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The Comparison between Healing of Mucoperiosteal Incisions Made by Electrosurgery and Scalpel

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THE COMPARISON BETWEEN HEALING OF

MUCOPERIOSTEAL INCISIONS MADE BY

ELECTROSURGERY AND SCALPEL

by

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AUTOBIOGRAPHY

Anthony T. Young was born in Chicago, Illinois on March 21, 1947.

He was graduated from Lane Technical High School, Chicago, Illinois in January 1965. In January of the same year, he entered Loyola University, Chicago, Illinois as a pre-dental student where he was graduated with the degree of Bachelor of Science in January 1969.

In January 1969 he began teaching elementary school in Chicago, Illinois until he started his professional training at Loyola University School of Dentistry in the following September. He was graduated with the degree of Doctor of Dental Surgery in June 1974.

In July 1974 he began a one-year General Dentistry Residency at the Veterans Administration Hospital at Downey, Illinois and received his certificate in June 1975.

In September 1975 he began his graduate studies in the Department of Oral Biology and Fixed Prosthodontics at Loyola University School of Dentistry, Maywood, Illinois.

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INTRODUCTION

The purpose of this study was to determine if electrosurgery caused abnormal effects on healing when mucoperiosteal incisions were made directly through the mucoperiosteum to alveolar bone. These incisions were compared histologically under the light microscope to similar incisions using a scalpel. Previous studies were primarily concerned with the deleterious effects of electrosurgery performed in close proximity or momentary contact with bone (Glickman, 1970; Ozimek, 1972; and Nixon, 1975). This investigation deviated from former studies by making deliberate incisions directly through the gingiva to the bone. This afforded a direct comparison of healing between electrosurgery and scalpel incisions. To my knowledge, no previous study has shown any results where contact with bone throughout the length of the incisions was used.

REVIEW OF THE LITERATURE

In 1580, William Gilbert, the physician of Queen Elizabeth I, performed experiments in magnetism and electricity and coined the term "electricity." Another landmark in the history of electricity and electrosurgery occurred in 1746 when the Leyden Jar Capacitor was developed. Later, Oersted (1821) discovered electromagnetic induction. Nolet (1834) developed an inductance coil and demonstrated the effects of electrical sparks. The discovery that the Leyden Jar discharged in an oscillating manner went to Henry in 1842. Forty-two years later in 1884, Hertz found these oscillations or waveforms could pass from a generator to a distant receiver without any connections. Three years prior in 1881, Morton combined all previous works by demonstrating an oscillating frequency of 100,000 cps which did not shock the body or cause muscle contraction. In 1891, d'Arsonval found the lower limit of 10,000 cps also contained a thermal component.

A ground plate to distribute the surface charge was first used in 1919 by Iredell and Turner. Then, in 1923, Wyeth observed endothermy (local heat production by high frequency from a spark gap generator) was valuable in treating cancer. Clark (1925) em-

ployed electrodessication and electrocoagulation for oral cancer

removal. Histologically, he found cells to be shrunken, elongated,

divided, and blood vessels thrombosed. He stated more fibrosis and

bone sloughing occurred with electrocoagulation. The first time

cutting took precedence over coagulation was in 1925 when Wyeth used

proper current levels generated in a vacuum tube and fine electrode

tips. The tissue was cut by minutely-localized disintegration of

cells at the tip of the electrode; this was called "acusection." A

short time later in 1929, McClean stated a vacuum tube oscillator

produced current with a waveform more conducive to cutting than to

coagulation.

Ellis (1931) measured tensile strength of numerous healing in-

cisions and found in skin, a tensile strength of 97% of normal tis-

sue following knife incisions, and 60% following electrosurgery.

Ten years later in 1941, Ogus used electrosurgery for gingivoplast-

ies. Orban showed severe inflammation, necrosis, and bone sloughing

due to electrocoagulation in 1944, and in 1945, he and Archer de-

scribed the reparative processes of connective tissue and epithelium

after electrosurgery.

It was shown by Hardwick (1953) the high resistance of bone

results in coagulation of bone cells by a current that does not

coagulate soft tissue. In 1955 Hartwell demonstrated the viability

of the connective tissue base adjacent to periosteum as an important

factor influencing the rate of epithelialization and ultimate heal-

ing. In 1957 Catchpole noted ground substance was important in healing.

Oringer (1960) stated coagulation still accompanied the cutting action, which he thought was produced by fully rectified current. In 1962 Mitchell and Lumb discussed the cause of volatilization as being due to vacuum tube oscillators producing continuous frequency sine wave current without damping. They theorized cell morphology was altered by dissolution of molecular structure in the path of the electrode tip. In the next year, 1963, Klingberg and Butcher noted the importance of the epithelium layer in healing; if more connective tissue is removed with epithelium, then healing is delayed further. That same year, Trott and Gorenstein established mitotic rates of rat oral and gingival epithelium. Combined with Stahl's (1968) autoradiographic technique, a definitive set of events for healing dynamics in the rat was established.

Toto and Annoni described the importance of an intact clot as a sealant and defense mechanism during healing (1965). Armstrong (1966) demonstrated it was possible to deepen periosteal involvement. In the same year, Harrison and Kelly showed the fully rectified units to be superior with less lateral heat dissipation. Another investigator, Klug, presented the notion that operator variance was important, but also noted gingivae regenerated to within 0.1 mm of its initial heights (also 1966).

In 1968 Pope used a loop electrode with a partially rectified

unit to perform gingivectomies on dogs and observed retarded heal-
ing, bone involvement, and decreased height of gingival contour.
In the same year, Battig stated spark gaps produced pulses of damped
frequency current of the sine wave form. Kelly demonstrated there
was no retardation of reepithelialization in monkeys after one week
(1968). Also in 1968, Malone and Manning performed gingivoplasty
with a partially rectified unit and found no adverse healing. In
another study they emphasized the choice of needle electrodes and
swift, deliberate strokes through the tissue as necessary for an
optimum tissue response.

Oringer (1969) said an indifferent plate creates a biterminal
circuit with an end result of deeper penetration of the electroco-
agulation effect. Later that year, Oringer placed lateral heat dis-
sipation in perspective to coagulation. The important factors he
mentioned were the time interval between applications of electrode
tip to tissues, and the motion of the electrode within the gingival
sulcus. He also stated bone necrosis was due to a current type
other than fully rectified. Additionally, Oringer stated inadequate
output of a fully rectified unit could cause simultaneous coagulation
and cutting, meaning that there was not enough power to create total
disintegration. In 1969 Schomburg and Malone showed electrode ster-
ilization to be unnecessary when the passive plate was used to com-
plete the circuit.

Malone, Kusek, and Eisenmann (1970) found healing in human

soft tissue to occur within seven days after surgery with reepithe-
lialization and keratinization. Glickman and Imber (1970) compared
shallow resections of gingivae in dogs and found no difference be-
tween the healing after the knife or electrosurgery. With deep
resection there was no problem with the knife, but electrosurgery
resulted in deleterious healing problems in bone, ie, necrosis,
sequestration, and resorption.

Ozimek (1972) found that in rats, unpredictable healing re-
sponses occurred when electrosurgery involved calcified tissues such
as bone and cementum. He noted there was a one-day delay in epithe-
lialization of electrosurgery incisions compared to scalpel incisions.
Additionally, he found more extensive connective tissue inflammation
in electrosurgical incisions that was not evident in scalpel inci-
sions.

In 1974 Schneider and Zaki performed a two-part experiment on
rabbits using the light microscope and the electron microscope to
investigate gingival wound healing following experimental electro-
surgery. Their studies involved soft tissue gingivoplasties, and at
the light microscope level they observed an altered homogeneous,
hyalinized-appearing connective tissue seen only in the electrosur-
gerized specimens. At the electron microscope level, the only dif-
ference evident between the knife and electrosurgerized specimens
was the presence of ill-defined collagen fibers. No other remark-
able differences were found.

Nixon, Adkins, and Keys (1975) used 25 guinea pigs and studied the effect of undamped fully rectified current with the electrode in direct contact with the periosteum. They found a substantially more extensive inflammatory reaction and greater destruction of periosteum after electrosurgery compared to the controls incised with a knife.

Wilhelmsen, Ramfjord, and Blankenship (1976) performed electrosurgical gingival "troughing" in Rhesus monkeys and found substantial gingival recession with apical migration of the sulcular epithelium. In addition, burn marks on root surfaces were noted where the electrode made contact.

The literature review presents few studies using mucoperiosteal flaps incised directly over bone. Glickman's study (1970) used a small loop electrode which was brushed through the gingiva almost to the bone in one procedure performed on a dog. He extrapolated results similar to Ozimek's subsequent thesis (1972) that compared 24 electrosurgical incisions and 24 scalpel incisions directly to bone in rat maxillae. Both researchers found that electrosurgical incisions contacting periosteum or tooth structure resulted in delayed healing. Nixon's study (1975) used 25 guinea pigs with similar procedures and results. No study has yet involved the comparison of healing between mucoperiosteal incisions using electrosurgery and the scalpel in primates. This investigation used Rhesus monkeys since these animals are generally accepted as choice speci-

mens for periodontal healing studies.

MATERIALS AND METHODS

A. Experimental Animals

Two adult Rhesus monkeys were used. Four electrosurgical and four scalpel incisions were made in each monkey.

B. Operative Procedures

Using refined electrosurgical current developed by the Cameron-Miller 255 electrosurgery unit and the thinnest needle electrode, incisions were made that completely penetrated the gingiva. A new, sterile Bard-Parker #12 surgical blade was used to make each scalpel incision. Contact with the alveolar bone was intentional and extended the full length of the incisions. All incisions were located buccally and were made with the cutting instrument held almost perpendicular to the alveolar process.

