

## Electrosurgery Burns Resulting from Use of Miniature ECG Electrodes

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During an electrosurgery operation, a young child received burns at the site of the ECG reference electrode. The electrosurgery unit was of the solid-state isolated patient-lead type, while the ECG unit had a grounded reference electrode. Although the cutting and coagulation powers were very low, the small size of the ECG electrodes led to the generation of a high current density. The ground-referenced power was generated in the electrosurgery unit at its operating frequency (500 kHz to 2 MHz) and bore no relationship to the excellent isolation of the unit at lower frequencies. Future burns of this type can be prevented by use of larger ECG electrodes and inductors in the range 22 mH to 100 mH or, more preferably, using only isolated patient terminal ECG units in an electrosurgical operation. Prevention of interactions of this kind between properly functioning monitoring and surgical units requires good communication among all members of the operating room team. (Key words: Equipment: electrical hazards; Complications: electrical burns.)

ELECTROSURGERY UNITS are used in numerous operations, and burns resulting from faults or misuse are not uncommon. In general, the surgeon is responsible for equipment under his control, while the anesthesiologist takes responsibility for his equipment (e.g., electrocardiogram unit). However, it is possible to produce burns when an electrocardiogram (ECG) unit with a grounded reference lead is used in conjunction with an electrosurgery unit that does or does not have its reference plate grounded.

This paper describes the extent of the ground-referenced radiofrequency (RF) current that may be generated when an isolated (from ground) patient terminal electrosurgery unit is in use. The danger of using

a ground-referenced ECG unit during electrosurgery is also discussed, with special reference to how this problem is exacerbated by use of miniature ECG electrodes.

To give further clarification to this problem and to permit recommendations to be established to avoid its recurrence, a case study is presented, together with a canine experimental study.

### Causes of Electrosurgery Burns

The problems involved with the use of electrosurgery units have been best detailed in a recent issue of *Health Devices*<sup>1</sup> dedicated entirely to these problems. While this report was complete in many aspects, it did not cover the seriousness of RF leakage currents in the presence of ground-referenced ECG units.

Becker, Malhotra and Hedley-Whyte<sup>2</sup> have summarized several ways in which burns can be produced during electrosurgery operations. Most of these included faults in electrosurgery units and/or associated equipment (ECG units). Under fault-free operating conditions, perhaps the most serious condition they reported was "divided current."

Although the output terminals of many modern electrosurgery units are isolated from ground, the isolation deteriorates at their operating frequencies (500 kHz to 2 MHz).

#### ABBREVIATIONS

mH	= millihenry
MHz	= megahertz
kHz	= kilohertz
mA	= milliamperes
rms	= root mean square (a sine wave with peak values of +1 and -1 has an rms value of 0.707)
mW	= milliwatts
$\Omega$	= ohm

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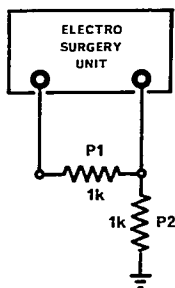


FIG. 1. Test circuit employed by electro-surgery unit manufacturers to specify their "RF Leakage Power Ratio,  $P1/P2$ "—where  $P1$  and  $P2$  are the powers dissipated in the respective resistors at a mid-scale control setting when used in the "pure" cut mode.

This particular deficiency tends to be obscured by the manufacturers' methods of quoting these operating leakage currents. Some companies quote a quantity called the "RF

leakage power ratio." This ratio is given by the following equation:

$$\text{RF leakage power ratio} = \frac{P1}{P2}$$

To determine this ratio the electro-surgery unit is adjusted to a mid-scale control setting and a 1,000-ohm resistor is placed across the patient terminals, together with a 1,000-ohm resistor from one patient terminal to ground (Fig. 1).  $P1$  then becomes the power dissipated in the 1,000-ohm load between the patient terminals;  $P2$  is the power dissipated in the other 1,000-ohm resistor. Under these test conditions, typical figures of 0.5 per cent and quoted for the RF leakage power ratio. When the electro-surgery unit is in the cut mode of operation at maximum setting, these figures indicate that approximately 2 watts could be dissipated in the ground line resistor. However, this assumes that the electro-surgery pen is never operated unless touching the patient (simulated by the 1,000-ohm load).

