase between the connective tissue and the dentin amputation site.

Comparison of findings

A 100 per cent correlation was also found between the successfully submerged segments and the attachment of connective tissue to the dentin amputation site. This correlation existed for both vital and endodontically treated segments. Attachment of the connective tissue to the dentin was an all-or-none phenomenon, in that varying degrees of attachment were not seen in the 5-week and 25-week monkeys.

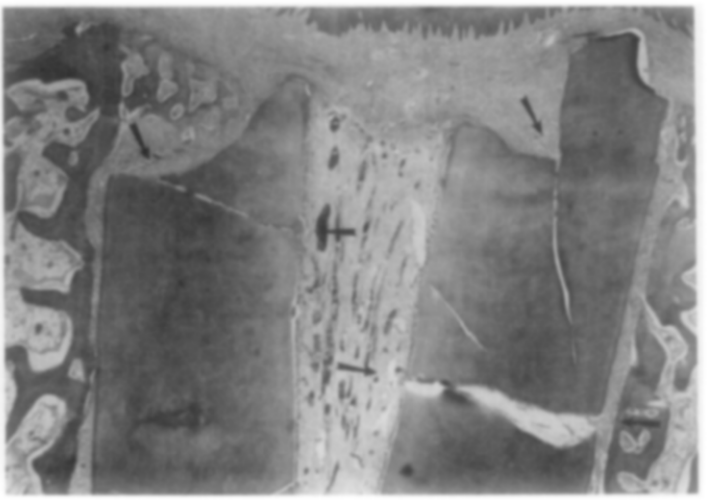

Fig. 4. A successfully submerged canine in the 5-week monkey. Note the multiple fractures with no evidence of any inflammatory infiltrate *(arrows.)* (Hematoxylin and eosin. Magnification, ×25.)

Table V. Coronal calcifications

Type of segments	*2-Week*	*5-Week*	*25-Week*	*Totals of segment types*
Successfully submerged				
Vital	0 of 3	3 of 3	6 of 6	9 of 12 = 75%
Gutta-percha	0 of 1	0 of 0	2 of 2	2 of 3 = 66.7%
Unsuccessfully submerged				
Vital	0 of 3	0 of 3	0 of 1	0 of 7 = 00%
Gutta-percha	0 of 5	0 of 6	0 of 3	0 of 14 = 00%
Gutta-percha	0 of 12 or 00%	3 of 12 or 25%	8 of 12 or 66.7%	

Table VI. Connective tissue attachment to the dentin amputation site

Type of segments	*2-Week*	*5-Week*	*25-Week*	*Totals of segment types*
Successfully submerged				
Vital	2 of 4	3 of 3	6 of 6	11 of 13 = 85%
Gutta-percha	0 of 1	0 of 0	2 of 2	2 of 3 = 66.7%
Unsuccessfully submerged				
Vital	0 of 2	0 of 3	0 of 1	0 of 6 = 00%
Gutta-percha	0 of 5	0 of 6	0 of 3	0 of 14 = 00%
	2 of 12 or 16.7%	3 of 12 or 25%	8 of 12 or 66.7%	

Bodian's silver stain for nerve fibers demonstrated pulpal nerve fibers closely following the blood vessels into the connective tissue of the alveolar mucosa. Nerve bundles were not observed at the pulp–connective tissue interphase. Single nerve fibers were observed in the last millimeter of pulp tissue and into the pulp–connective tissue interphase. The branching of pulpal and alveolar mucosa nerve fibers was observed. The singular branching nerve fibers