One anterior and one posterior incision were made in each quadrant using one method of incision per quadrant (Table 1). The anterior and posterior incisions were angled so either buccal-lingual or horizontal sections would pass through the incised areas. The incisions were made as deliberately and as quickly as possible. Contralateral sides of the opposite arches in each monkey were in-

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Table 1.--Incisions

	Location	Type
24-hour monkey	Maxilla - Right side	Scalpel
	Maxilla - Left side	Electrosurgery
	Mandible - Right side	Electrosurgery
	Mandible - Left side	Scalpel
14-day monkey	Maxilla - Right side	Scalpel
	Maxilla - Left side	Electrosurgery
	Mandible - Right side	Electrosurgery
	Mandible - Left side	Scalpel

cised with either electrosurgery or the scalpel to prevent each monkey from favoring either side.

After the incisions were made, the tissue between the incisions was elevated as mucoperiosteal flaps. Each flap was immediately replaced as close as possible to its original position.

C. Tissue Preparation

One monkey was sacrificed 24 hours after the incisions were made to determine if any remarkable, histologic differences occurred that rapidly after surgery. The other monkey was surgerized, then received antibiotics and a soft diet for nine days. On day 14 this second specimen was sacrificed. Both monkeys' incisions were left exposed to the normal oral environment.

After each animal was sacrificed, the skull was immediately immersed in 10% formalin. Then the incised areas were prepared and sectioned as usual for slides that were stained with hematoxylin and eosin. Control sections were obtained from nonsurgerized areas in each monkey. Sections were made as listed in Table 2. The double-blind method of examining data was employed on each slide.

The following features were examined on each slide where the sections made this possible:

(1) the surface of the incised tissues

(2) the presence and character of inflammation

(3) the extent and quality of reparative processes

(4)   the histology of the periosteum at each incision base

(5)   evidence of bone resorption and necrosis.

Photomicrographs were taken of these features as x40, x100, x200, or x450.

Table 2.--Microscope Slide Sections

24-Hr Monkey

Jaw Incised	Location and Type of Incision	Plane of Section
Maxilla - Right	Anterior - Knife	Horizontal
Maxilla - Right	Posterior - Knife	Buccal - Lingual
Maxilla - Left	Anterior - Electrosurgery	Buccal - Lingual
Maxilla - Left	Posterior - Electrosurgery	Horizontal
Mandible - Right	Anterior - Electrosurgery	Horizontal
Mandible - Right	Posterior - Electrosurgery	Buccal - Lingual
Mandible - Left	Anterior - Knife	Horizontal
Mandible - Left	Posterior - Knife	Buccal - Lingual

14-Day Monkey

Jaw Incised	Location and Type of Incision	Plane of Section
Maxilla - Right	Anterior - Knife	Buccal - Lingual
Maxilla - Right	Posterior - Knife	Horizontal
Maxilla - Left	Anterior - Electrosurgery	Horizontal
Maxilla - Left	Posterior - Electrosurgery	Buccal - Lingual
Mandible - Right	Anterior - Electrosurgery	Buccal - Lingual
Mandible - Right	Posterior - Electrosurgery	Horizontal
Mandible - Left	Anterior - Knife	Buccal - Lingual
Mandible - Left	Posterior - Knife	Horizontal

RESULTS

Examination of the slides involved the histologic comparison
of each slide with known control sections. After examining each
previously numbered slide, the findings of each were compared to the
controls and any histologic differences noted. The slides were then
identified by type of incision, and the results pooled so that gener-
al comparisons could be made. Aside from the initial examination,
pooling the results eliminated needless description of minute details
from slide to slide. It also provided for histologic comparisons of
one group of slides to another. Representative photomicrographs were
taken from each group.

A. Control Sections

These slides showed the monkeys had normal appearing hard and
soft tissues (Fig A and B). Normal epithelium was noted with rete
pegs intact. The lamina propria exhibited uniform staining with a
normal amount of collagen and connective tissue elements. Few cap-
illaries were seen and no demonstrable inflammation was present.
The periosteum was intact and adjacent to bone that presented a nor-
mal histologic appearance.

Fig A.   Note the normal appearing lamina propria, periosteum, and

bone (control; H & E x450).

Fig B.   The relationship between the overlying epithelium, connec-

tive tissue, periosteum, and bone is normal and healthy

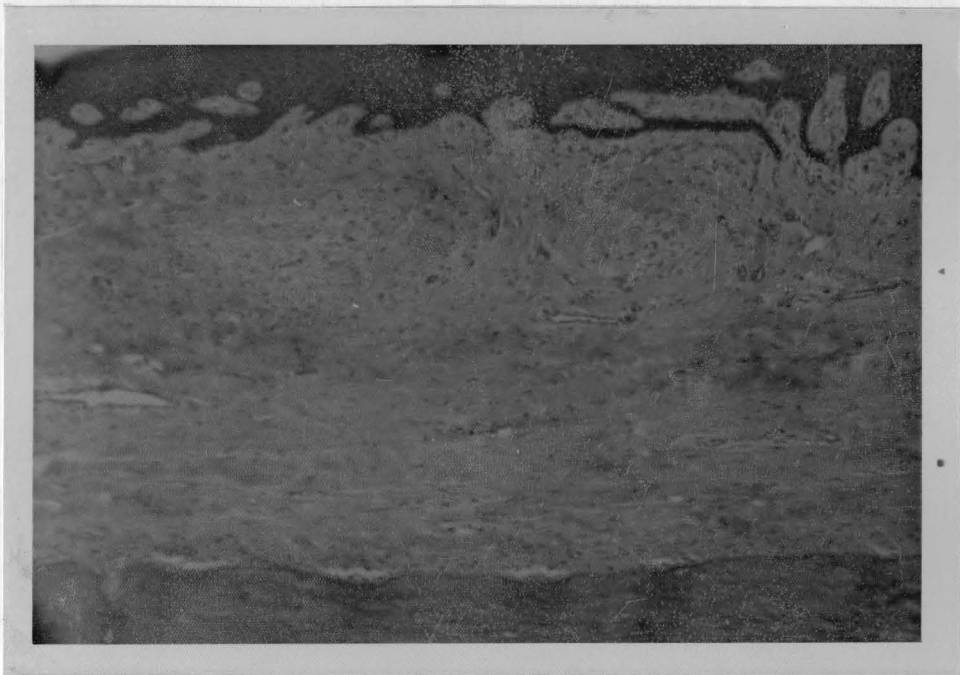(control; H & E x100).

Figure A

Figure B

B. Sections of 24-hour Scalpel Incisions

Figures C and D demonstrated typical scalpel incisions. Note the periosteum was nicked with the scalpel but remained intact. The basal cell layer with the uniform staining lamina propria and its connective tissue have maintained their integrity. A mild inflammatory response initiating repair was observed. Minute areas of hemorrhage and fibrin clot can be illustrated.

C. Sections of 24-hour Electrosurgery Incisions

Characteristic electrosurgery incisions are depicted in low power (Fig E and H). Figure G showed where the electrode contacted bone with the resulting blood clot formation. The epithelium has been disrupted from the lamina propria at the basal cell layer. The degenerating lamina propria showed darker staining adjacent to the incision. The connective tissue had apparently lost its cellular and fibrillar definition immediately adjacent to the incision. Figure J demonstrated a proliferative leukocyte infiltration of the lamina propria subadjacent to an incision. This is considered one of the initial stages of acute inflammation. Rete pegs were not observed adjacent to the incision. High magnification of Figures F, G, and I demonstrated the bone was nicked with the electrode. However, no burn marks are apparent, indicating the electrode had been in contact with ossified structures for a minimal length of time.

Fig C. Low magnification of typical scalpel incision at 24 hours.

Some hemorrhage and fibrin clot are seen. Periosteal cov-

ering is somewhat intact (scalpel; H & E x40).

Fig D. Note the nick in the periosteum and the evenly stained

ground substance. A mild inflammatory response indicating

repair has begun (scalpel; H & E x100).

Figure C

Figure D

Fig E. Low magnification of 24-hour electrosurgery incision. Note
that the bone was contacted and the presence of a blood
clot. The lamina propria has been disrupted and the margins
of the incisions stained more intensely (electrosurgery;
H & E x40).

Fig F. High magnification of Figure E showing disrupted, more in-
tensely stained lamina propria (electrosurgery; H & E x200).

Fig G. Higher magnification of Figure E showing that the electrode

contacted bone but left no burn marks. Bone marrow area on

the lower right appears to be necrotic, which accounts for

the belated healing (electrosurgery; H & E x200).

