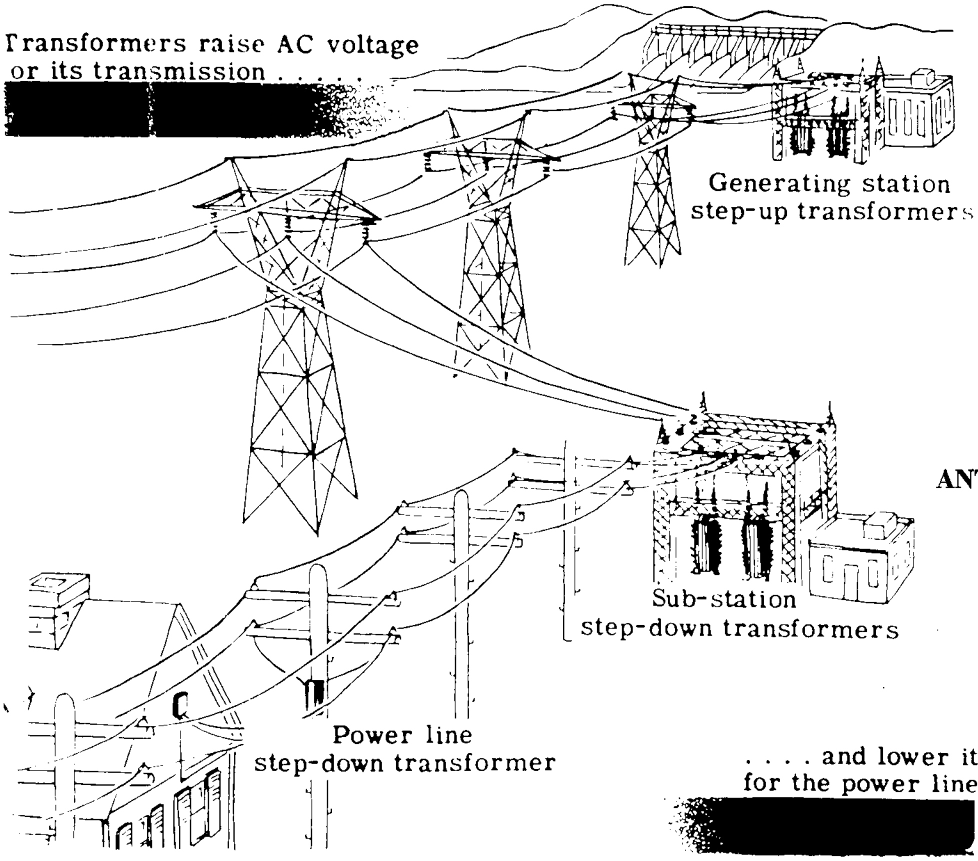


Figure 1

by
ANTHONY J. ADDUCCI
Medtronic, Inc.

Special Electrical Considerations

in intensive monitoring

In the last 5 to 10 years we have seen a tremendous increase in the amount of electrical equipment used in our hospitals. Operating rooms, heart cath labs, and coronary care units are overflowing with sophisticated monitoring, recording, and stimulating equipment. At the last American Heart Convention I attended, I noticed that there with an over-abundance of electronic monitoring and stimulating equipment. It looked more like a meeting of electronic engineers than a medical meeting. Drug companies were in the minority.

What does all of this mean to you, the medical staff of a hospital? Well, it's getting harder and harder for manufacturers to make equipment "operator proof," i.e., eliminate the possibility of human error. Eventually, training in the proper use of electrical equipment will have to be included in medical schools, schools of nursing and allied health professions, or through continuing education. Until that time, nurses and physicians are going to depend on the medical electronic technicians to help with assistance in operating and maintaining electronic equipment.

Electrical Ground

One of the things I have found in talking to technologists, physicians, and nurses throughout the country is a lack of understanding of what is a true electrical ground. What are they really doing when they ground a piece of equipment? So let's start out by defining what electrical ground is.

Presented by Northlands Regional Medical Program, Minnesota Heart Association ICCU Project in conjunction with Charles T. Miller Hospital, St. Paul, Minnesota.

A ground is a connection, whether intentional or accidental, between an electrical circuit or equipment and the earth. Why do we use the earth? Well, the earth has an unlimited capacity to give up or receive electrons. When a charged object is touched to the earth, it gains or loses electrons until it reaches the same potential or electrical pressure as the earth.

If two charged objects are touched to the ground, both objects assume the same potential or electrical pressure as the earth. Therefore, no pressure difference exists between any pair of objects connected to the earth; voltage difference equals zero. By convention, we have chosen zero potential for the earth; therefore, any objects touched to earth will have zero or ground poten-

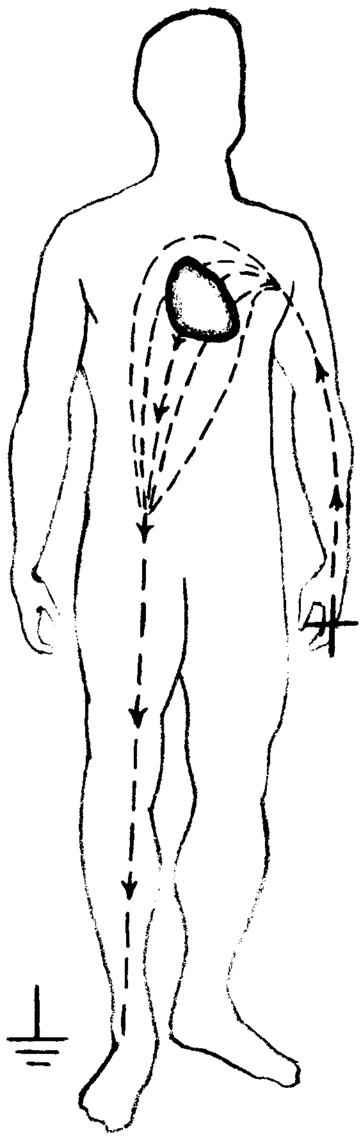


Figure 3

tial. Another question asked is, how does ground get into the hospital power system?