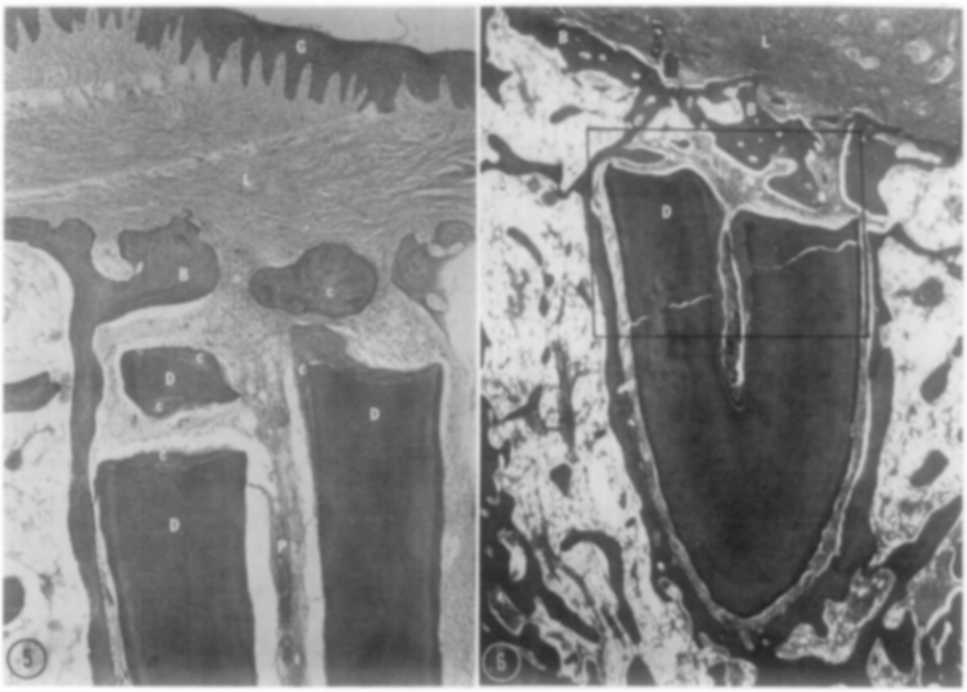

Fig. 5. A vital central incisor, successfully submerged, in the mandible of the 25-week monkey. Note the absence of any inflammatory infiltrate. *B*, Bone. *c*, Cementum-like tissue. *D*, Dentin. *G*, Gingival epithelium. *L*, Lamina propria. (Hematoxylin and eosin stain. Magnification, ×25.)

Fig. 6. A successfully submerged vital lateral incisor in the 25-week monkey. Note the overlying bone *(B)* fractures and lamina propria *(L)*. (Hematoxylin and eosin stain. Magnification, ×10.)

were found in greater quantity in specimens which were not excessively constricted by coronal bridging.

Periodontal ligaments of operated segments were found to have less dense collagen content and to be smaller in width than those of control teeth in the same sections. A tendency for the periodontal ligaments of the operated segments to tear more readily during sectioning was also observed. A comparison of the amputated and nonamputated teeth in the three monkeys was made, and the following phenomena became more evident as the experimental periods increased:

1. The apical and oblique fibers became disoriented.
2. The periodontal ligament width decreased.
3. The collagen content of the bundles of the periodontal ligament became less dense.
4. The periodontal ligament became more avascular.

Four of the fifteen successfully submerged segments in this study had single or multiple fragments of dentin which were tolerated without an inflammatory response. Conversely, the fragments of the segments open to the oral fluids had undergone more extensive resorptive and inflammatory changes.

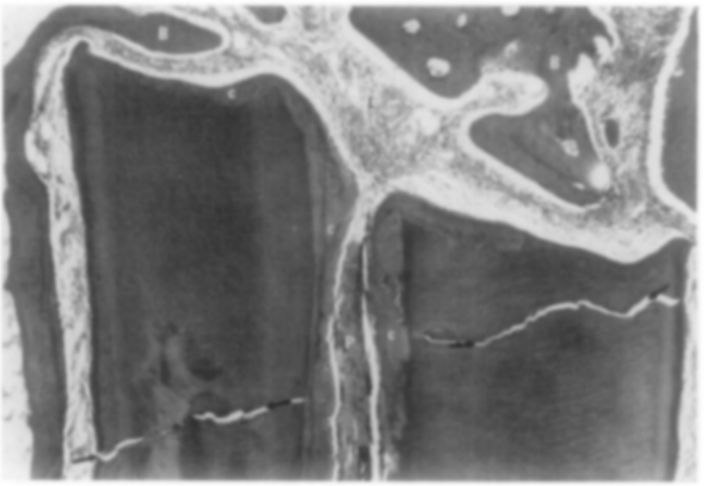

Fig. 7. An enlargement of the area demarcated in Fig. 6. Coronal calcifications are seen as cementum-like tissue *(c)*. *B*, Bone. *P*, Pulp. Fractures *(arrows)*. *L*, Lamina propria. (Hematoxylin and eosin stain. Magnification, ×25.)

Neither ankylosis nor internal resorption was observed in any of the specimens of the control teeth or operated segments of the 2-week, 5-week, or 25-week monkeys.

The gutta-percha–filled segments in all three monkeys showed slightly more inflammatory reaction around the coronal end of the canal than did the vital segments. In segments which were not successfully submerged, those filled with the gutta-percha demonstrated epithelial proliferation toward the coronal extent of the lateral borders (Figs. 8 and 9). The epithelial proliferation was accompanied by a mixture of polymorphonuclear leukocytes and lymphocytes.