Fig H. Low magnification of electrode contact with bone. Osteo-

clasia activity would be required for the initiation of re-
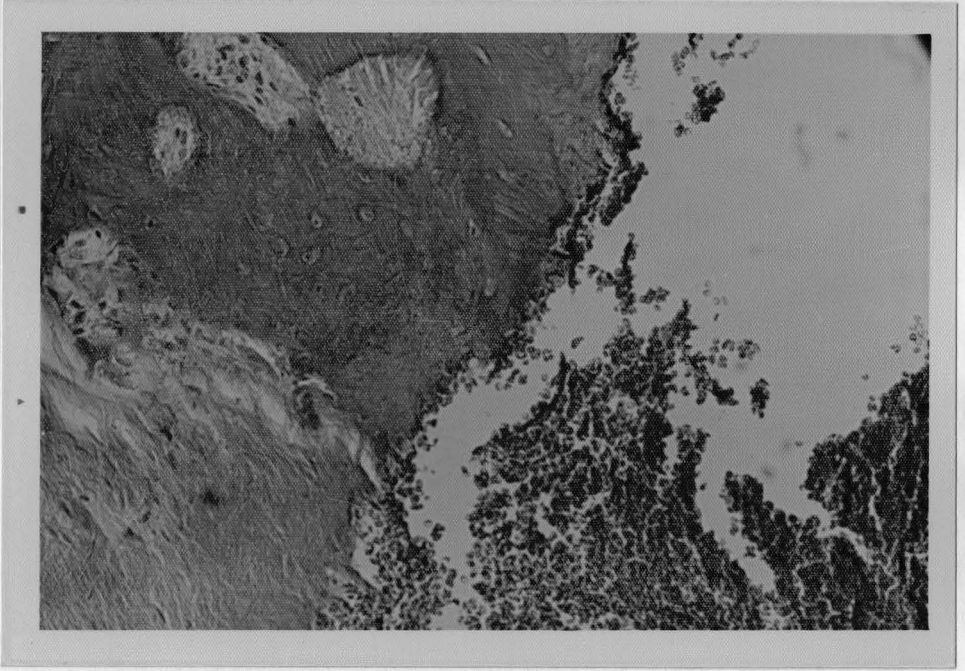
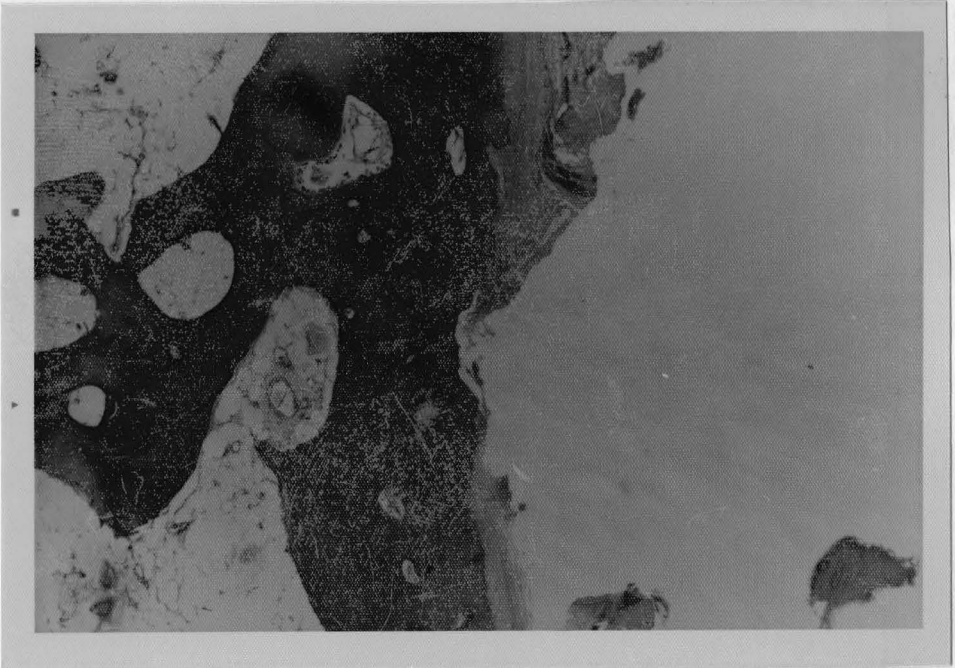pair (electrosurgery; H & E x40).

Figure G

Figure H

Fig I. High magnification of Figure H showing area of electrode contact without burn marks. Note disrupted vacuolized lamina propria (electrosurgery; H & E x200).

Fig J. Note intense inflammation of the 24-hour electrosurgery incision (electrosurgery; H & E x200).
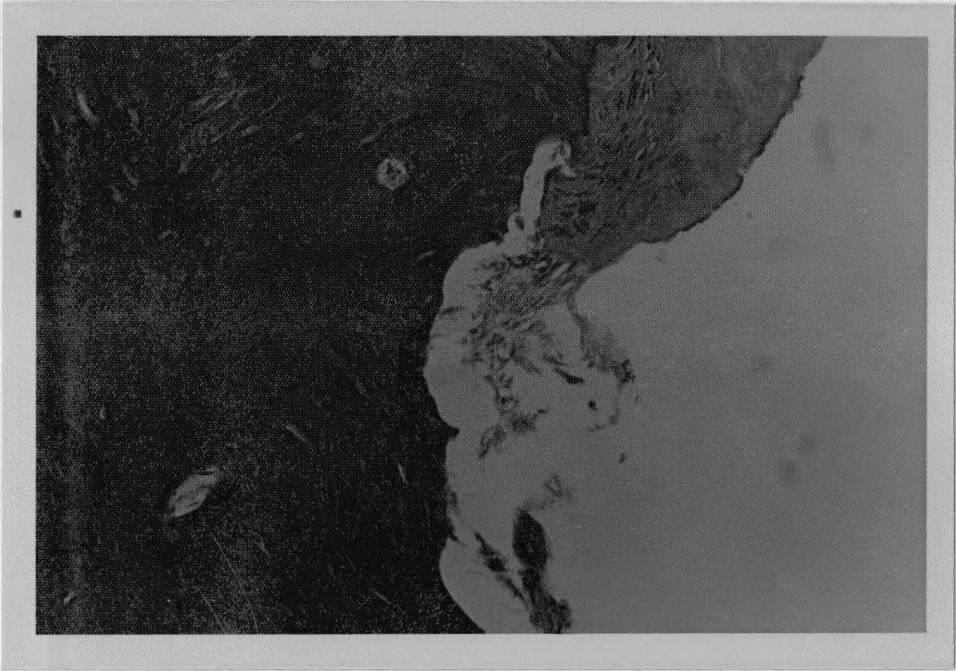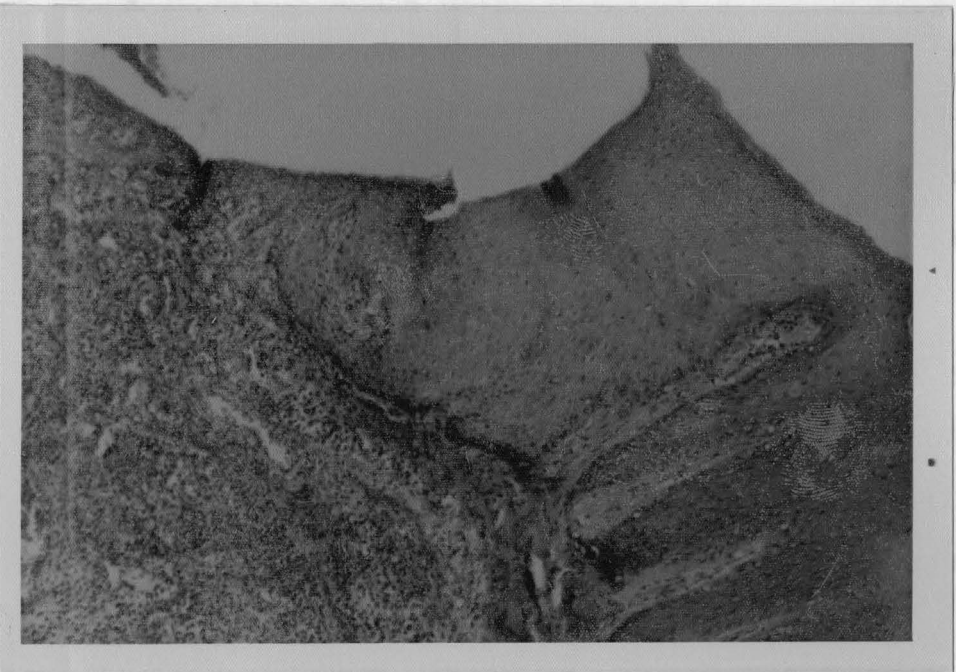
Figure I

Figure J

D. Sections of 14-day Scalpel Incisions

These sections showed polymorphonuclear leukocyte invasion
with a moderate concentration of cells. Figure K shows surface epi-
thelialization is near completion. The connective tissue is not
disrupted and repair is almost complete. In Figure L the basal cell
layer is intact and contacts the basement membrane. The greater
staining intensity could be related to increased amounts of immature
collagen and increased nutrients available in the ground substance
for repair.

E. Sections of 14-day Electrosurgery Incisions

Delayed healing is demonstrated in Figure M that showed in-
complete epithelial maturation and migration. The incisional cleft
remained open. Atypical epithelial cells had lost their definition,
were abnormal in size and shape, and contained pyknotic nuclei.
The basal layer of epithelial cells no longer retained its morpho-
logic orientation with the lamina propria and had lost its cohesive-
ness (Fig N and O).

The lamina propria demonstrated an acute inflammatory reaction
with polymorphonuclear leukocyte infiltration, a lack of fibrillar
definition, and capillary engorgement (Fig Q).

Figure P shows a higher magnification of the bone resorption
seen in Figure M. The periosteum has been severely disrupted as re-
flected by osteoclast activity with concomitant Howship's lacunae.

Fig K. Fourteen-day scalpel incisions demonstrating complete
        epithelial migration. Repair is almost complete (scalpel;
        H & E x100).