I think the best way to answer this is to go back to the power station at Niagara Falls (Fig. 1). As we can see, at the falls we have a power generating station. By using the energy of the falls, large AC generators produce somewhere around 6,000 volts of electricity. This is stepped up to 120,000 volts at low current to be transmitted over the transmission lines. The low current and high voltage is necessary to prevent voltage drops along the transmission lines.

Also back at the power station, a number of copper rods are sunk into the earth at about 60 feet in depth to form a kind of grid to try and obtain a true ground potential. One of the transmission lines is also grounded at this potential and along the route it is periodically grounded to the earth to keep it from picking up any stray potentials.

At the transformer serving the hospital, a ground connection is again established with the earth and then introduced to the hospital distribution system. At the distribution panel, the neutral wire is again connected to ground through the water pipes which, of course, go into the earth and are at a good ground potential.

Pathological Effects of Electricity

The first death caused by electricity occurred in France in 1879.[1] Over the years, the incidents of accidental electrocution have increased steadily. At a recent medical meeting, Dr. Carl W. Walter, a surgeon at Peter Bent Brigham Hospital in Boston, stated that over 1,200 people are electrocuted annually in hospitals. This, of course, is a controversial statement and very difficult to prove. He stated that his figures were taken from an actuary for a national insurance company.

Since Dr. Walter's statement, Ralph Nader has jumped on the bandwagon, and expressed concern over the safety of medical devices. So, as you can see, the subject of electrical hazards is a very real and current problem for everyone in the medical profession and industry.

TABLE 1. Effects of Electric Current

60 Cycle	Through Trunk (1 Second Contact)
AMPERES 0.001	EFFECTS Threshold of perception. Tingling.
0.016	"Let-go current."
to 0.050	Pain. Possible fainting, exhaustion, mechanical injury. Heart and respiratory function continue.
0.1 to 2 or 3	Ventricular fibrillation. Respiratory center intact.
6.0 or more.	Sustained myocardial contraction followed by normal rhythm. Temporary respiratory paralysis. Burns if contact area is small.

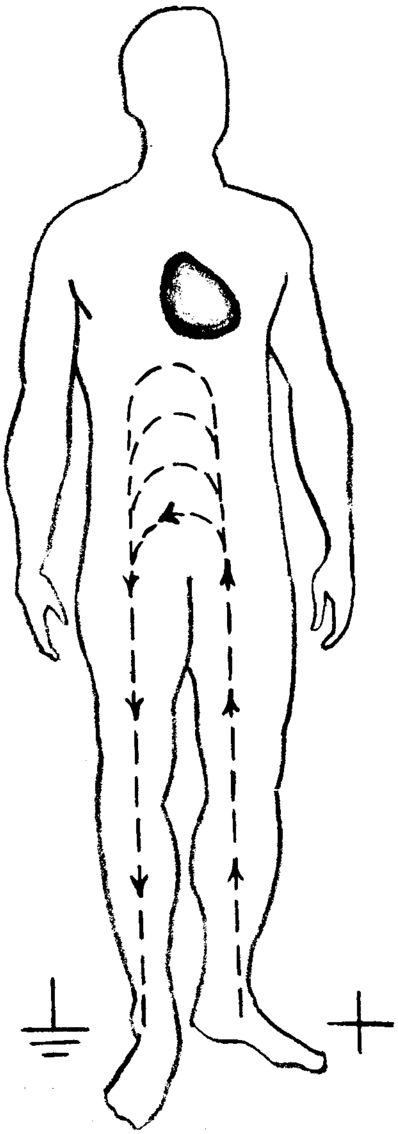


Figure 4

What are some of the factors in electrical shock? One is the magnitude of current flow through the body. Actually, the lethal effects of electric shock are caused by *current flowing through the body,* not by the voltage and resistance. Voltage and resistance are only indirectly related to electric shock. For example, if we had a 50 volt source of AC applied to dry skin, which has a very high resistance, this would not be lethal; however, a half volt applied to an electrode attached to the heart would be fatal. *Current is what kills!*

Death from a 115 volt, 60 hertz (cycle) alternating current results from ventricular fibrillation. Ventricular fibrillation has occurred in humans at a current flow from arm to arm as low as 100 ma.[2] Larger currents produce violent muscular contractions, and can render the victim unable to breathe. Additional increments affect the central nervous system causing respiratory arrest and convulsions.

At the site of contacts, current density is high and can produce massive tissue destruction due to production of intense local heating. As frequentcy of the current is increased from 60 hertz up to 100,000 and 200,000 hertz, muscular contraction is less. The heat produced, however, is increased and burns are more possible. This property of more heat and less muscular contraction at higher frequencies is important for coagulation and cutting where frequencies from 500,000 to a megahertz are used.

Effects of Current

In Table I, Fig. 2, we see the effects of electric current passing through the trunk for 1 second; this again is 60 hertz alternating current.[3] We can see that 1 ma of current is called the threshold of perception; that is, a tingling sensation is felt—we probably all have felt this at one time or another while touching a faulty toaster or other appliance. This is normally not dangerous.

If we go up to 16 ma, we get what is called a "let go" current. This means if you grasped a conductor or wire with 16 ma flowing through it, you would be unable to let go of the wire. I think we have all seen examples of this in the James Bond movies where the villain grabs hold of an electric fence and cannot release his grasp.

