Because of the increased usage of sophisticated electrical equipment in the operating room, a knowledge of the inherent electrical hazards is vital. The author provides a basic outline of the principles of electricity and the applicable cautions.

It has long been accepted that varying degrees of risk exist for the patient in the operating room. Recent attention to the ecology in this environment where we spend so much of our time has shown that the medical personnel likewise are subjected to many hazards. Along with the well known dangers of flammable and explosive anesthetics must now be added pollution, especially with halogenated anesthetic gases, and electrical hazards, occasioned by the vast increase in the numbers and complexity of electronic apparatus now employed in surgery.

The increased incidence of spontaneous abortions in female members of the surgical team, as compared with their medical counterparts,\(^1\) the increased risks of congenital abnormalities, leukemia-like diseases, headaches, and depression may represent effects of inhaling small quantities of anesthetic agents on a chronic basis as they exude from our pop-off valves. This has led to increased research and the development of scavenger systems to rid the operating room of these volatile pollutants. But, what of the problem of electrical hazards in the operating room?

**Electricity**

The subject of electricity can be extremely complex. Analysis of the circuitry of some of our sophisticated monitors requires advanced knowledge of the subject, which most of us do not possess nor do we plan to acquire. In-

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**Definitions**

2. Voltage: (emf) The pressure driving electrons through a conductor.
3. Ampere: The rate of flow of electrons through a conductor (analogous to liter/min).
4. Watt: Unit of electrical power (one ampere at a pressure of one volt is one watt of power).
5. Joule: (Watt-Second) Unit of electrical energy (power multiplied by time of application).

**OHM's Law**

\[ V = I \times R \text{ or } I = \frac{V}{R} \]

Electrical pressure in Volts (V) is the product of Resistance (R) in ohms and current (I) in amperes. Current, therefore, is directly proportional to voltage and inversely proportional to the resistance:

| Moist Skin | 110 Volts | 1,000 Ohms | 0.11 Amperes |
| Dry Skin, shoes, clothing | 110 Volts | 100,000 Ohms | 0.001 Amperes |

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stead it is more prudent to review some of the basic principles of electricity, and consider some of the variables we understand and have within our control. In so doing, we can make a concerted effort to better comprehend and thus reduce the hazards presented to our patients and to us in our daily work by the electrical instruments on which we depend.

Electricity seeking a pathway through the intact, dry skin meets a greater resistance than through a moist or broken skin as demonstrated by Ohm’s law. Thus, patients with electrodes which pierce the skin or especially patients with catheters and pacemaker lines which lie in or near the myocardium become "electrically susceptible" and can be electrocuted (ventricular fibrillation) by extremely small currents. These currents would have a direct path to the heart, virtually unimpeded by the customary resistance offered by the intact integument.

Such breaching of the integumentary resistance allows the body to become a conductor, thus permitting microcurrents in the micro-ampere range to result in electrical shock. These currents are too minute to be perceived by the awake subject. Microshock, then, does represent a definite hazard to electrically susceptible patients, not only in the operating room, but also in the cardiac catheterization laboratory, the recovery room, the intensive care unit, and other areas of the hospital. Such currents, predominantly leakage currents, may originate from obscure sources and produce their damage without being detected.

| Current | DC—Direct Current—Flow may be intermittent but always in the same direction. AC—Alternating Current—The pressure of the current rises to a peak declines to zero, then reverses its direction and repeats the process. These two alternations or one cycle, are completed in 1/60 seconds, or (60) cycles per second. (60 Hertz) |

**Effects of current**

The consequence of electrical current through body tissues depends upon the frequency of the current, the duration of the application, the pathway taken, the density of the current, and the response of the particular tissue. The density, which refers to the concentration of flow per unit area, is of great importance. The needle electrode, for example, will produce a greater density of current at the point of contact than the plate electrode. Besides, the needle electrode invades the natural barrier of the integument. Macroshock refers to passage of current through the body in this perceptible range.

The incidence of accidental microshock in electrically susceptible patients

<table>
<thead>
<tr>
<th>Physiological effects</th>
<th>Through Intact Skin</th>
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<tbody>
<tr>
<td>1 Milliampere</td>
<td>Threshold of perception</td>
</tr>
<tr>
<td>5 Milliamperes</td>
<td>Maximum harmless current</td>
</tr>
<tr>
<td>10-20 Milliamperes</td>
<td>“Let go” current</td>
</tr>
<tr>
<td>50 Milliamperes</td>
<td>Pain, fainting</td>
</tr>
<tr>
<td>100-300 Milliamperes</td>
<td>Ventricular fibrillation</td>
</tr>
<tr>
<td>6-10 Amperes</td>
<td>Sustained myocardial contraction</td>
</tr>
</tbody>
</table>