Fig L. High magnification of Figure K showing mild inflammatory
        cell infiltration and intact basal cell layer immediately
        adjacent to the lamina propria. Since this tissue is still
        undergoing repair, it stains more intensely (scalpel; H & E
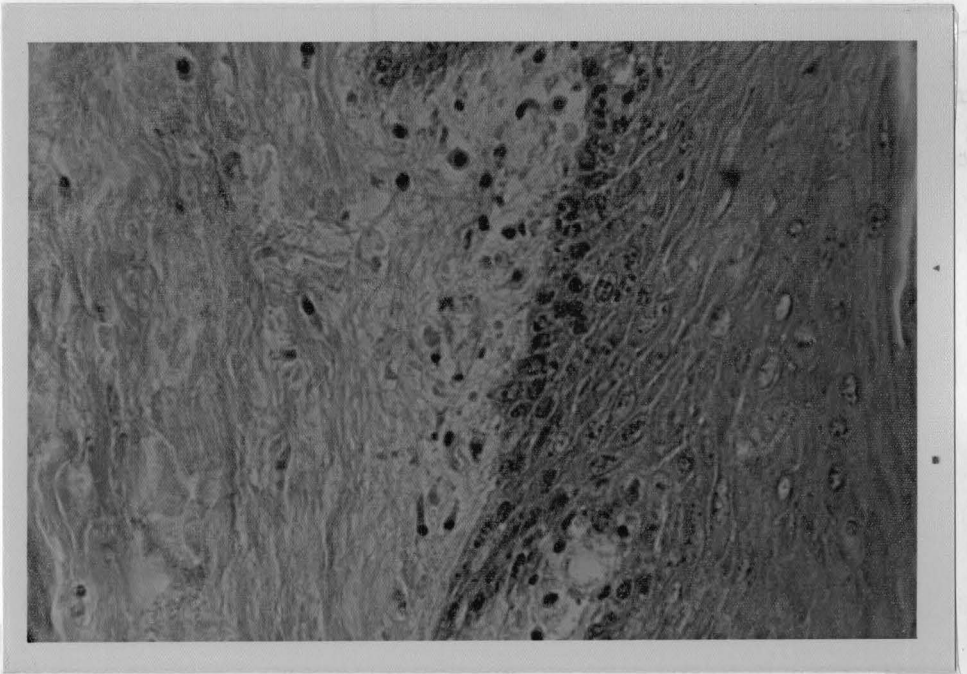   x200).

Figure K

Figure L

Fig M. Section of 14-day electrosurgery incision depicting incom-
plete epithelial migration and maturation. Note cleft be-
tween basal cell layer and lamina propria. Active repair
between underlying bone and surface epithelium is evident.
Matrix injury is still in progress. Sufficient connective
tissue death is contributed to belated epithelial healing
(electrosurgery; H & E x40).

Fig N. Higher magnification of Figure M showing moderate inflam-
mation extending to the basal layer of epithelium. Moderate
to severe degenerative changes are seen in the lamina pro-
pria (electrosurgery; H & E x100).

Figure M

Figure N

Fig O. Higher magnification of Figure M depicting atypical epithe-
lial cells with disrupted junction between lamina propria
and the epithelium. Some pyknotic nuclei can be seen. A
pale, delicate, edematous network and residue of cells is
present (electrosurgery; H & E x450).

Fig P. Higher magnification of Figure M showing necrosis and osteo-
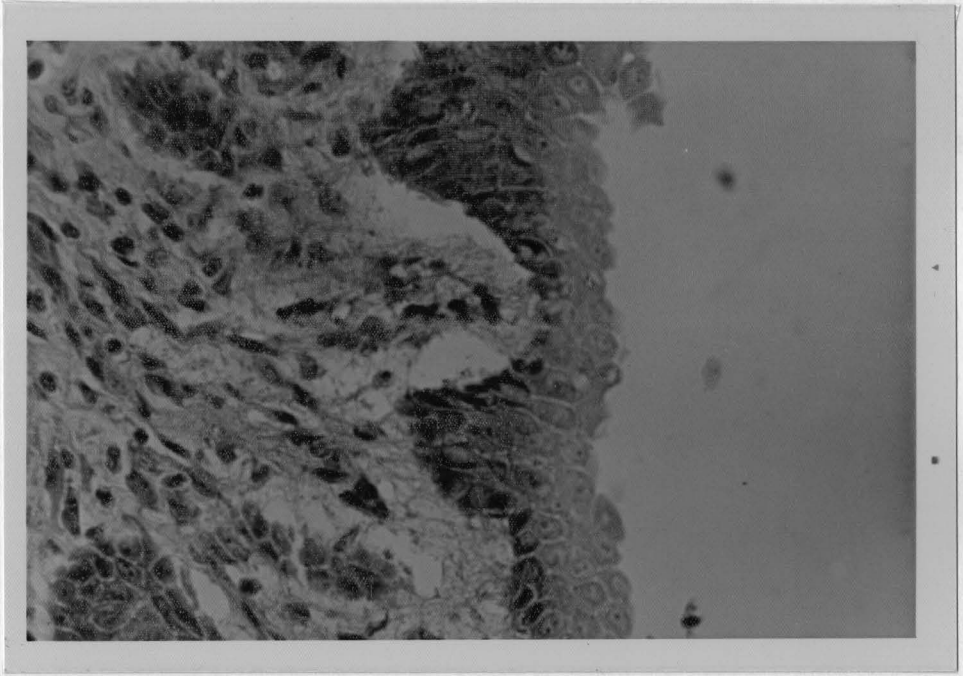clastic activity with Howship's lacunae (electrosurgery; H
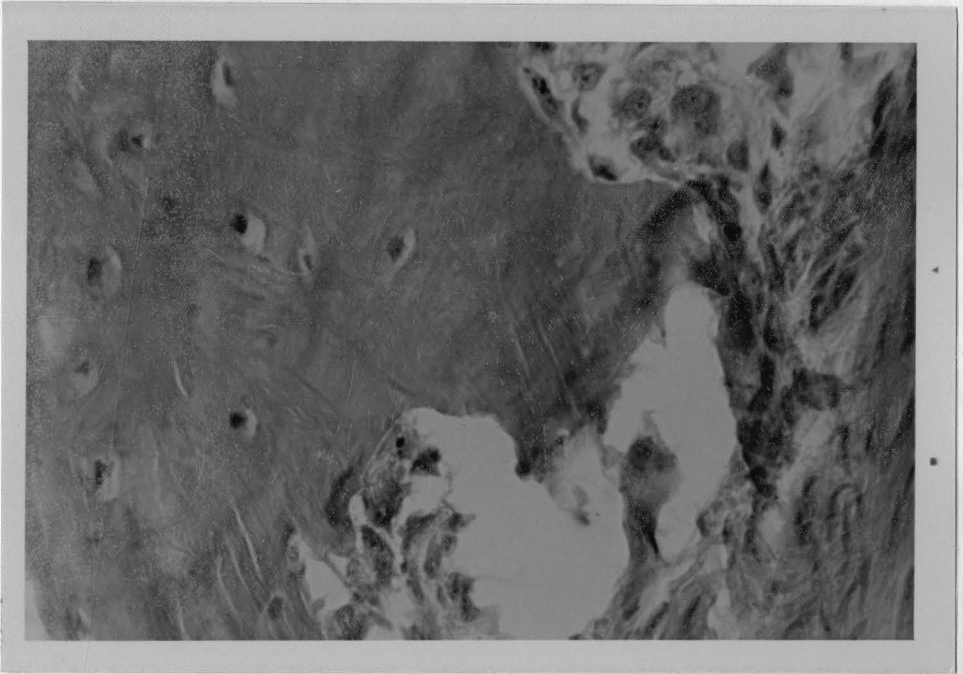& E x450).

Figure O

Figure P

Fig Q. A different 14-day electrosurgery specimen that clearly

shows the inflammatory cells, lack of complete fibrillar

definition, and capillary engorgement. The surface epithe-

lium shows obvious degenerative disturbances (electrosur-

gery; H & E x100).

Figure Q

In isolated instances the inflammatory process was not as evident. However, Figures R and S show delayed epithelialization associated with bone resorption. In contrast, the higher magnification of Figure R seen in Figure T depicts osseous repair with collagen and bundle bone adjacent to mature bone.

In addition, empty lacunae could be found near the area of electrode contact. It was difficult to determine whether the osteocytes "shrunk" away from the lacunae walls during tissue processing, whether they were dehydrated due to electrosurgical current, or whether impaired nutrient function of the periosteum caused their degeneration.

Fig R. Fourteen-day electrosurgery incision with delayed epithe-

lialization. Not many inflammatory cells are present in

this section (electrosurgery; H & E x40).

Fig S. Higher magnification of Figure R depicting abnormal epithe-

lialization. The basal cell layer is abnormal and pyknotic

nuclei can be seen. The basement membrane is not clearly

defined. Few inflammatory cells are present (electrosurgery;
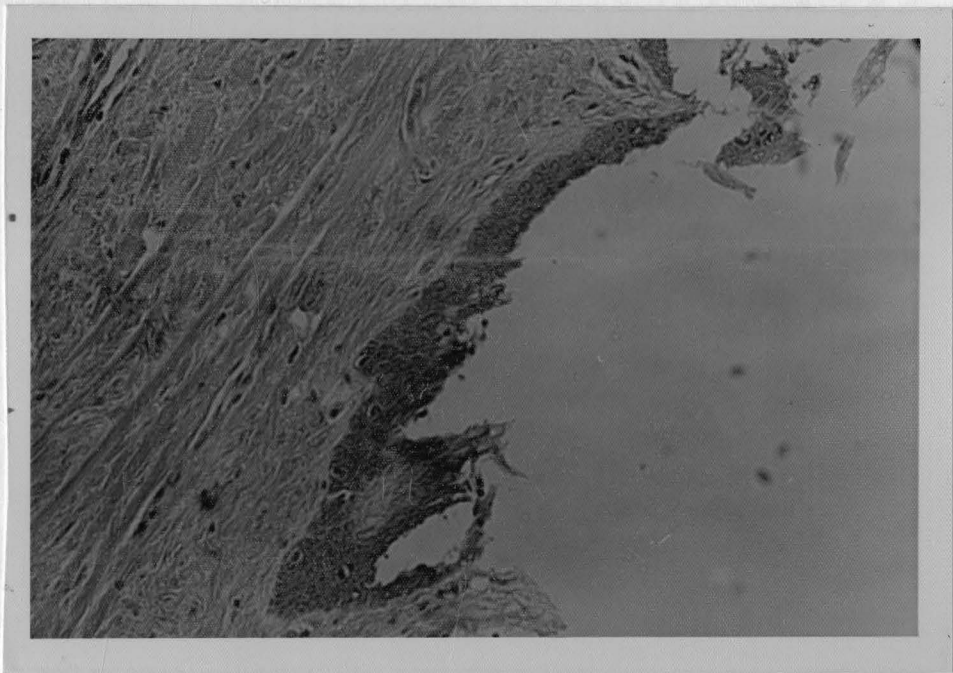
H & E x200).