If we go up to 50 ma, we have pain, possible fainting, exhaustion, and mechanical injury. All of you know that by putting your hand inside of a chassis you can get a shock which, although is not lethal in any way, can cause you to remove your hand quite rapidly, and possibly leave part of your hand within the chassis.

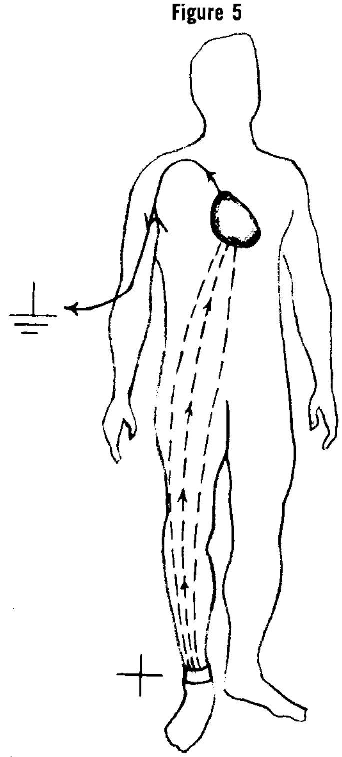
When we go to 0.1 or 2, or 3 ampheres we have ventricular fibrillation; however, the respiratory center is still intact. If we go up to 6 amperes or more, we have sustained myocardial contraction followed by normal rhythm. Also, we would have temporary respiratory problems and possible burns at the contact areas. The sustained myocardial contraction is the rationale behind the AC defibrillators where a large AC current causes the heart to contract followed by normal sinus rhythm.

In Fig. 3, we see a person who has his right foot grounded and his left hand touching a hot chassis. The human body can be thought of as a rubber bag containing a saline solution, and as such is a volume conductor. Current will be dissipated through the body and only a small part of it will pass through the heart. In this situation, it would take at least 100 ma to fibrillate the heart.

In Fig. 4, we have the patient's foot on ground and the other foot at a high voltage. As you can see, very little current passes through the heart; however, this person would certainly be very uncomfortable with the resultant current.

Fig. 5 shows the most dangerous situation. Here we have the patient cathe-

Figure 5



terized; that is, a catheter traveling to the heart. The catheter is at ground potential; his leg is at a higher voltage.

In this situation, we have a low resistance path to ground, current is concentrated at the heart through the catheter electrode, and the current density (current per square centimeter) is very high. In this situation, Dr. Whalen of Duke University found that 180 microamperes is sufficient to fibrillate the human heart.[4] Dr. Whalen obtained this information by carefully measuring the current needed to fibrillate human hearts during open heart surgery.

Causes of Electric Shock

The most common cause of electrical shock in the hospital operating room or ICCU is the presence of an electrical charge on the exposed metal parts of electrical equipment. This charge can be due to inadequate insulation, faulty components, or improper grounding. If a person touches a hot chassis at 115 volts and is at the same time grounded, he is a conductive path to ground and is naturally going to get a shock.

In operating rooms, the floors are at ground potential in order to minimize the danger of explosion due to static charge build-up. Personnel even wear conductive footwear to keep them at ground potential. Touching the defective piece of equipment in this situation will produce a shock.

However, this shock will probably not be lethal, because, according to the Code For The Use Of Flammable Anesthetics from the National Fire Fire Protection Association, it is required to have at least a minimum of 10,000 ohms resistance in an operating room floor. So, if a person does touch a defective piece of equipment, and is at ground potential, he will not necessarily receive a lethal shock—it may roll his eyeballs back a little bit, but it won't be lethal.

In Fig. 6, we have a situation that can occur in an ICCU. A patient is connected to a line-powered pacemaker and a line-powered EKG machine. These particular EKG and pacemaker are the earlier types which had 2-prong plugs and the chassis is directly or indirectly at power line ground potential. In this particular situation, there is no leakage current since the units are plugged in and attached properly.

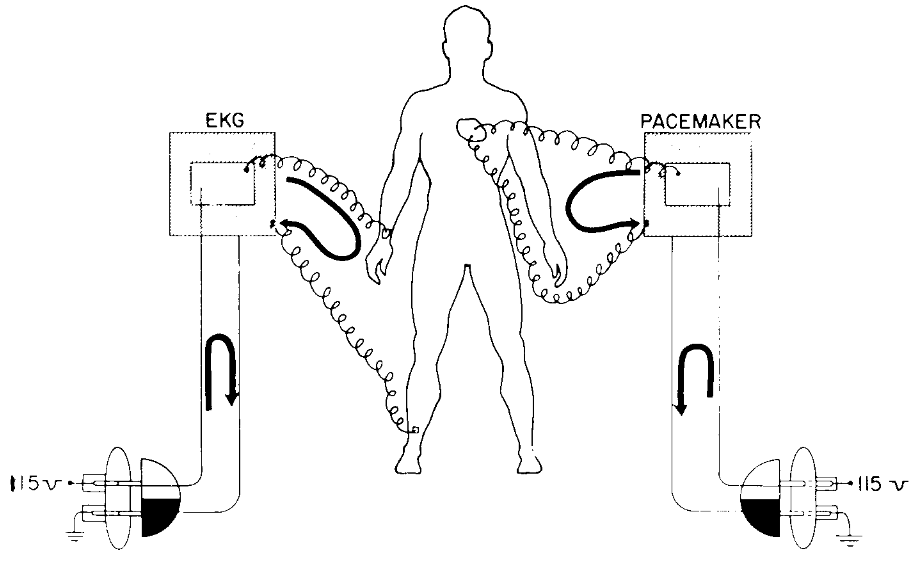
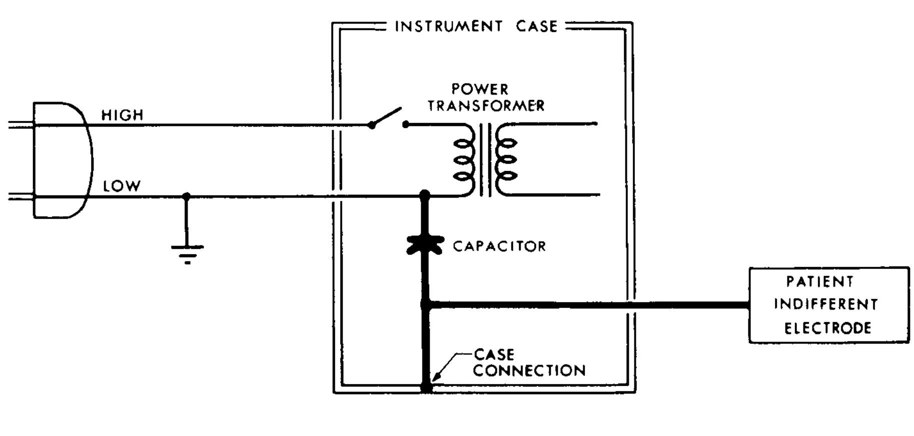