**“Microshock”**—current, too minute to be perceptible, but dangerous because it is applied directly to the myocardium.

<table>
<thead>
<tr>
<th>Through Intact Skin</th>
<th>Direct to Heart</th>
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<tbody>
<tr>
<td>60 Cycle</td>
<td>Ventricular Fibrillation</td>
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<tr>
<th>Dogs—20 Microamperes (lowest) to 258 Microamperes (average)</th>
<th>Man—180 Microamperes (lowest) to 583 Microamperes (average)</th>
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</thead>
<tbody>
<tr>
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is hard to determine. However, it is certain that these accidents can and do happen, so we must direct our attention to their prevention. Confusion with experiments on dogs led to the erroneous conclusion that microshock as low as 20 microamperes can be fatal to man. Information relative to man has been largely acquired during open heart surgery and is to be interpreted in this context. It seems clear, however, that microcurrents much higher than 20 microamperes are necessary to produce ventricular fibrillation in electrically susceptible patients.

Leakage current
This current, usually small, becomes available for many reasons, including insulation failure. It must reach the earth by the path of least resistance; separate ground wires are used to supply this path.

Grounding
A ground is a connection which conducts electrons from electrical circuits or equipment to earth. Such a connection may be intentional or accidental. Any electrical pressure difference between a charged object and the earth is equalized through the ground. A good ground should be a nearly perfect conductor, so that current will use it preferentially as the path of least resistance for travel back to the earth. A faulty ground may force the current to take an alternate path wholly or in part. The patient or one of us may be that alternate path.

Conventional circuit
In a conventional circuit, the transformer output conductor at a pressure of 110 volts is called the hot or live conductor. Another terminal, usually at the point where the power enters the building, makes contact with the earth and is known as the grounded, cold or neutral line. Current flows from the hot line to the electrical appliance and back to the earth. The earth has almost an unlimited capacity to accept electrons and is, therefore, the reference point for electrical neutrality. A grounded individual has to contact only one wire to complete the circuit and be shocked. The current pathway is as follows:

\[
\text{Power source} \rightarrow \text{hot wire} \rightarrow \text{grounded individual} \rightarrow \text{earth}.
\]

Isolation transformer
Ungrounded circuits are used in the operating suite. The primary circuit (the power source) feeds the secondary circuit in the operating room, through an isolation transformer, which, in turn, interposes a magnetic field between the two circuits. Unlike the conventional circuit, neither side of the secondary circuit is grounded—a floating circuit exists.

Grounded personnel are protected from shock since inadvertent contact with a live conductor will not complete a circuit to true ground. Though the grounded subject contacts both circuits through the ground of the primary circuit and the live wire of the secondary circuit, he completes neither circuit. Actually, leakage currents result in some flow but usually of small magnitude.

The ungrounded circuit is monitored by a sentinel, and leakage current of more than 2 milliamperes triggers a visible and audible alarm. The offending appliance must be promptly disconnected and checked.

Electrical hazards
The main electrical hazards in the operating room result from the following:

1. The Bovie or other electrosurgical equipment.
2. Patient monitors.
3. Other electrical apparatus.

Salient problems are:
1. Ignorance of hazards on the part of operating room personnel.
2. Inadequate or improper design of equipment.
3. Inadequate maintenance.
4. Improper use of equipment.
5. Abuse of equipment.
The human agent is the most important variable in the production of electrical injuries. Proper attention to the things in our control will prevent the vast majority of these mishaps.

**Prevention**

Some pertinent preventive measures include the following:

1. Only equipment which meets safety standards of organizations, such as the National Fire Protection Association (NFPA), should be used in the operating room.

2. Instructions as to the proper grounding and application of such equipment to the patient should be followed to the letter.

3. Any electrical equipment should be handled and used with due care and respect.

4. Avoid meddling with equipment without concomitant knowledge.

5. Avoid thermal abuse. Keep delicate objects away from hot surfaces; combustibles will ignite.

6. Be careful with portable machines; since they are easily moved, they are easily dropped and damaged.

7. Conductive shoes and equipment, which are precautions against static sparks, make us more vulnerable to electric shock and electrocution in areas where there are conventional circuits. These shoes should be worn only in areas where the isolation transformer is operating.

8. Avoid situations which tend to breach the natural resistance of the skin and produce high density currents to electro-sensitive tissues.

9. Stand clear when patients are being defibrillated or cardioverted. Conductive anesthetic equipment and conductive shoes make us more prone to inadvertent shock and ventricular fibrillation.

10. The question of the possible danger of microwave ovens, now in popular use, to patients with pacemakers has been of concern. These patients are electrically susceptible and thus are subject to microshock. Though improved design has lessened this susceptibility, extra precaution must be observed with these patients. The electrocautery, if mandatory, such as in a TURP, must be placed so that the ground is near the cautery and remote from the pacemaker generator. Additionally, a demand pacemaker should be converted to a fixed-rate pacemaker during the time the cautery is being used.