Figure R

Figure S

Fig T. Higher magnification of Figure R showing collagen and bundle

bone with minimal evidence of inflammatory cells. Osteocytes

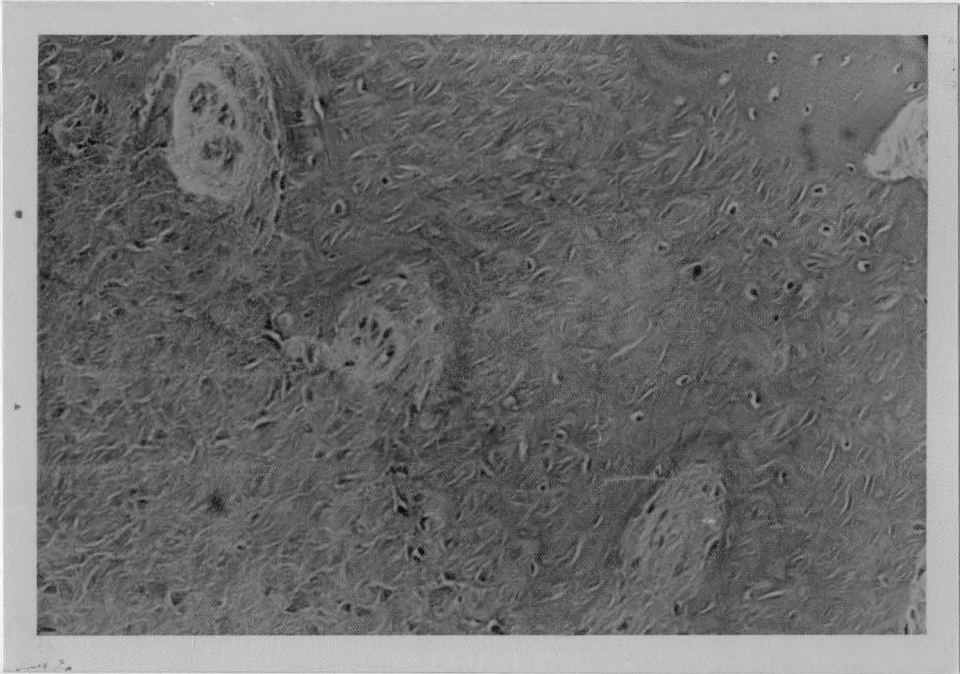appear to be in the state of repair (electrosurgery; H & E

x200).

Figure T

DISCUSSION

The intent of this study was to demonstrate mucoperiosteal in-
cisions can cause complicated and/or delayed healing. The major con-
sistent difference found between the electrosurgical and scalpel mu-
coperiosteal incisions was delayed healing. Histologically, the scal-
pel incisions caused only relative injury to the periosteum. Perio-
steal damage was limited to the contact point of the blade with the
bone. Healing proceeded uneventfully in most of these incisions.
The major difference between the 14-day scalpel incision sections
and the control sections was the slight inflammatory response pre-
sent in the healing tissues, which was predictable.

Bone necrosis reflected by Howship's lacunae in sections of
electrosurgical incisions may be a primary factor that caused de-
layed epithelialization and disruption of the lamina propria. Since
performing electrosurgical incisions in the vicinity of bone has
been known to produce unpredictable results, this study used elec-
trosurgery to incise directly to the bone through the mucoperiosteal
incisions. This approach of mucoperiosteal incisions consistently
resulted in complicated and delayed healing. The electrosurgical
current was directly responsible for abnormal healing results when

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used to make mucoperiosteal incisions.

In order to minimize the deleterious effects of heat build-up at the electrode tip, a concerted effort was made to perform all incisions as quickly as possible. The results were in agreement with previous studies (Glickman, 1970; Ozimek, 1972; Nixon, 1975), and few histologic or photomicrographic differences were noted when compared with these investigations.

The diversity of tissue responses reported in the literature was due to the broad range of specimens used to evaluate electrosurgery. Although mice, rats, guinea pigs, dogs, monkeys, and humans have been used as specimens, the experimental results demonstrated that deleterious healing occurred regardless of the specimen used (Pope, 1965; Glickman, 1970; Ozimek, 1972; Nixon, 1975; Wilhelmsen, 1976). The experimental design in each case used incisions through the gingiva to periosteum producing predictably belated healing.

In contrast to these investigations, there were studies whose purpose was to elicit the most innocuous responses possible (Malone, 1969; Eisenmann, 1970; Schneider, 1976). In each investigation, only soft tissues were incised and healing followed uneventfully.

Host response was an important parameter to consider in these investigations. The human response would be predictably better in each instance, particularly in the maxillary incisions, due to the increased blood supply in this area.

Electrosurgery is an excellent modality that may be used for the following procedures: in periodontal surgery for removing tenacious tissue tags interproximally, performing frenectomies and gingivoplasties, removing opecula, planing edentulous ridges, elongating clinical crowns, and gaining access to subgingival caries.

The major advantage of electrosurgery over the scalpel is the accessibility of the electrode tip into areas where conventional instrumentation with a scalpel is impossible. Another advantage is the excellent hemostasis achieved with electrosurgery facilitating tissue dilatation prior to impressions for prosthodontic consideration. An excellent application of electrosurgery is the manner in which a "bleeder" can be quickly sealed using the coagulating current setting.

Use of electrosurgery is contraindicated in patients with a pacemaker or where inevitable contact with periosteum or bone is expected to be more than momentary, ie, radiated patients or patients with a collagen deficiency.

When performing electrosurgery, it is desireable to have a refined, fully rectified unit with the thinnest needle electrode. This will insure a higher degree of efficiency with negligible deleterious effects and minimizes "operator variance."

If the operator restricts his use of electrosurgery to soft tissue modifications using refined instrumentation and acceptable technical approaches, he can insure a more theraputic profile for

this instrument. This modality is used routinely without problems by oncologists, urologists, general surgeons, and other paramedical personnel.

It would be ludicrous to require dentists who use electrosurgery to be more cautious and prudent (when approaching the tissues around a single tooth in a confined area of the oral cavity) than other medical personnel who routinely use less refined instruments in a bolder manner under less restricted operating fields.

Electrosurgery is not a panacea, but merely a refined manner in which to treat patients; it is still in its infancy. The paucity of innovative research and the reluctance of dental researchers to recognize the significance of employing the assistance of other investigators has hindered advancements of electronic surgery.

Electronic engineering, crystallography, biochemistry, biophysics, and other specialty consultations would expedite research in electrosurgery. This would benefit all theraputic applications of electrosurgery. There was enough research reported in the literature of other sciences that this author, with expert assistance from an electronic technician, has been able to advance mechanisms and theory on the effects of electrosurgery. How it works and why hard tissues should be avoided are discussed in Appendices A and B.

During healing, the electrosurgical mucoperiosteal incisions were found to vary in the inflammatory response elicited (see Appendix B). It is not clear at this time why varying degrees of in-

flammation occurred in the same animal. The redundant or trite
phrase "operator variance" may be appropriate, but, more likely, the
peculiarities of electrosurgical current were probably responsible
when periosteal tissues were involved.

Previous authors suggest operator variance may be the cause
for varying degrees of deleterious healing after electrosurgical
procedures. At this point, the author of this study maintains "op-
erator variance" is a normal consideration when using electrosurgery
if the electrosurgery performed did not involve periosteal tissues.
In order to obtain acceptable experimental results, previous authors
had to contend with the various peculiarities of the nature of elec-
trosurgery. Therefore, this author concludes that more than likely,
previous experimenters did, in fact, use electrosurgery properly.
Understanding the operation of an electrosurgical unit would bene-
fit any novice operator and is of paramount importance if used daily
in clinical practice (see Appendix A).

Research on the effects of electrosurgery in soft tissues with
or without hard tissue involvement has been literally exhausted.
Current areas for innovative research include the following:

(1) refining and updating the electronic components in elec-
    trosurgery units using integrated circuitry and electron-
    ic clocks that divide a second into one million or more
    parts allowing finer control over the current.

(2) experimenting with different methods of modifying the RF

(radio frequency) and/or using different RF values.

(3) investigating more thoroughly the mechanisms and theory

of bone resorption and method of operation of RF.

(4) investigating the biological hazards of RF

(a) Is enough energy concentrated at the electrode to

cause free radicals?

(b) Is enough energy present to dissociate DNA or other

macromolecules?

(c) Is RF cumulative in tissues of the body?

(d) Are any biological hazards of microwave radiation

applicable to RF radiation?

(e) Is healing altered by experimenting with different

methods of modifying the RF and/or using different RF

values?

Dentistry should insist on the updating and refinement of elec-

trosurgery units. Current electrosurgery units are <u>decades</u> behind

the state of the art of electronics. Few units use completely solid

state circuitry. Integrated circuitry is essentially nonexistent.

No unit employs power output metering that is essential to safe, ef-

fective operation. Other improvements necessary for sound operation

include: capacitive isolation between the unit and electrode cable,

over current protection at the output, linear output control, and

use of standard electrical color codes for cables (black always in-

dicates ground . . . except in electrosurgery units).

SUMMARY AND CONCLUSION

Using either electrosurgery or the scalpel, two full thickness
mucoperiosteal incisions were made contacting bone in each quadrant
of two Rhesus monkeys. One monkey was sacrificed within 24 hours;
the other specimen at 14 days. The surgerized tissues were then
prepared by standardized laboratory procedures for light microscopic
examination with hematoxylin and eosin stain. These slides were ex-
amined by the double-blind method. Control sections were made from
tissues not surgerized.

