

Histologic evaluation of electrosurgery with varying frequency and waveform

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While level of operator skill may determine the degree of tissue destruction produced during electrosurgery, the electronic characteristics of electrosurgical machines may also significantly contribute to tissue changes.¹⁻⁴ The present study examined the relative effects of different carrier frequencies and waveforms of four electrosurgical machines on incisions in hamster tongues.

MATERIALS AND METHODS

Carrier frequency and waveform characteristics of each machine were measured using a cathode-ray oscilloscope (Tektronix 531A)* and a high-voltage probe (Tektronix 6013)† at 2000 ohms (Fig. 1). The four machines selected for the study differed in output waveforms and frequency, which were fixed and not adjustable. Friedman¹ and Schon⁴ have described the various frequencies and waveforms generated by different electrosurgical machines.

Three machines were of the full-wave rectification type, with carrier frequencies representing 1.7,‡ 2.8,§ and 4.0|| MHz. These were used to evaluate the effects of differences in carrier frequency on the hamster tongue.

Two machines had identical carrier frequencies of 1.7 megahertz but different waveforms—full-wave rectification* and continuous waveform.† These

machines were used to evaluate the effects of differences in waveform on the tissue of the hamster tongue.

Experimental incisions were made using a specially constructed mechanical device (Fig. 1) to eliminate operator variability. The instrument produced the incisions on the superior surface of the tongue at a speed of 8.0 cm/sec to a depth of 1 mm using a Coles E-2-B straight-wire electrode‡ held perpendicular to the dorsum of the tongue. The power output for all machines was set at a constant 23 watts rms. The hamster was fixed rigidly on a platform, the body resting on the neutral electrode, with the tongue extruded and held firmly by a clamp in the cutting path.

The animals were anesthetized intraperitoneally with pentobarbital sodium at 0.6 mg/100 gm body weight. Using three animals for each machine, the tongues of 12 female adult hamsters were cut at 4 mm intervals. The animals were sacrificed immediately after each series of cuts was completed. Each tongue was excised from its base and placed in 10% neutral buffered formalin for more than 72 hours and then embedded in paraffin by the standard procedure.

Serial sections were cut parallel to the long axis of the tongue and perpendicular to the cut surface. Each section was 6 μ thick; every tenth section was mounted on a slide. The sections were then coded

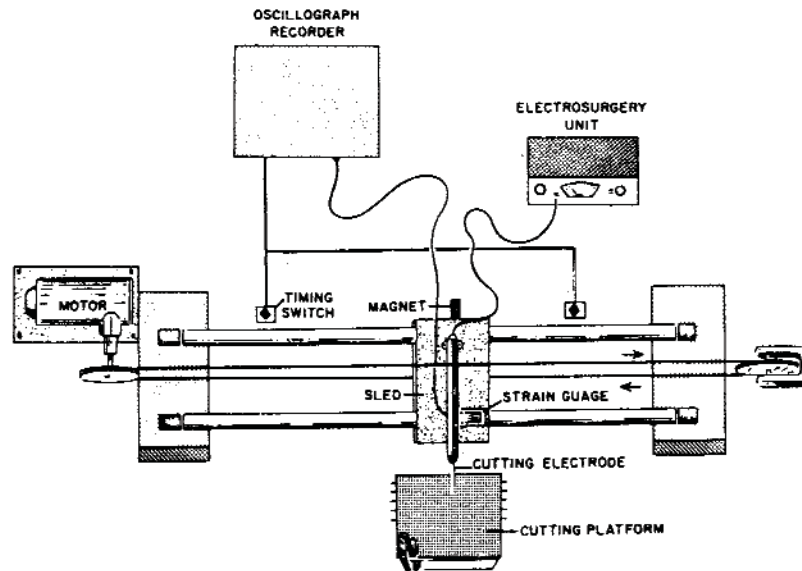


Fig. 1. Diagram of motorized system used for controlling speed and depth of cut by the electro-surgery machine to eliminate the variables induced by human operator(s).

Table I. Lateral extent of tissue alterations produced by different machines (in microns)

| Tissue layer | Machine | | | | Mean | Analysis of variance | |
|-------------------|---------|--------|--------|--------|--------|----------------------|--------------------|
| | I | II | III | IV | | Among layers | Among machines |
| Epithelium | 679.26 | 511.67 | 390.67 | 466.89 | 533.93 | F = 99.8 p < .001 | F = 4.8 p < .01 |
| Connective tissue | 324.47 | 310.83 | 186.00 | 256.78 | 278.35 | | |
| Muscle | 80.66 | 43.05 | 108.67 | 55.52 | 70.27 | | |
| Mean | 361.46 | 288.52 | 228.44 | 259.73 | | | |
| Frequency | 1.7 | 2.8 | 4.0 | 1.7 | | | |
| Modulation | FW* | FW | FW | CW† | | | |

*Full-wave.

†Continuous-wave.

and independently read by two investigators using a single-blind method. The extent of tissue alteration was measured in microns with an eyepiece micrometer. The criteria used to determine tissue and cellular alterations were:

1. *Nuclear changes* indicating degeneration and/or necrosis of the nucleus, such as pyknosis, karyorrhexis, and karyolysis.