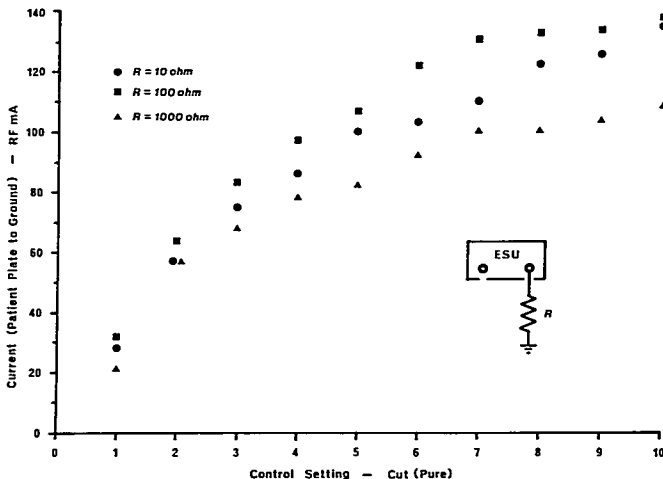


FIG. 2. RF leakage current to ground plotted against control setting for the Valleylab SSE-2 unit operated by a model E6003 foot-switch. Like most other electromedical leakage current situations, the results are not a direct function of the load resistor.

In a typical operation the foot-switch may be operated by a nurse while the surgeon uses the pen. In this condition it is quite usual for the unit to be in operation while the pen is not in contact with the patient. This mode of operation (effectively without the 1,000-ohm resistor across the patient terminals in figure 1) causes the leakage current through the ground resistor of figure 1 to be quite different. A typical graph of this leakage current plotted against electrosurgery unit control setting in the cut mode (pure) is shown in figure 2. The graph gives curves for three values of ground resistor—10, 100, and 1,000 ohms.

It can be seen that at a setting of 5, (*i.e.*, mid-scale) the leakage current to ground is approximately 100 mA rms—similar curves were produced by Becker *et al.*<sup>2</sup>

While under certain conditions manufacturers indicate that the leakage to ground of their electrosurgery unit is a fraction of 1 per cent, under normal operating conditions it is not unusual to obtain leakage currents that are far higher than anticipated.

Becker *et al.*<sup>2</sup> indicated that current densities of 1.32 mA/mm<sup>2</sup> will cause burns. Comparing their figure with the curves of figure 2 (maximum leakage of approximately 130 mA), it is clear that the electrosurgery unit represented by these curves should not be used in association with any ground-referenced patient electrode that is less than 100 mm<sup>2</sup> in contact area (*i.e.*, 130 mA ÷ 1.32 mA/mm<sup>2</sup>).

The time factor referred to by Becker *et al.*<sup>2</sup> in their summary ("Approximately 100 mA/cm<sup>2</sup> for approximately 10 seconds can cause skin damage") relates to the fact that tissue is capable of dissipating a certain amount of energy in a given time. When this critical level is exceeded, more energy is applied to the skin than the capillaries and subcutaneous tissues can dissipate. Consequently, a burn results. After a short heating period (determined by the magnitude of the current density) the time factor just determines the severity of the burn. In this respect, it is significant that the National Fire Protection Association<sup>3</sup> quotes a safe power density level of 15 mW/mm<sup>2</sup>.

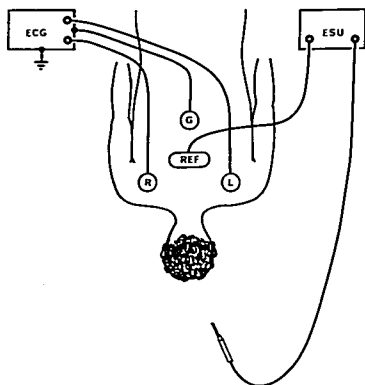


FIG. 3. Equipment layout for the reported operation that caused a significant burn under the ECG reference electrode, G.