The scalpel incisions in each case exhibited normal repair
and healing. The electrosurgical specimens presented different hist-
ologic pictures. Twenty-four-hour and 14-day specimens showed evi-
dence of decreased osteocyte viability, which accounted for reepithe-
lialization, bone necrosis, and delayed healing. The lamina propria
and periosteum were severely disrupted immediately adjacent to the
incisions. Although epithelial cells migrated to cover the lamina
propria at 14 days, the surface epithelium remained thin, friable,
and lacked acceptable maturity. Healing was obviously delayed.

The postsurgical histologic comparisons of healing of mucoper-
iosteal incisions made by electrosurgery and scalpel demonstrate the

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deleterious effects of electrosurgery. Therefore, recommendations that mucoperiosteal incisions should be avoided when using electro-surgery are consistent with the results of the present study.

Electrosurgery should be restricted to soft tissue modifica-tions or if periosteal involvement inadvertantly occurred, a surgi-cal pack is a mandate.

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APPENDIX A

ELECTRONIC PRINCIPLES OF ELECTROSURGERY

Electromagnetic energy is one of three known major energy groups, the other two being gravitation and nuclear forces. Electromagnetic energy consists of small quanta of energy called photons. The energy contained in each photon is given in the formula:

$$E = h\nu$$

where E is the energy in ergs, h is Plank's Constant (6.626×10^{-27} erg-seconds), and ν (nu) is the frequency in cycles per second (cps). The behavior of these photons can be described as waves, and predictions concerning the behavior of these waves can be made using simple laws of wave mechanics. Electromagnetic waves are described in terms of frequency or wavelength that are related by the equation:

$$c = \lambda\nu$$

where λ (lamda) is the wavelength, ν (nu) is the frequency, and c is the speed of light in a vacuum equal to 3×10^{10} cm/sec. We shall be discussing these waves in the operation of the electrosurgery unit.[1]

The electromagnetic waves are organized into the electromagnetic spectrum (Fig 1)[9] starting with a frequency of zero, or direct current (DC), and extending through low frequency radio, VHF, UHF, microwaves, infrared, visible light, ultraviolet, x-rays, and gamma
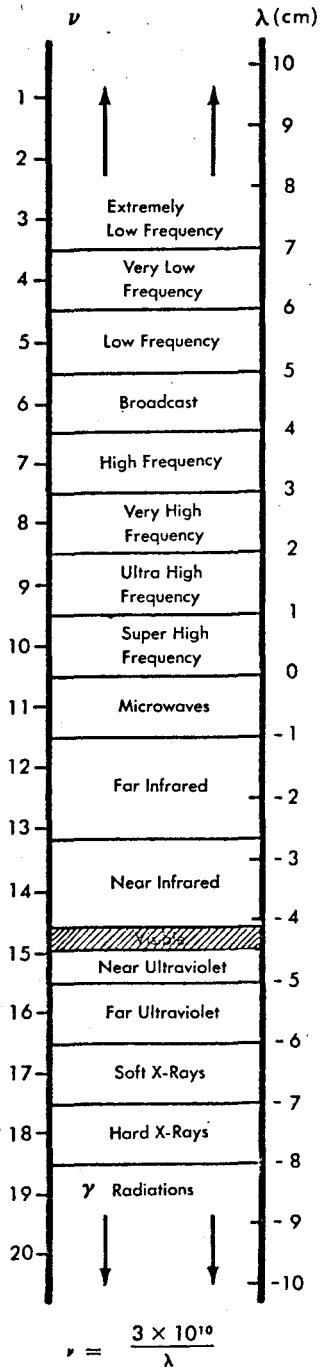
41

ν λ(cm)

10

1   9

2   8

Extremely
3   Low Frequency
7

Very Low
4   Frequency
6

5   Low Frequency
5

6   Broadcast
4

7   High Frequency
3

Very High
8   Frequency
2

Ultra High
9   Frequency
1

Super High
10 Frequency
0

11 Microwaves
-1

12
Far Infrared
-2
13

-3

14 Near Infrared
-4

15
Near Ultraviolet
-5

16 Far Ultraviolet
-6

17 Soft X-Rays
-7

18 Hard X-Rays
-8

19 γ Radiations
-9

20
-10

$$\nu = \frac{3 \times 10^{10}}{\lambda}$$

Fig 1

rays. In theory, the spectrum could extend up to infinite frequency and zero wavelength; however, little research has been done concerning frequencies above gamma rays that lie between 10^{19} and 10^{21} cps.

Radio frequency (RF) is that portion of the electromagnetic spectrum that lies between 3 kHz (3,000 cps) and 300 gHz (300 billion cps). One typical electrosurgical unit works at a frequency of 1.75 MHz, which lies between the AM broadcast band and the high frequency aircraft communications band.[2]

It is helpful to look at a typical electrosurgical unit and discuss each section in some detail. Figure 2 shows a block diagram of a simple electrosurgery unit.[3]

The RF oscillator is the heart of the system. It is the function of the oscillator to supply the RF current that is ultimately used at the electrode tip. There are two popular methods of constructing an oscillator. The first is by use of a crystal and the other is the use of a tuned tank circuit.

When crystals of certain substances are compressed or expanded, a voltage appears across opposite faces of the crystal. The polarity of the generated voltage changes when the nechanical force is changed from one that compresses to one that expands the crystal. Conversely, when a voltage is applied between the opposite faces of such a crystal, it will expand or contract depending on the polarity of the applied voltage. This phenomenon is called the piezoelectric effect. Although many crystalline substances are piezoelectric, natural

quartz has about the best frequency stability and is the most widely used crystal in the electronics industry.

If an alternating voltage is applied across the opposite faces of a crystal, it will vibrate. The amplitude of the vibrations is very small at most frequencies but becomes very large at one frequency called the resonant frequency of the crystal. The resonant frequency of a crystal depends on its physical dimensions, particularly its thickness in the direction of vibration. The thinner the crystal, the higher the frequency.

When a capacitor and inductor are arranged in parallel, the circuit is called a tuned tank circuit, and is the simplest form of oscillator (Fig 3).[8]

If the capacitor (C) is charged and allowed to discharge through the inductor (L) the electric energy will be stored in the magnetic field of the inductor. As the charge on the capacitor drops to zero, the magnetic field around the inductor builds to its maximum intensity. When the charge on the capacitor reaches zero, the magnetic field around the inductor will begin to collapse and cause current to flow in the opposite direction, recharging the capacitor to its original value of charge but with opposite polarity. This continues indefinitely in a perfect circuit, creating a flywheel effect at a particular frequency. The frequency at which the circuit oscillates is called the resonant frequency and is given by the formula:

$$f_o = \frac{1}{2\pi \sqrt{LC}}$$

where f_o is the resonant frequency, L is the inductance of the coil

in henrys, and C is the capacitance of the capacitor in farads.

Since a perfect circuit does not exist, the resistance of the

circuit causes the oscillations to die away slowly. This effect is

called damping. In any practical oscillator, to make up for the

energy lost is heat due to the resistance of the circuit. The re-

sulting steady waveform is called an undamped wave.[4]

As can be seen from the third equation, the resonant frequency

of a tuned tank circuit can be changed by changing the value of L or

C. The most common way to vary the resonant frequency is by the use

of a variable capacitor.

In a typical electrosurgical unit a fixed oscillator supplies

the RF current and a series resonant circuit is used to vary the cur-

rent to the patient. The resonant frequency (f_o) of the series re-

sonant circuit is typically the same as the f of the RF oscillator.

The current curve through a series resonant circuit is shown in Fig-

ure 4.

As can be seen from Figure 4, if the series resonant circuit

were made tunable the current supplied to the patient from the fixed

frequency RF oscillator could be regulated from minimum to maximum

as the series resonant circuit is tuned from point A to f_o. It

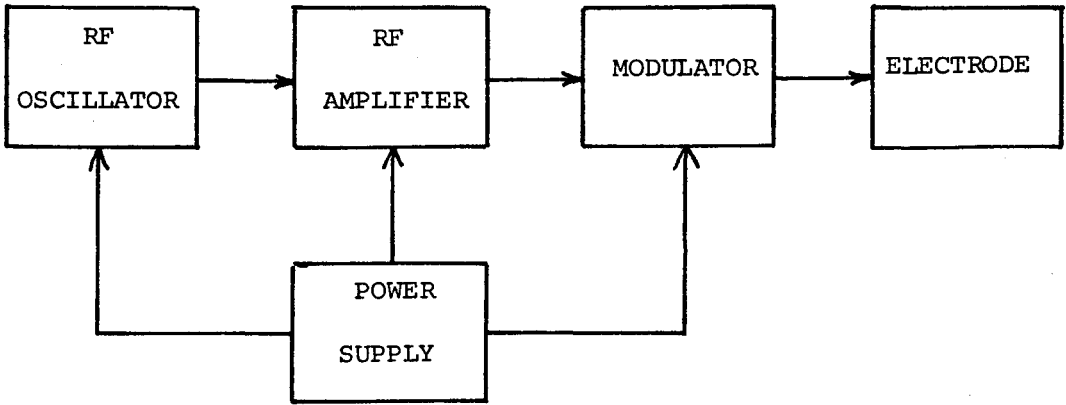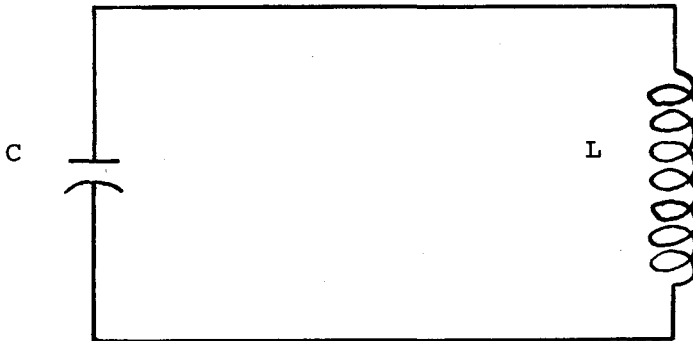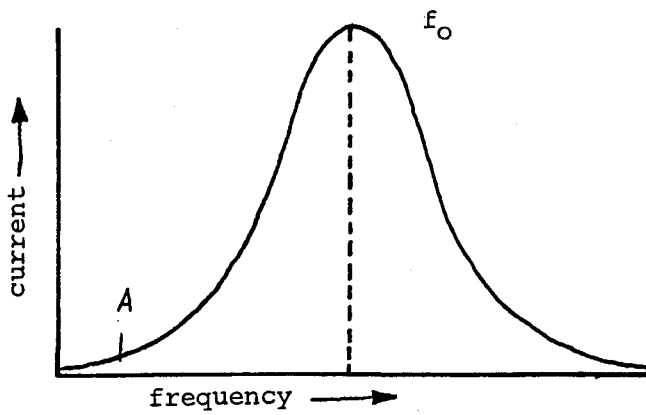should be noted that this current increase is nonlinear, and great