Figure 6

Converting to Ground

The next few illustrations show some examples of how equipment chassis can be converted to power line ground. This can be done through capacitive coupling (Fig. 7) or through resistance coupling (Fig. 8).

In this schematic, the patient's right leg is at ground potential, and power line ground is also connected to the chassis through a 200,000 ohms resistance. If the 2-prong plug is accidentally connected in backwards, and there is a 50-50 chance of this occurring, we now place 115 volts onto the chassis through the 200,000 ohms resistance. The 200,000 ohms resistance will act as a current limiter, but will still allow 550 microamperes of leakage current to flow through the patient to ground. This particular EKG ma-

Figure 7


chine was in wide use in the 1950's, and I am sure there are many still around in hospitals today.

Fig. 9 shows what can happen if one of these EKG machines is plugged in backwards and a line-powered pacemaker is connected to the patient. We notice here that the chassis is now at the power line potential of 115 volts, even though the EKG machine is turned off.

This means, as we saw from the diagram, that a high voltage is on the patient's right leg, and since the heart is at ground potential, 550 microamperes of current can flow from the right leg, through the heart, and back to the ground of the pacemaker. As we stated previously, 180 microamperes is enough to fibrillate the patient.

In Fig. 10 we see a case that actually happened.[4] A patient was brought in, in an emergency. The EKG machine was turned off although plugged in backwards. The pacemaker was off and not even plugged in, but somebody previously thought they would make the equipment safer by running an external ground from the pacemaker chassis to the ground side of the line. As we can see in this case, leakage current was sufficient to fibrillate the patient.

Today, most equipment is built a little safer and uses 3-prong plugs. This is by far the safest way to go when line-powered equipment must be used on a patient. But even in this case, there is always a danger of potential leakage currents due to sporadic hospital construction and poor wiring practices. It is possible for the third prong safety ground of one wall socket to have a different potential than the safety ground on a wall socket across the room.

Fig. 11 shows that there can be a sufficient ground loop so that a potential can exist between the safety grounds and cause leakage current to flow through the patient.[5] This could be reduced, however, if ground bus bars existed between the wall sockets. Probably the safest approach to the coronary care patient is to avoid, as much as possible, any contact with power line ground when a patient is catheterized.

In Fig. 12 we see this is accomplished by using a battery-powered pacemaker. In this situation, the wires going to the heart are in no way connected to power line ground, so that even if voltage does exist on the patient, it will not travel through the heart to ground. The only danger in this case is if a person at ground potential should touch the exposed part of the catheter and thus introduce ground into the system. This can be avoided by insulating the terminals of the battery-powered pacemaker.