### Report of a Case

In a recent case, a young child received burns while undergoing a neurologic operation that involved use of an electrosurgery unit<sup>1</sup> with isolated patient terminals and a ground-referenced ECG unit.<sup>§</sup> Due to the small size of the child, a miniature disposable electrosurgery reference plate<sup>¶</sup> was used, together with miniature disposable ECG electrodes.<sup>\*\*</sup> The arrangement employed is illustrated in figure 3.

At the end of the 3-hour operation, several small burns were found under the grounded reference electrode of the ECG unit. Both the electrosurgery and ECG units were inspected, tested, and found to be fault-free and in good working order.

The skin contact of the electrosurgery reference pad used on the child was 46 mm (1.8 inches) in diameter. According to the NFPA recommendations,<sup>3</sup> this pad would be suitable for carrying approximately 25 watts. During the operation, the control settings on the electrosurgery unit were at 1 for coagulation and 1.5 for cut. With these settings, the electrosurgery unit would produce about 20 watts of power in the pure cut mode. There-

<sup>1</sup> Valleylab SSE-2 operated by a model E6003 foot-switch.

<sup>§</sup> Burdick, model CS505.

<sup>¶</sup> American Hospital Supply Corporation, catalogue #65-118-010.

<sup>\*\*</sup> Harco, model HAR-150.

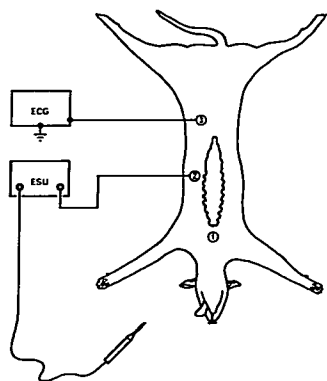


FIG. 4. Equipment layout used for the simulated study on a dog. The thorax of the animal was empty at the termination of a previous series of operations and studies.

fore, the electrosurgery reference pad was suitable (as defined by NFPA #76CM, 1970<sup>2</sup>) for the operation.

The disposable ECG electrodes used in this case were rubber disks 19 mm in diameter into which were punched six holes 1 mm in diameter on a 6.5-mm-diameter pitch circle. A seventh hole 1 mm in diameter was punched in the center of the disk. Contact between the patient and the metal electrode was achieved by electrode jelly inserted into the holes of the electrode disk. When such a disk is pressed into close contact with the

skin, the direct electrical contact between metal electrode disk and skin is achieved through seven holes each 1 mm in diameter—i.e., 5.5 mm<sup>2</sup>.

From figure 2 it is evident that at a cut setting of 1.5, a current of 50 mA can flow to ground when the electrosurgery unit is operated without the pen in contact with the patient. If this total leakage current has to pass through a disposable electrode of 5.5 mm<sup>2</sup> conducting area, then a current density of 9.1 mA/mm<sup>2</sup> exists at the patient's skin surface. This figure is well beyond the critical level of 1.32 mA/mm<sup>2</sup> set by Becker *et al.*<sup>2</sup> A similar problem, if not so critical, still exists when the electrosurgery unit is used for coagulation.

### Simulation

To test the above theories for the cause of the electrosurgery burn observed in this patient, the following simulation study was conducted on a dog after a series of catheterization and heart operations in which the animal had been sacrificed. The same electrosurgery and ECG units used in the operation on the child were employed in the simulation. The arrangement of the simulation is illustrated in figure 4. The area of use of the electrosurgery pen (1), the location of the electrosurgery unit reference plate (2), and the location of the ECG ground electrode (3) are shown. Four separate tests were conducted; relevant data and results are summarized in table 1.

TABLE 1. Summary of Test Data and Results

	Distances (mm)			ECG Electrode Area (mm <sup>2</sup> )	Coagulation			Cut			Comments
	1-2	1-3	2-3		Set-ting	Total Time (Min)	Duty Cycle (Per Cent)	Set-ting	Total Time (Min)	Duty Cycle (Per Cent)	
Test 1	180	300	140	5.5*	1	6	50	1.5	6	50	Burn under ECG electrode
Test 2	270	410	170	5.5*	1	10	50	—	—	—	Burn under ECG electrode
Test 3	—	—	170	5.5*	1	10	50	—	—	—	No contact with pen; worse burn under ECG electrode
Test 4	—	—	160	314†	1	20	50	—	—	—	No contact with pen; no burn

\* Harco HAR-150.