Fig 2

Fig 3

Fig 4

care should be taken when choosing the output setting for a parti-
cular operation as there is a sharp current rise between some adja-
cent settings on the output control while there is very little dif-
ference between other adjacent settings.[5]

In a typical unit a variable capacitor in series with a coil
(making a series resonant circuit) is mounted on the front panel of
the unit and is controlled by a knob marked off in fixed increments,
usually 1 to 10, and marked output. In some older units, such as
the Cameron-Miller model #255, separate outputs are used for cutting
and coagulation with different variable capacitors for each output.
In newer units such as the Macan, a switch is used to control the
internal circuitry through the same output.

Once the oscillator produces an RF waveform, the current must
be amplified to a usable level. This is done in most units by a
single RF amplifier tube. The amplified RF waveform is then im-
pressed on the output of the power supply in such a way as to give
the desired output waveform at the electrode tip. The process of
impressing one wave on another is called modulation and will be dis-
cussed below.

The power supply has many functions. It must take the power
available from the wall outlet or other power source and make it
usable throughout the unit. Normally, the input power to the unit
is 115 or 230 volts at 60 cps. Besides supplying power for the var-
ious lights, plate voltage for the amplifier and filament voltage if

the unit has a vacuum tube, the output of the power supply is modulated with RF.

There are two main types of waveforms produced in a typical power supply. These are half-wave rectified and full-wave rectified. Either of these can be filtered or unfiltered. The input of the power supply is a sine wave with a frequency of 60 cps (Fig 5a).

During half-wave rectification as the positive pulse rises from 0 to +Max and then falls back to 0, the diode conducts current through the load. As the negative going pulse falls from 0 to -Max and again rises to 0, current tries to flow in the opposite direction; however, the diode will only pass current in one direction. The diode then blocks the negative pulse and current does not flow through the load until the next positive pulse. The resulting current through the load is as seen in Figure 5b.

During full-wave rectification, opposite pairs of diodes conduct during each half cycle causing current to flow in the same direction through the load regardless of the polarity of the input wave. The output waveform is as in Figure 5c.

Sometimes it is desireable to have a DC output from the power supply. This is done by a technique called filtering. A simple filter is shown in Figure 6. Although there are many different kinds of filters, the one shown is the simplest and most common.

As the first positive pulse from the power supply enters the filter circuit, the capacitor C charges to the +Max of the input
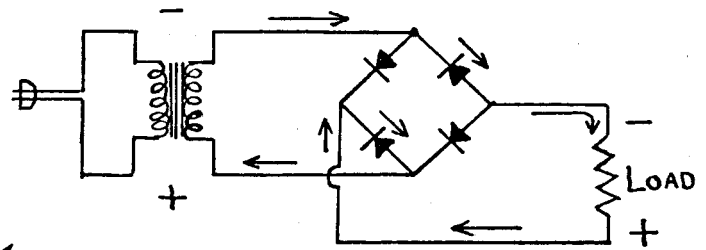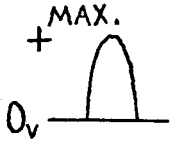
Input
115v 60c

(a)

DIODE

+MAX
0v
−MAX
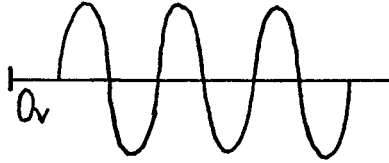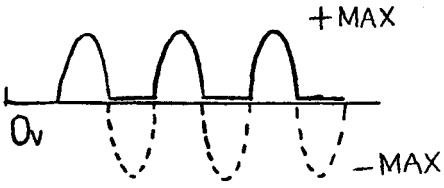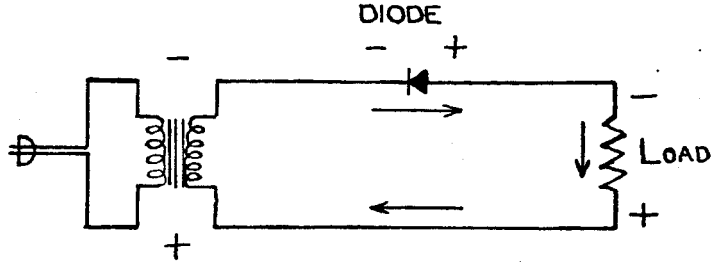
(b)   Half wave rectification

+MAX.
0v

0v
−MAX.

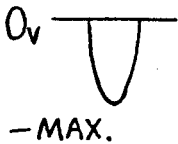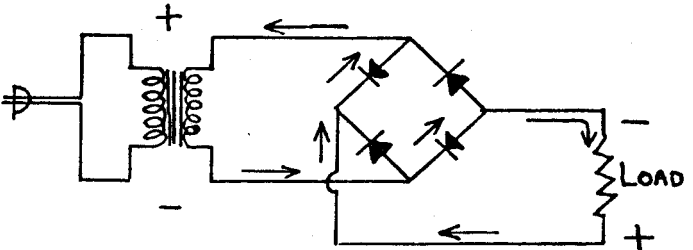(c)   Full wave rectification

LOAD

Fig 5

wave. As the pulse drops to 0, the capacitor discharges slowly through the load R keeping the voltage at nearly +Max until the next pulse recharges the capacitor to +Max. This phenomenon is diagrammed in Figure 7.

As can be seen from the solid line in Figure 7, there is a small amount of waviness in the output waveform. This is called ripple voltage and is inherent in all power supplies except batteries. However, with proper selection of components, ripple can be kept to a minimum with .01% being about the best.[6]

There are many different modulation techniques and the kind chosen for a particular unit is not really important. It is important, however, to understand what is accomplished in the modulator.

The circuitry of the modulator is constructed in such a way that when there is no voltage present at the power supply input (Fig 8a), no RF current will flow through the modulator. The normally open footswitch keeps the power supply voltage from entering the modulator. When the footswitch is pressed the voltage from the power supply enters the modulator and allows RF current to flow at a rate directly proportionate to the voltage level at the power supply input. As the voltage rises from 0 to +Max at the power supply input, more and more RF current is allowed through the modulator. As the power supply input drops from +Max to 0, the modulator conducts less and less until at 0v, no RF current flows. When the power supply is half-wave rectified and unfiltered, the output
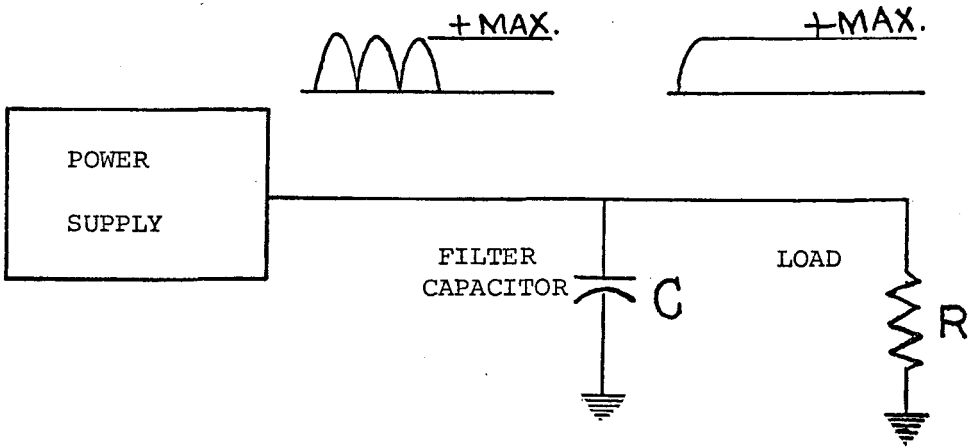
+MAX.

+MAX.