Far more important than listing the measures to be taken against these mishaps is the actual maintenance of a constant program of surveillance and education, with due attention being paid to the ever-present human factor. Employing reasonable discipline and common sense in our everyday performance in this hazardous area will eliminate most of the problems. The anesthetist is in an excellent position to be the overseer of safety during surgical procedures. To protect our patients from injury has always been our bounden duty. To extend this care to our colleagues and ourselves is a calling of no less importance.

**Electrosurgical equipment**

The high frequency electrocautery unit (circa 2,000,000 cycles/sec) is used with increasing frequency today. Many people do not understand its function nor its potential danger. An extremely high current density at the small active electrode causes rapid heating. The ground pad must make contact with a large area of the patient's skin allowing low density current at the area of exit. A small area of contact may cause high density current and therefore severe burns at the site of exit. Omission of the ground plate will force the high frequency current to seek an alternate return path, such as the monitoring electrodes or any conductive object in contact with the patient. Needle electrodes will act like the cautery tip and produce severe burns. Electrically susceptible patients may be electrocuted.

It is mandatory to ensure that the
ground plate is properly placed to make contact with a large area of the patient's skin, avoiding bony prominences. Conductive jelly should be used when necessary to lower the skin resistance. Obviously, the ground must be plugged into the generator, and the ground wire checked for continuity. Whenever a unit malfunctions, especially if increased power is needed, the ground pad and wire must be carefully rechecked.

Such devices, so commonly used in our operating rooms today, are principal offenders as far as potential electrical hazard is concerned. It cannot be overemphasized that the electrocautery must be subjected to constant surveillance by all personnel concerned to protect our patients from severe burns and other electrical injury.

It is encouraging to note that some attention is being paid to the recommendation by NFPA 56A that equipment which introduces current into the patient's body must have an isolated current output. This isolation of the output from ground will protect the patient from being an unintentional return path for currents seeking ground. If this standard should be adopted, electrocautery burns would be drastically reduced.

**Maintenance**

The most hazardous parts of any electrical equipment are the power cords and power plugs. In this regard:

1. Worn or damaged cords should be promptly replaced. Temporary mending with tape is inadvisable and dangerous.

2. Cords and cables should be coiled to prevent sharp flexing and protected from the scissoring action of doors, operating tables, and circlelectric beds, and from trauma from x-ray machines.

3. Ground wires should be protected from abuse. (A Lubin plug can prevent the fracture of the ground wire, leaving the conducting wires intact.)

4. Improper extension cords should be avoided.

5. The grounding prong from a plug should never be broken for use in a two-prong socket; nor should the plug be changed to omit the ground wire.

6. Furthermore, cheaters which adapt a three-prong plug to a two-prong socket should be avoided; the coverplate screw to which the pigtail is attached may not even be grounded.

7. External ground wires are electrically ineffective at best, and require that the persons using them have a knowledge of the problems to be solved. Unfortunately, this is rarely the case. Often, the alligator clips do not make a proper connection and are erroneously placed.

8. Ground wires should be connected before the equipment is turned on and left attached until after the power is turned off. The proper three-prong plug is so constructed for this purpose.

Generally speaking, it is also important to avoid using household equipment in the operating room environment. Do not use equipment for purposes for which it was not designed; such mismatch between capability and utilization can be dangerous. Defibrillators must have their outputs checked and their functional ability tested often. Since they are rarely used, they may tend to be forgotten until needed. And, finally, keep casters clean! Dirty, obstructed casters can result in toppling of expensive electrical equipment, with consequent damage and malfunction.

A regular program of equipment testing is mandatory for safety. Any electrical problems must be promptly solved by someone knowledgeable in these matters. No shortcuts should be taken, nor should procrastination be allowed. New equipment should also be evaluated by an expert before it is placed in service.

There is most often a lag between the time that equipment problems are identified and documented and the time that regulatory agencies suggest, recommend, and finally regulate safety measures to prevent such problems. During
this period of transition, it is left to the individual, such as you and me, to reduce these hazards to a minimum by becoming aware of the problems, and by employing vigilance and common sense. Until the design and performance of our equipment make it absolutely safe, cautionary usage must be employed. While the light fixture still hangs over the bathtub, let us concentrate on ensuring that no one turns on the light while taking a bath.

Summary

That electrical hazards exist in the operating room is obvious. The increased use of sophisticated monitors has not only increased this danger but has produced a group of electrically susceptible patients in the operating room, intensive care unit, and sometimes in other parts of the hospital. Knowledge, responsibility, constant vigilance, and common sense are necessary to reduce these dangers. But above all is the requirement for a continued program of education for all echelons of personnel and a protocol for surveillance of the equipment and situations that may subject our patients and ourselves to these injurious and sometimes fatal forces. The electrocautery is seen as an instrument demanding particular care and respect.

REFERENCES


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This paper was presented at the American Association of Nurse Anesthetists 43rd Annual Meeting, Clinical Session, and Postgraduate Course held during August, 1976 in San Francisco, California.

The author wishes to point out that the opinions or assertions in this article are his own and are not to be construed as official or reflecting the views of the Navy Department or the Naval Service at large.