† Ferris Red Dot.

TEST 1

A miniature disposable electrode†† was used for the ground ECG reference. The distances between the reference electrode, the electro-surgery reference plate, and the area of operation of the electro-surgery pen are given in table 1. The electro-surgery unit settings were adjusted to 1 for coagulation and 1.5 for cut. The foot-switch was operated by one individual while the electro-surgery pen was operated by another.

The electro-surgery unit was run in the coagulation mode for a total period of 6 minutes at 50 per cent duty cycle (operating with the coagulation on for 10 seconds and off for the following 10 seconds to give a total coagulation time of 3 minutes). At the start of each 10-second period of coagulation, the pen was out of contact with the animal for approximately 1 second (a typical operating condition.) The period of coagulation was followed by a total period of 6 minutes on cut with a 50 per cent duty cycle (again with 10 seconds switched on and 10 seconds switched off).

At the conclusion of the test the ECG electrode was removed and small burns corresponding to the holes in the electrode were seen on the surface of the skin.

TEST 2

It was decided to investigate whether the coagulation leakage current alone was capable of causing a burn. The arrangement was similar to that of Test 1.

A total time of 10 minutes at a 50 per cent duty cycle (10 seconds switched on and 10 seconds switched off) was used to give a total coagulation time of 5 minutes. Again, the electro-surgery pen was not in contact with the animal for a period of approximately 1 second when the unit was switched on at the start of each 10-second period. At the completion of the test, the ECG electrode was removed, revealing burns similar to those obtained in Test 1.

TEST 3

To determine whether the most dangerous situation existed when the pen was not in

TABLE 2. Data from a Typical Unit\*

Output Voltage (V rms)	Resistive Load (ohms)
840	∞
430	500
280	200

\* An indication of the poor load regulation of modern solid-state electro-surgery units is given by these data.

contact with the patient, a test was conducted during which the pen was never in contact with the animal even though the coagulation mode was switched on. A total period of 10 minutes at 50 per cent duty cycle (10 seconds switched on and 10 seconds switched off) was used for this test. Removal of the ECG electrode after the test revealed burns worse than those obtained in either Test 1 or Test 2.

TEST 4

Test 3 was repeated using a larger jelled disposable electrode‡‡ whose area of jelled contact was 314 mm<sup>2</sup> (20 mm diameter). A total test time of 20 minutes at 50 per cent duty cycle (10 seconds switched on and 10 seconds switched off) was used to give a total coagulation time of 10 minutes. At the conclusion of the test no burn was found underneath the ECG electrode.

Discussion

While there have been many articles on leakage currents at the line frequency of 60 Hz<sup>1,2,5,6,7,8</sup> and their fibrillating effect upon the heart, the average hospital remains unaware of the potential hazards of leakage currents in electro-surgery units when they are running at their operating frequency (500 kHz to 2 MHz). The methods used by electro-surgery manufacturers to specify their RF leakage currents tend to be misleading and to give no real indication of the potential hazards presented by their units. All solid-state isolated-output electro-surgery units have the same problems.

Apart from defective equipment, the use of ground-referenced ECG units in the pres-

†† Harco-model HAR-150.

‡‡ Ferris Red Dot.

ence of electrosurgery apparatus probably offers the greatest potential hazard to the patient and operator alike. The older tube-operated and ground-referenced ECG monitors are generally as accurate as modern units; however, with increased use of electromedical apparatus in the patient area, the use of any ground-referenced patient-terminal equipment in such an area offers increased potential hazards. It is largely due to this particular feature that ground-referenced terminals on medical equipment are considered obsolete—even though the equipment may be only five or six years old and fully operational.