DISCUSSION

Maintaining the exclusion of oral fluids from the amputated root segments was the most important single factor affecting the successful submersion of root segments. The monkey biscuits fed to the 2-week and 5-week animals were not softened before being given to the animals; whereas the 25-week animal was fed a soft diet after surgical submersion of the root segments. The monkeys were often observed to gnaw on the stainless steel cages when they were excited.

Vital root segments were submerged much more successfully than segments filled with gutta-percha (Table IV). The factors involved in the poor submersion success rate of endodontically treated segments might be explained by the loss of the collateral circulation afforded by the pulpal tissues. The presence of the gutta-percha acting as a foreign body may have contributed to the chronic inflammatory response found over the segments and to epithelial downgrowth, as previously demonstrated by Glickman and associates,[7] Smith,[8] and Pietrokovski.[9] It is interesting to note that Poe[16] had 100 per cent success in the submersion of eighteen vital segments in dogs.

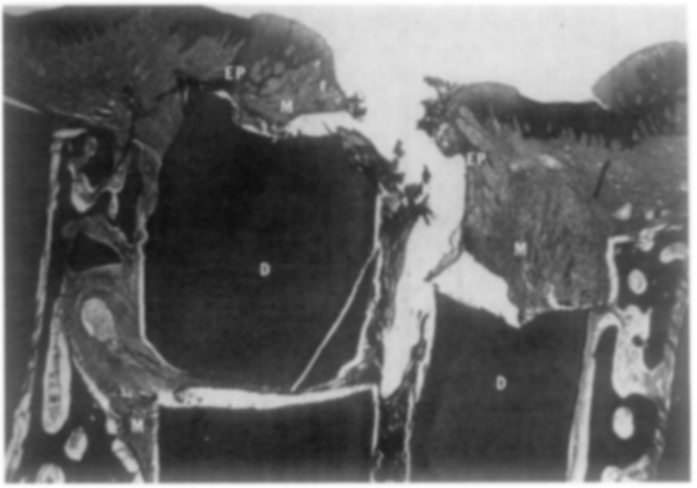

Fig. 8. An unsuccessfully submerged endodontically treated canine in the 25-week monkey. Note the epithelial proliferation *(EP)* and mixed inflammatory infiltrate *(M)*. *D,* Dentin. (Hematoxylin and eosin stain. Magnification, ×10.)

Howell and associates[1] and Poe[16] have routinely removed crevicular epithelium from the margins of the facial and lingual flaps prior to primary closure. A creviculectomy was not performed in the present study, which had an overall submersion success rate of 41.7 per cent. The presence of crevicular epithelium located adjacent to the freshly fractured and traumatized root segments may have also contributed to the poor submersion success rate. Howell stated: "We have found that unless a creviculectomy is performed, the epithelium will serve as an entrance to the root during healing. For this reason, all epithelium has to be removed before the flaps are sutured together over the root."

Pericoronal inflammatory responses were found only in segments which were open to oral fluids. The presence of oral fluids within fragments of dentin was associated with an increased inflammatory response. The pericoronal inflammatory response to unsuccessfully submerged segments has been a common finding.[5-8]

Seven segments from the three monkeys which were filled with gutta-percha and open to the oral fluids exhibited a periapical inflammatory reaction. A polymorphonuclear leukocyte infiltrate was seen in these cases, which indicated the presence of an irritant other than the filling and sealing materials. Oral fluids leaking through the filling materials could explain this inflammatory reaction that was seen at the periapex. It should be noted that only segments which were open to the oral fluids demonstrated any periapical inflammation, other than the overfilled segments.

The 100 per cent correlation between successfully submerged segments and the absence of pulpal or periapical inflammation in this study is in agreement with the work of Poe and associates.[15] Sonnabend[14] and others[11-13, 17] found that the odontoblasts were absent and the normal pulpal tissues were replaced

Fig. 9. An endodontically treated canine in the 25-week monkey. This unsuccessfully submerged specimen demonstrates epithelial proliferation, *EP*, and a mixed inflammatory infiltrate, *M*. (Hematoxylin and eosin stain. Magnification, ×10.)

with connective tissue. These same investigators also found very small root canals associated with the connective tissue. It is important to note that these studies were for longer periods than those of Poe and associates[15] and the present study.