2. *Coagulation necrosis* consistent with cellular degeneration as indicated by complete loss of cellular detail and reduction of the cell to an amorphous opaque and basophilic mass.

3. *Cytoplasmic changes* indicating cellular degeneration as characterized by increased granularity of the cytoplasm with or without fragmentation of the cellular membrane.

The zone of cellular alteration was defined as that region of cells demonstrating some or all of the above

characteristics and extending to the cells of normal appearance. The zone where there was a mixture of normal and altered cells was approximately 20 μ wide.

RESULTS

Table I. summarizes the average depth of tissue alteration (in microns) lateral to the incision site of each tissue layer for each machine. Differences among these means were statistically assessed by the analysis of variance.⁵ The *F* test indicated that overall differences among machines were significant ($p < .01$), as were differences among the 3 layers ($p < .001$). However, differences among the effects of the machines varied with tissue layers ($p < .01$). Machine I, with full-wave rectification and an operating frequency of 1.7 megahertz, differed significantly and in varying degrees from machine III



Fig. 2. Photomicrograph of typical experimental cut made into the hamster's tongue by the electrosurgery machines used in the study. (Hematoxylin and eosin stain, $\times 80$.)

(epithelial layer, $p < .001$; connective tissue layer, $p < .01$; muscle layer, $p < .60$). Machine I differed from machine IV in the epithelial layer and from machine III in the epithelial and connective tissue layers. Since machines I and III had the same waveform but widely different operating frequencies, this suggests that frequency was a significant factor in the extent of tissue alteration. Similarly, machines I and IV had the same operating frequencies but different waveforms. The resulting significant difference observed in the epithelium suggests that the *waveform* was a significant factor in the extent of tissue destruction, especially in the superficial tissue layers.

HISTOLOGIC RESULTS

The defect produced in the tongue approximated the shape of the cutting electrode (Figs. 2 and 3).

Epithelial layer. With all machines the keratin layer immediately adjacent to the cut surface was coagulated and characterized by an intense acidophilic stain and an amorphous arrangement of the degenerating keratin (Figs. 2 and 3). This alteration



Fig. 3. Photomicrograph showing the cellular details of the tissue changes from the experimental defect. (H & E stain, $\times 200$.)

was limited to an area immediately adjacent to the defect and did not penetrate laterally through the keratin layer for more than 50μ .

Immediately beneath the keratin layer the epithelial cells exhibited marked coagulation necrosis (Figs. 2 and 3). The epithelial cells nearest the defect were amorphous, with little or no cellular detail. Laterally from the defect the epithelial cells showed densely pyknotic nuclei interspersed with regions of karyolysis and karyorrhexis.

In the prickle cell layer the degenerative changes also decreased in severity with lateral distance from the defect. The cells closest to the incision were elongated, the cytoplasm demonstrated some granularity, and the long axis of the injured cells appeared to be arranged obliquely to the defect (Fig. 3). At the maximum depth of the altered cells there was a zone of about 20μ where the damaged cells blended together with the normal cells.

In the basal cell layer the damage was similar to that seen in the upper layers of the epithelium. The cells immediately adjacent to the cut surface exhib-

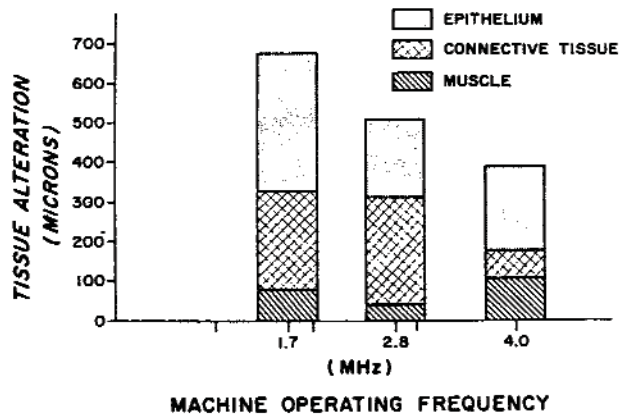


Fig. 4. Histogram showing amount of tissue affected (in microns) by machines operating at 1.7, 2.8, and 4.0 MHz. Greatest injury occurred at the lowest operating frequency and was especially evident in the epithelial layer (*top*). The waveform was constant.

ited coagulation necrosis and densely staining pyknotic nuclei. The altered cells closer in proximity to the region of normal cells were elongated, arranged approximately parallel to the cut surface, and finally blended into the normal epithelium (Fig. 3).

Connective tissue layer. The connective tissue layer exhibited much less destruction than the epithelial layer (Figs. 2 and 3). The connective tissue cells closest to the operative site demonstrated coagulation necrosis which resulted in an amorphous margin at the cut surface. Farther from the zone of coagulation necrosis and toward the normal connective tissue the cells became more densely basophilic and exhibited pyknotic nuclei. The fibers in this region were stained basophilic, and the basophilia decreased until the normal character of the fibers appeared, leaving a poorly defined 20 μ zone where the normal and altered connective tissues became indistinguishable.