The miniature electrodes described in this report are developments of the electrodes reported by Lucchina and Phipps<sup>9</sup>. Their composition, 30 per cent silver and 70 per cent silver chloride, achieves the best compromise between voltage difference across the electrode jelly and resistance of contact with the skin. The advantage of these "floating electrodes" is related to the good electrical contact they maintain under exercise conditions. A detailed review of these electrodes and others is given by Geddes and Baker.<sup>10</sup>

The maximum output power of a typical electrosurgery unit when operating with a 500-ohm non-inductive load is 370 W rms (see table 2). These figures indicate a maximum current flow of 860 mA. To limit the current density to 1 mA/mm<sup>2</sup>, an electrode would be required to have an area of 860 mm<sup>2</sup> (i.e., 30 mm × 30 mm). The average strap-on limb electrode is approximately 20 mm × 30 mm in size. Consequently, these electrodes are still not sufficient (when used on a ground-referenced ECG unit) to cope with the maximum possible RF current from the electrosurgery unit in a fault condition (e.g., if the electrosurgery pen should touch a grounded object while it is switched on).

Clip-on universal electrodes are in the range of 30 mm × 50 mm (1,500 mm<sup>2</sup>) in size and are, therefore, suitable for ECG monitoring—at least during use of an electrosurgery unit with the "typical" specifications given above.

Accepting that the present generation of isolated-output solid-state electrosurgery

units have relatively large RF leakages,<sup>2</sup> it is necessary to define how these leakages can be prevented from passing along grounded ECG reference leads—i.e., rather than having to resort to excessively large ECG electrodes. The most effective way to limit the RF ground current in the ECG electrodes is by use of an inductor.<sup>2</sup>

The design criteria for this inductor are: 1) The impedance,  $X_{L1}$ , at the electrosurgery operating frequency (500 kHz) should be sufficient to limit the current to a safe current density at the ECG electrode. 2) The impedance,  $X_{L2}$ , at 60 Hz, should be less than 1 k $\Omega$ . The input impedance of ECG amplifiers is of the order of 10 M $\Omega$  so that 1 k $\Omega$  does not adversely affect the sensitivity of the machine (in fact, certain manufacturers build 1 k $\Omega$  resistors into the ECG cables used on their monitors. 3) The inductor should be a standard value of such a size that it can be built easily into the system. Inductors in the range 22 to 100 mH (i.e., equivalent to maximum RF leakage currents of 11 to 2.4 mA) satisfy these three basic criteria.

The ECG monitor and electrosurgery unit used in the reported operation were both electrically safe (in that they met their respective manufacturers' specifications). The burns were due to a combination of effects (primarily related to the fact that the circuit isolation of isolated electrosurgery units is poor at their operating frequencies of 500 kHz to 2 MHz) that were exacerbated by use of miniature ECG electrodes.

### Possible Solutions

Future burns due to similar interactions can be avoided in a variety of ways. The following solutions to the problem are listed in order of descending suitability.

### NEW ECG UNITS

It is recommended that only modern, isolated-patient-lead ECG units be used during electrosurgery operations. Purchase of a new ECG unit would negate both the need for tedious alterations to old ECG leads and the need for a complete change of ECG electrodes. Based on the same kind of reasoning, it is necessary (due to increased use of

electrodiagnostic and monitoring equipment in the management of patients) to plan the phased installation of isolated patient-terminal equipment in critical areas such as operating rooms, coronary care units, and intensive care units. The number of potential interactions between ground-referenced units in critical care areas is so great that any ground-referenced equipment offers more hazards than can be anticipated by the average physician or maintenance engineer.

Even with installation of a new ECG unit, use of miniature floating electrodes is not recommended. The pre-jelled, larger contact area disposable electrodes are safer and take up no more space than the miniature floating electrodes (due to the size of the adhesive disks employed).

Polarizing electrodes are potentially hazardous when used during defibrillation. Although the electrodes used in the present study were of a polarizing type, any suitably large disposable, non-polarizing silver/silver chloride electrode could be used safely.

#### MODIFICATION OF ECG LEADS

If it is necessary to continue use of ground-referenced ECG units during electrosurgery operations, or similar procedures, then the following modifications *must* be conducted to ensure safety of operation: 1) the ECG reference electrode should be as large as possible, and 2) a current-limiting inductor (in the range 22 mH to 100 mH) should be inserted in the reference lead (and ideally all other leads) as close to the ECG electrodes as possible. In practice, this would be at the connector block of the ECG cable.

While the latter alternative is far cheaper than purchasing a new monitor, it is dependent upon availability of personnel and facilities to modify the ECG leads, and should be considered a poor substitute for

the supply of the appropriate equipment for the job.

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