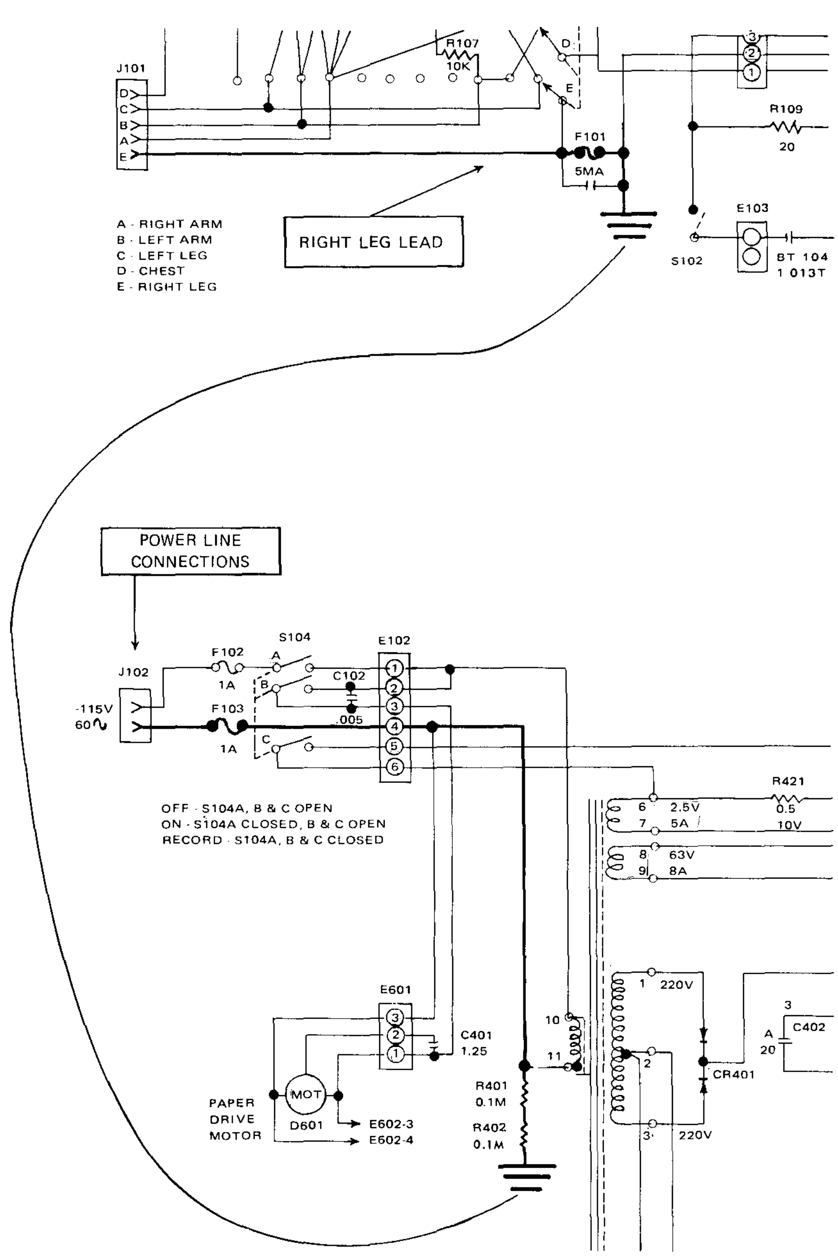


Figure 8

Relative Nature of Ground

I think at this point it might be worthwhile to say something about the relative nature of ground. In Fig. 13 we see a conductor traveling through the hospital say from the 5th floor down to the basement, where it is con-