Poe and associates[15] found evidence of coronal calcifications in the 2-month, 3-month, and 4-month dogs. The present study found coronal bridging in the 5-week and 25-week monkeys, but not in the 2-week monkey (Table V). Poe and associates used a high-speed bur with water spray to remove the crown of the dog's premolars, thus producing dentin chips which may have stimulated calcifications. The possibility of the presence of dentin chips in the present study was remote, since the crowns were severed with a mallet and chisel.

Bevelander,[6] and others[9-13, 17] have reported the growth of cementum on freshly exposed dentinal surfaces when the oral flora was eliminated. The present study also confirmed this finding in the 5-week and 25-week animals, but not in all of the 2-week monkey specimens (Table VI). The 2-week specimens could have had early stages of cemental attachment, but shrinkage due to histologic preparation may have masked this phenomenon.

Claflin,[5] Björn and associates,[3] and Sonnabend[14] have reported changes in the periodontal ligaments of both vital and pulpless submerged root segments. These changes are consistent with those classically described for periodontal ligaments which are not in function.[18, 19]

Butcher and Taylor[17] and Björn and associates[3] reported periapical resorption associated with some submerged root segments. None of our successfully submerged segments demonstrated any periapical resorption, whereas four of the segments open to oral fluids were found to have only resorption of cementum and less than 1 mm. of dentin.

Cardoso and Mitchell[20] found that the time interval from the pulp-exposure operative procedure to the end of the experimental period had little bearing on the incidence or extent of pulpal and periapical pathologic tissue. These findings were confirmed in the present study, but the teeth with large pulp chambers which were open to oral fluids demonstrated more profound pulpal and periapical degenerative changes.

Kakehashi and his co-workers[21] found that germ-free open rat teeth would form pulp caps even in the face of gross impaction of food. In contrast, the normal rats with normal oral microbiota produced pulpal and periapical pathologic tissue because of the pulp chambers being open. In the present study the normal monkey pulps were traumatized and exposed briefly to air-borne bacteria and possibly to saliva. A flap was then approximated over the freshly torn pulpal tissues which may have allowed some bacteria to enter the surgical site until primary closure was accomplished. The potential for pulpal healing in the present study indicates that normal monkey pulps can withstand traumatic coronectomy, a transient bacterial invasion, and suture removal, provided that the primary closure is maintained.

Neither the size of the root canals nor the length of the observation periods appeared to create variations in coronal bridging, connective tissue attachment, or submersion success rate. The tissues involved in coronal bridging and connective tissue attachment appeared to mature as the observation periods increased.

SUMMARY

Nineteen vital root segments and seventeen root segments filled with gutta-percha, in three monkeys, were surgically submerged and studied histologically after healing periods of 2, 5, and 25 weeks. Normal vital pulpal tissues, which were traumatically amputated and exposed to a transient bacterial invasion, blended into the overlying connective tissue in all specimens in which primary closure was maintained. Gutta-percha–filled root segments which were successfully submerged were associated with a mild pericoronal inflammatory response, whereas the vital successfully submerged segments were free of any type of inflammatory infiltrate.

Vital segments demonstrated a higher submersion success rate (twelve of nineteen) than that of gutta-percha–filled segments (three of seventeen). A 100 per cent correlation existed between successfully submerged vital segments and coronal bridging by calcified tissue in the 5-week and 25-week monkeys. Conversely, none of the segments which were open to oral fluids demonstrated coronal bridging. A 100 per cent correlation was also found between successfully submerged segments (vital and gutta-percha–filled) and the attachment of a cementum-like tissue interphase between the connective tissue and the dentin amputation site in the 5-week and 25-week monkeys. By contrast, none

of the segments which were open to oral fluids exhibited the cementum-like tissue attachment.

Successfully submerged segments which were fractured during amputation exhibited a connective tissue attachment surrounding the fragments, whereas unsuccessfully submerged fractured segments demonstrated acute inflammatory infiltrates in the tissues surrounding the fragments.

The periodontal ligaments of the experimental teeth exhibited histologic signs consistent with those classically described as disuse atrophy. Pulpal nerve fibers were found to have branched and infiltrated the connective tissue above the coronal extent of the segments of the 25-week monkey. The nerve fibers followed closely the pathways of the blood vessels.

The pulpal tissues of unsuccessfully submerged vital segments demonstrated degenerative changes consistent with those described as pulpal abscesses. Some specimens exhibited degenerative changes to and through the apical foramina and involved the periapical tissue. Unsuccessfully submerged segments (vital and gutta-percha–filled) demonstrated acute inflammatory infiltrates pericoronally, as well as epithelial proliferation toward the pericoronal extent of the segments.

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