POWER

SUPPLY

FILTER
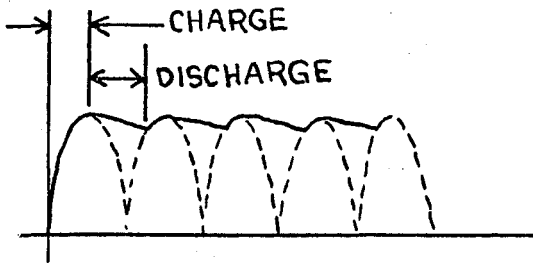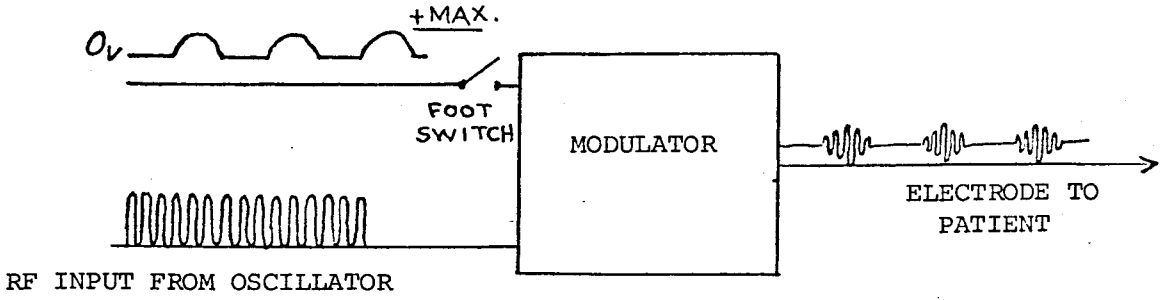CAPACITOR C

LOAD

R

Fig 6

CHARGE

DISCHARGE

Fig 7

waveform to the patient is as shown in Figure 8a. The RF pulses

occur at a rate of 60/sec. Figure 8 shows full-wave rectified un-

filtered (b) and full-wave rectified, filtered (c).[7,8]

POWER SUPPLY INPUT

0_v _____ +MAX.

FOOT
SWITCH

MODULATOR

ELECTRODE TO
PATIENT

RF INPUT FROM OSCILLATOR

(a)

POWER SUPPLY INPUT

0_v _____ +MAX.

MODULATOR

ELECTRODE TO
PATIENT

RF INPUT FROM OSCILLATOR

(b)

POWER SUPPLY INPUT

0_v _____ +MAX.

MODULATOR

ELECTRODE TO
PATIENT

RF INPUT FROM OSCILLATOR
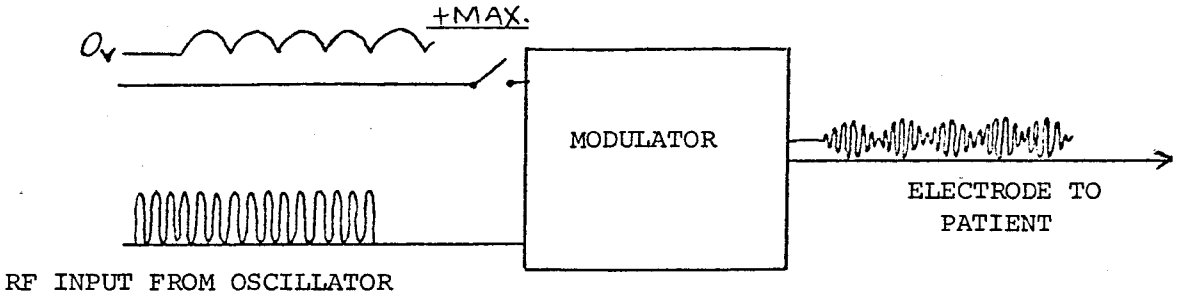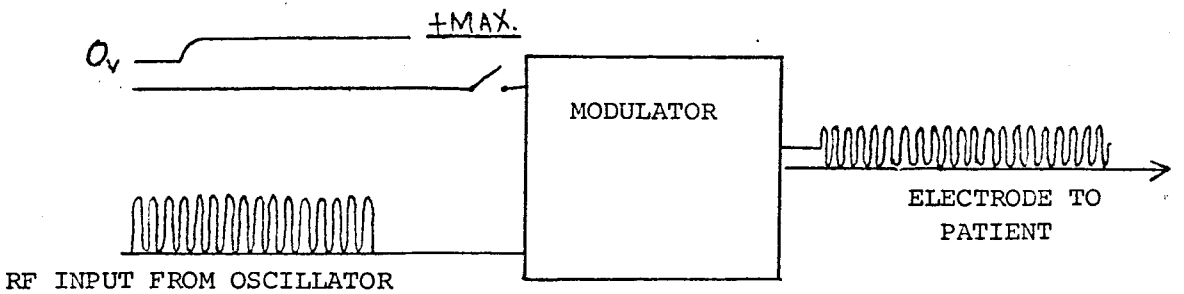
(c)

Fig 8

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APPENDIX B

MECHANISMS OF BONE RESORPTION INITIATED BY RADIO FREQUENCY

ELECTROMAGNETIC WAVES GENERATED IN ELECTRONIC SURGERY

The crystalline nature of calcified tissues in the oral cavity
is, in our opinion, of prime importance in causing bone resorption
when electrosurgery is used on or near bone. Crystals have been
used to generate various frequencies in electronics for over 50 years
(this mechanism is called the piezoelectric effect and is explained
in Appendix A). It is not unlikely the crystalline components of
bone (cementum and even dentin) can conduct the high frequency os-
cillations produced by the electrosurgery unit directly to viable
osteocytes when contact with the electrode is made. When a beam of
charged particles, ie, RF, passes through a crystal lattice, it is
referred to as "channeling." This has been reported by Brandt in
1968.

In soft tissues of the oral cavity, the current from the
electrosurgery unit meets less resistance than in bone and easily
cleaves the tissues. Two phenomena occur: one is direct molecular
oscillation or vibration, and the other is resistive heating.

In the first situation, the high frequency electrosurgery
current is sinusoidal and "flip flops" polar molecules at the fre-

quency of the oscillator in the electrosurgery unit. Resistive

heating, in the second instance, causes an instantaneous vaporiza-

tion of the water content of the tissues creating the "vacuoliza-

tion" or "blowing apart" of cells often described in the literature.

The two processes do not occur independently. The instantan-

eous dehydration of the water content of the tissues, however, is

not sufficient to be the cause of the deleterious effects in bone

stated previously with the use of electrosurgery. Since distilled

water is an excellent insulator, the presence of salts, inorganic

ions, carbohydrates, lipids, and nucleic acids in vivo facilitate

the current flow resulting in molecular oscillations coupled with

resistive heating; both are required in order to cleave soft tissues.

High resolution electron microscope examination has correlated

the crystallinity of bone and tooth apatite to the fine structures

of these tissues in normal and pathologic conditions (Selvig, 1970).

The piezoelectric effect was first demonstrated in bone in

1947 by Hussman (1958). Termine and Posner (1967) used x-ray dif-

fraction and demonstrated amorphous calcium phosphate could be con-

verted to crystalline apatite on exposure to water in vitro. Their

results showed crystalline apatite to average 65% of the total cor-

tical bone mineral. Bloom and Fawcett (1968) described the mineral

content of bone to average 65% of the fat-free dry weight of mature

adult bone.

The origin of the piezoelectric effect in bone has been shown

to arise in part or in whole from the presence of organic molecules particularly collagen (Marino and Becker, 1971), which has also been shown to exhibit the piezoelectric effect (Hussman, 1976). This is important to note since collagen determines the pattern of mineral alignment and architecture in bone. Collagen is a long chain polymer and can be degraded by the piezoelectric effect resulting from the application of high frequency oscillations (Bassett, 1968).

The piezoelectric effect in bone was shown by Marino and Becker (1974) to be independent of age, sex, and lapse of time following either death or removal of the bone specimen from the donor. Bone could therefore exhibit the piezoelectric effect in vitro and in vivo. However, in vitro studies cannot demonstrate bone necrosis; some additional phenomena must be responsible for bone necrosis in living tissues.

Bone has many crystalline forms in vivo (Posner, 1969; Selvig, 1970), but for the purpose of this discussion bone will be considered as a simple, single crystal. When the electrode tip contacts viable bone a voltage is developed across the bone (or crystal) between the electrode tip and the capacitively coupled ground plate (or ground if no plate is used; not recommended clinically). This makes the crystalline structure of bone oscillate at the frequency of the oscillator in the electrosurgery unit causing the piezoelectric effect.

Most electrosurgery units operate at about 1.75 MHz. When

this frequency is applied to bone, the polarity across the faces of the bone crystals changes 1,750,000 times per second. The amplitude of the oscillations is directly proportional to the applied voltage and the applied voltage is directly proportional to the resistance of the crystal for any given voltage generator.

Behari, Guha, and Agarwal (1975) applied a voltage of 220 volts to dry, mature human tibia specimens and measured the current at 10^{-7} amperes. Using Ohm's Law of Resistance (E=IxR), where E = voltage, I = current, and R = resistance, it can be calculated that the average resistance of these bone samples was 2.2×10^9 Ohms. Since this resistance is very high, the oscillations would also be very high compared to the static state.

These oscillations conducted through the crystalline structure of bone can easily damage the osteocytes in their lacunae, particuliarly those near the point of electrode contact, where the voltage developed is highest. Varying degrees of penetration of the radio frequency due to haphazard arrangements of the apatite crystals in bone could be one reason for varied reports of delayed healing.

Once osteocytes have been altered by the RF, varying effects may result depending on the amount of RF that reached the osteocytes. It is possible for enough RF to reach an osteocyte and cause its immediate death due to a combination of resistive heating and molecular oscillation. Another possibility may occur where a mini-

mal amount of RF energy reaches an osteocyte and the cell survives for a period of time before death ensues.

The latter situation probably is another reason delayed healing is reported. The extent of delayed healing would depend on the depth of penetration of the RF energy through the bone. The deeper the RF penetrates, the more osteocytes are affected, delaying healing even further. Normal physiologic bone resorptive sequences must than be initiated to remove dead or dying osteocytes. It has been noted above (p 28) that osseous tissue affected by RF appears to undergo repair in isolated instances. This was considered to be an exception and inconsistent with the results reported here.

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APPROVAL SHEET

The thesis submitted by Anthony T. Young has been read and approved by the members of the faculty of the Graduate School.

The final copies have been examined by the director of the thesis and the signature which appears below verfies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form, and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

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