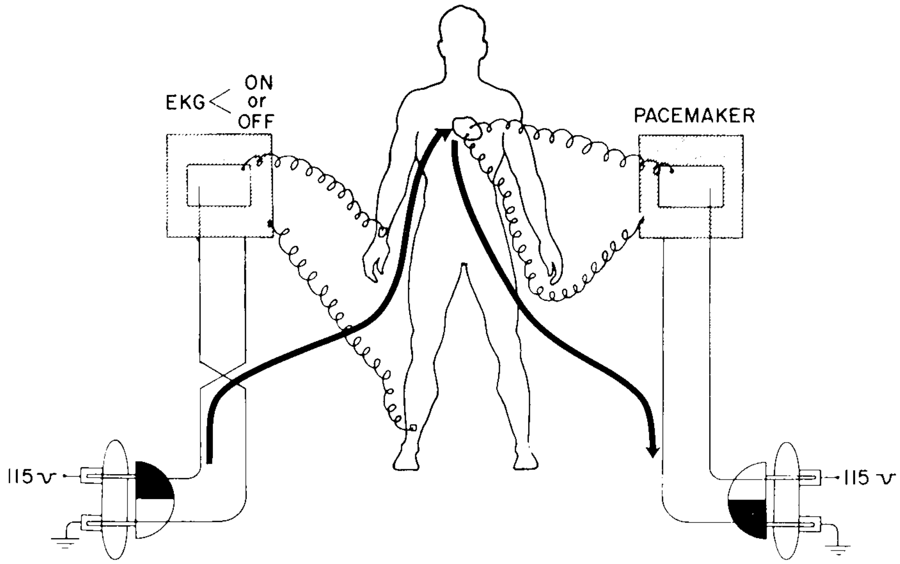


Figure 9

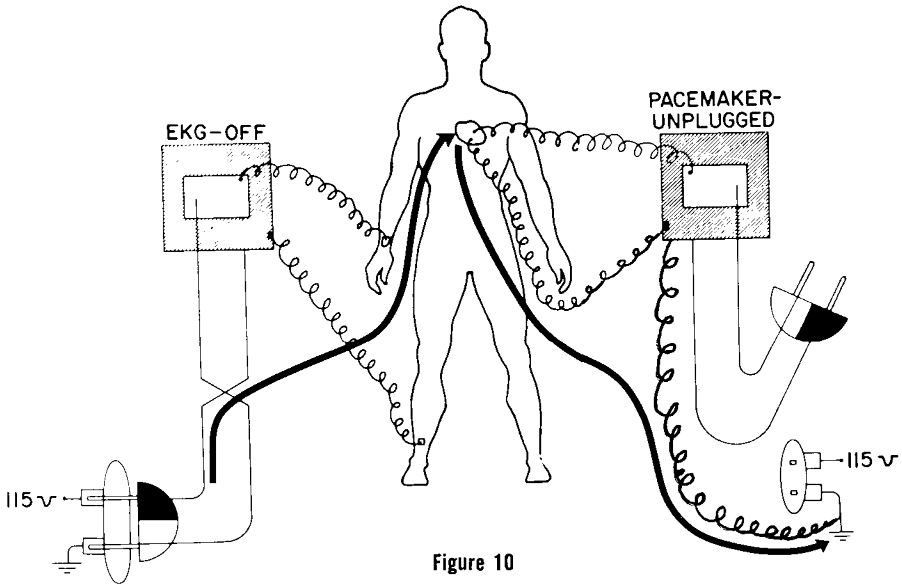


Figure 10

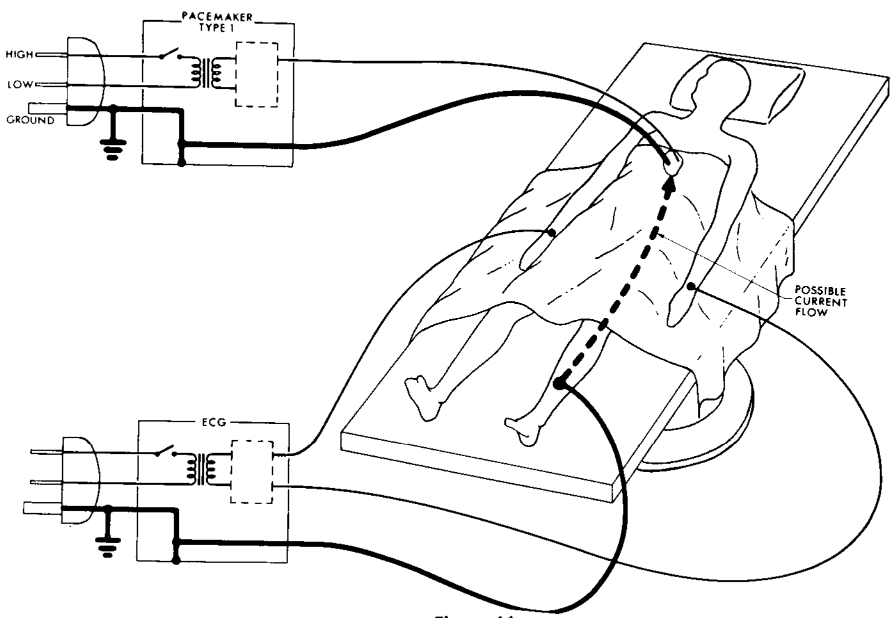


Figure 11

nected to ground. Now, unfortunately, no conductor connected to ground is perfect, all conductors have resistance. When current flows through this resistance, electrical pressure or voltage drops, according to Ohm's Law ($E = IR$). Thus, the objective of grounding is to make this E (voltage) as small as possible at the ground side of the circuit.

In practice, current travels through the ground wire to the basement (ground). There will be a voltage drop and, if another piece of equipment is connected to another ground at a different potential, current can flow between the two ground points and through the patient.

Fig. 14 shows how a patient fits into this picture. The EKG ground lead is attached to one ground point, say on the right leg, and the pacemaker ground is attached to the ground side of the line, possibly on the other side of the room. Since there is more resistance in this ground, a voltage will exist which could cause leakage current to travel from the pacemaker ground through the heart and through the EKG lead to ground.

Another situation that occurred at one of our local hospitals was a case where a patient was being burned at the EKG leads when the surgeon used the cautery machine. On checking the cautery ground, it was found that there was some rust present causing resistance, so current (which takes the path of least resistance) went into the EKG ground and burned the patient.

Now, what are some examples of improper grounding? Well, here we have Fig. 15, a patient on a dialysis machine.[3] Notice that the 2-prong EKG machine is hooked up to the patient and plugged into the wall. Someone ran an external ground wire to a water pipe which is fine; however, when we look closer at this water pipe (Fig. 16), we see that the water pipe was freshly painted the day before, and is not an effective ground.

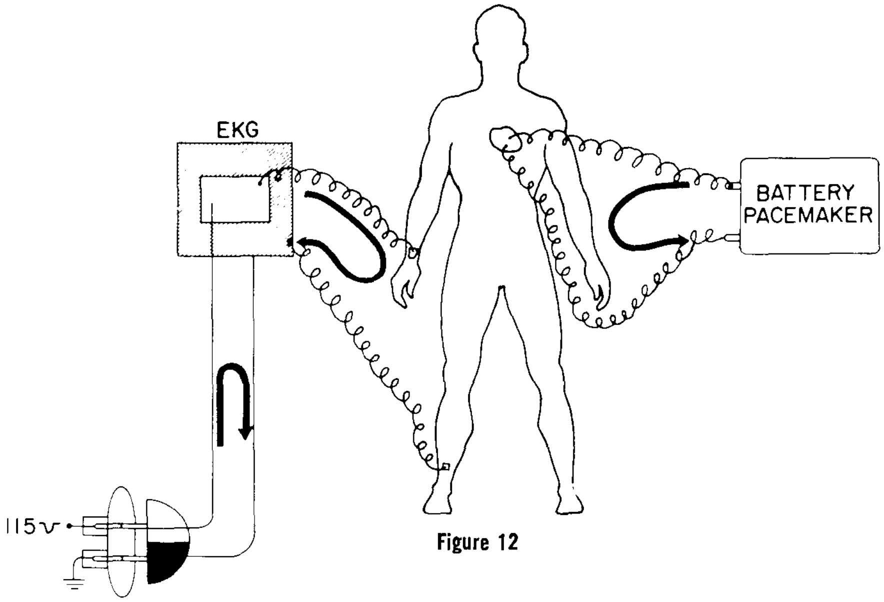


Figure 12

There have also been cases where hospital personnel have grounded patients to curtain rods, metal pails, or insulated tables. This, of course, shows a lack of understanding of what we are trying to do when we ground equipment. Again, we must ground to a true ground potential.

Isolated Power Systems

Another way of avoiding grounding problems is to isolate the power system of the operating room or the ICCU. This is done by using an ungrounded power system or an isolated system.