Muscle tissue. The muscle tissue exhibited the least alteration (Fig. 3). Lateral to the cut surface, coagulation necrosis of these cells was minimal, with the contiguous surface of the muscle cells showing increased acidophilia. Some bundles of muscle fibers lost their cross-striations and demonstrated moderately pyknotic nuclei.

None of the sections showed evidence of inflammatory cells.

DISCUSSION

Tissue changes appeared to vary with the frequency and waveform of the four instruments. The findings of this study confirmed and extended

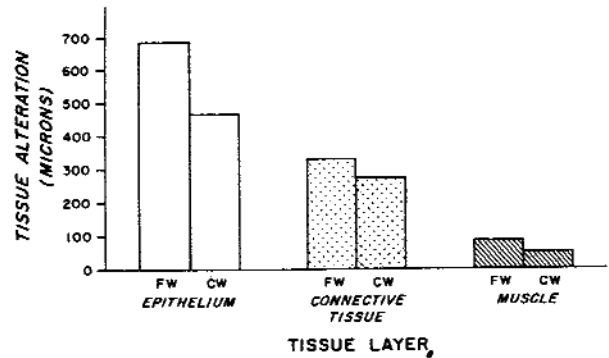


Fig. 5. Histogram comparing the effects of the full-rectification waveform (FW) and the continuous waveform (CW) on each of the three tissue layers. The operating frequency was constant at 1.7 MHz. Note that the full-rectification waveform produced more injury in each of the three tissue layers when compared with the continuous waveform.

the findings of Friedman and associates⁶ and Sozio and associates.⁷

Effects of different frequencies. With the waveform and power output held constant, tissue alterations increased as machine carrier frequency decreased. This effect was most pronounced in the epithelial layer, where the machine with the lowest frequency of operation produced the greatest amount of tissue alteration. The changes were progressively less in the connective and then in the muscle layers at the three frequencies tested (Fig. 4).

All of the findings in this part of the experiment, with the one exception of tissue alteration produced in muscle by machine III at 4.0 MHz, support the conclusion that tissue injury is greatest with the machines with the lowest operating frequencies (in this case, 1.7 MHz). This conclusion is consistent with previous findings indicating that the temperature produced in fat and muscle tissue varies inversely with frequencies from 10 to 1000 megahertz.⁸

Effects of different waveforms. Tissue alteration also varied with waveform in the tests performed with the two machines operating at the same frequency (1.7 MHz). Although the differences between the tissue alterations produced by these machines were statistically significant only in the epithelial layer, the findings suggest that the continuous-wave machine produced less injury in every layer (Fig. 5). This finding was in keeping with expectations, since the full-wave rectification machine has a higher peak power by a factor of 1.4 when operated at the same rms power output as the

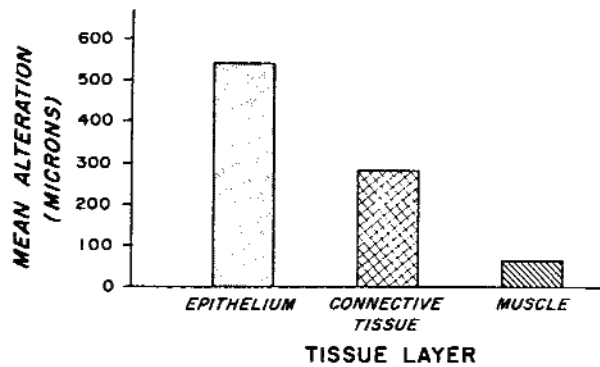


Fig. 6. Diagram showing that the most injury consistently occurred in the epithelial layer and the least in the muscle layer.

continuous wave machine. The higher peak power of the full-wave machine generates higher peak electric fields and current densities, which cause the greater tissue alteration.^{1, 2}

Tissue alteration in different tissue layers. Tissue alteration decreased with the depth of the tissue layer for the three frequencies and two waveforms evaluated in the study (Fig. 6). Depth of cell destruction was found to be nonlinear from layer to layer and also nonlinear within layers when compared to distance below the outer surface of the epithelium.

Another finding characteristic of all machines and independent of depth of tissue layers was the presence of a band of coagulation necrosis at the immediate margin of the defect. This was probably caused by the heat generated in the tissue by the electromagnetic field of the electrosurgical instrument. This region of necrosis had a fairly uniform thickness (50μ) and extended around the entire electrode-cut surface.

SUMMARY AND CONCLUSIONS

This investigation was designed to determine the differences in tissue alteration produced by electrosurgical machines with different carrier frequencies and waveforms.

Histologic analysis showed that:

1. The machine with full-wave rectification and the lowest frequency of operation (machine I, 1.7 MHz) produced significantly greater tissue alteration in the superficial tissue layers than the full-wave rectification machines with higher frequencies of operation.

2. The continuous-output waveform produced significantly less tissue alteration in the superficial tissue layers than the modulated type at the same frequency of operation.

3. Histologically, the experimental defect showed a band of coagulation necrosis approximately 50μ wide along the margin of the incision. Tissue destruction decreased laterally and inferiorly from the surface of the defect.

4. The experimental defect was similar in shape to the physical form of the cutting electrode.

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