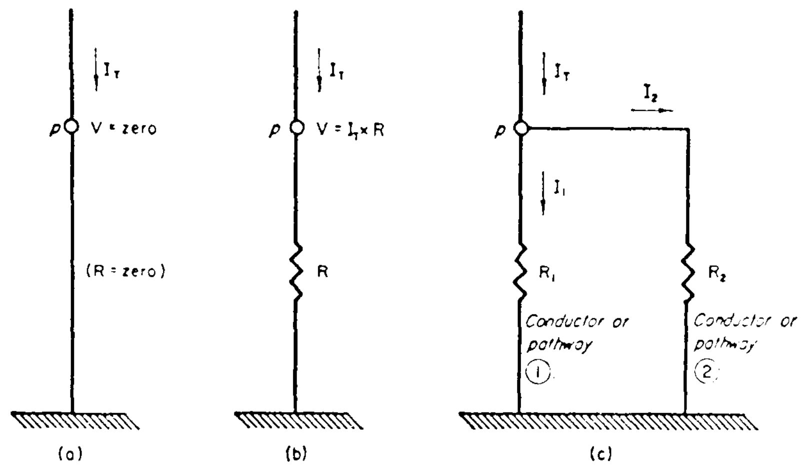
For isolation we use a power transformer and effectively isolate the secondary from the power line ground (Fig. 17A). This means that if you stuck a screwdriver in the wall socket while you were at ground potential, there would be no electrical shock since there is zero potential between either side of the line and ground.

However, the isolated system is now effectively grounded by you. Now, if your friend across the room places a screwdriver in the other socket, you both will get a shock. Many operating rooms use an isolated or ungrounded electrical system. The reason is to afford protection from electrocution by personnel who are in contact with ground and also to diminish fire and explosion hazards since equipment faults to ground will not produce a spark.

The disadvantages, of course, are that in an isolated system, a fault to ground converts the ungrounded system to a grounded one with no indication of this happening.

To insure a truly isolated system and to detect when it becomes a grounded system, a continuously detecting fault

Figure 13



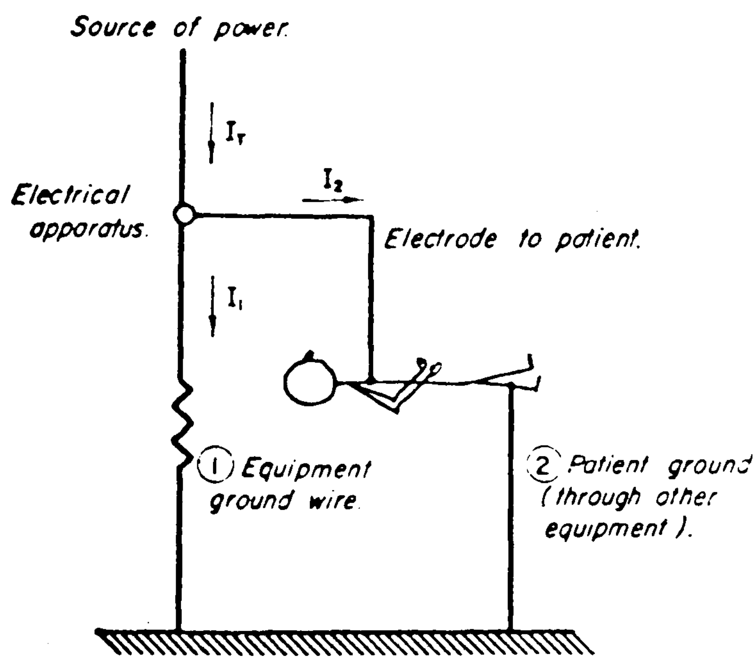


Figure 14

(d)

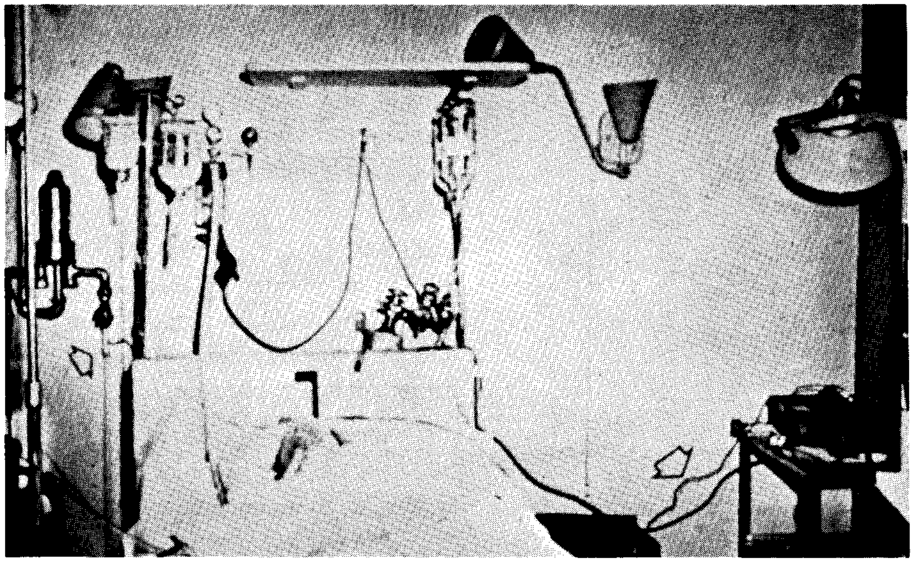


Figure 15

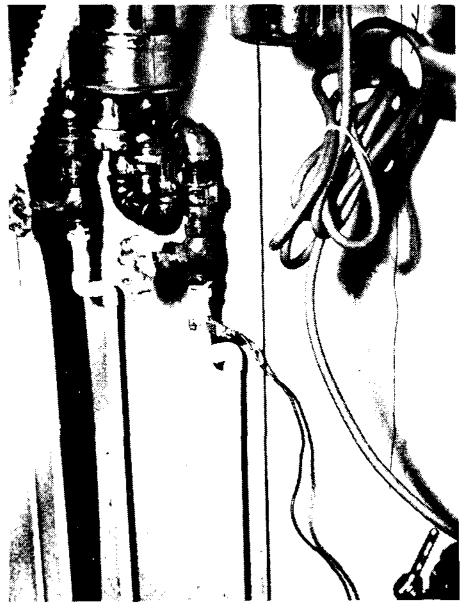
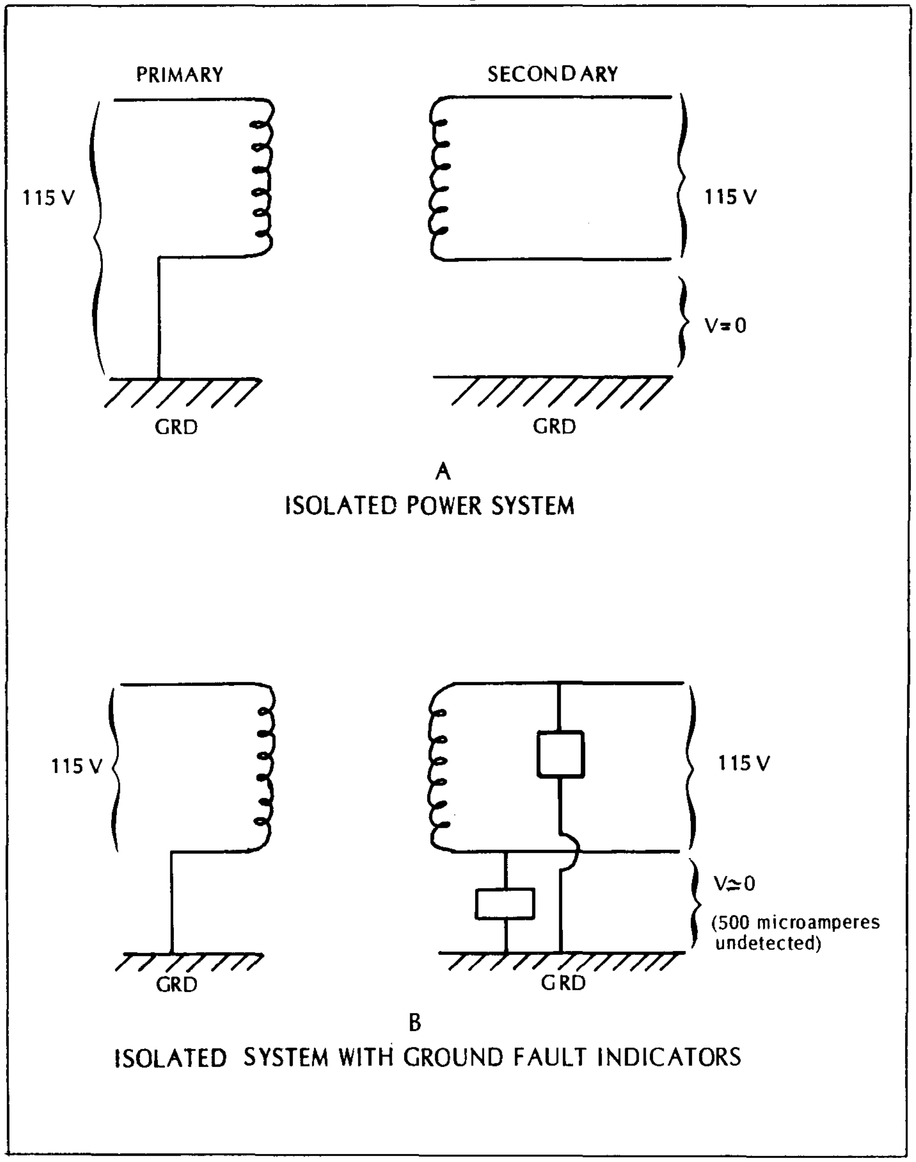


Figure 16

Figure 17



indicator must be used. Now when we introduce a fault indicator, we also introduce a link between the isolated line and the power line ground (Fig. 17B), and it has been found that 500 microamperes can pass undetected in this system.[3] We know that 180 microamperes has been shown to produce ventricular fibrillation.

Therefore, we can say that ungrounded operating rooms or ICCU's do not isolate from microampere electrocution; that is, whenever we have a patient catheterized, we have a different situation, a different environment. We can think of this as similar to the early days of X-day when it was discovered that special precautions had to be taken with an X-rayed patient because of the dangerous environment he was in. So, too, today we have to take special precautions with the catheterized patient, as far as his electrical environment is concerned.

Conclusion

What are the safety precautions that we can take? In hopes that we haven't painted too gloomy a picture, there are things that can be done:

1. Whenever possible use battery-powered equipment, especially when

the patient is catheterized or has electrodes attached to his heart.

2. If battery-powered equipment is not available, use 3-prong plugs and plug all units attached to the patient to a single outlet.

3. Avoid external ground wires; if used, always check for fatigue to make sure that the connection to ground is good and be sure to instruct hospital personnel to connect these ground wires to a true ground.

4. Have all equipment checked for stray voltage, faults, etc., about once a month by all electricians or a medical electronic technician.

5. Have personnel report all shocks received on equipment immediately.

REFERENCES

1. Camishion, R. C., "Electrical Hazards in the Research Laboratory", **Journal of Surgical Research,** 6:221, May, 1966
2. Weinberg, D. I., Artley, J. L., Whalen, R. E., and McIntosh, H. D., "Electric Shock Hazards in Cardiac Catheterization", **Circ. Res.,** 11:1004, 1962
3. Bruner, J. M., "Hazards of Electrical Apparatus", **Anesthesiology,** 28:396, March-April, 1967
4. Whalen, R. E., Starmer, C. F., and McIntosh, H. D., "Electrical Hazards Associated with Cardiac Pacemaking", **Ann. N.Y. Acad. Sci,** 111:922, 1964
5. Poulsen, J., "Eliminating the Electrocution Hazard from Internal Cardiac Pacemaking", **Corbin-Farnsworth Technical Publication,** 1969