Determination of Leakage Currents in Medical Equipment*

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Recent studies have amply demonstrated that certain current medical procedures (cardiac pacing, cardiac catheterization, cardioversion and the like) can be associated with electric shock hazards to patients.[1-3] These shock hazards usually stem from inadequate grounding of powerline-operated equipment. If two pieces of powerline-operated equipment are connected to a patient and different ground potentials exist on both machines, current can flow from the ground connection of one machine through the patient to the ground of the second machine. If the path of the current in the patient passes through the heart, ventricular fibrillation may result. This brief report describes a simple technic that can be used routinely to test the adequacy of equipment grounding.

Testing for Leakage Current

To determine the magnitude of a current leak in any powerline-operated machine, voltage is measured across a 1000 ohm resistor connected between the powerline ground and the chassis of the machine (Fig. 1). A vacuum tube voltmeter must be used to insure an accurate voltage reading. The leakage is calculated from the voltage drop across the resistor using Ohm's law. This resistor represents the approximate resistance of the heart.[2] One side of the resistor is connected to any ground connection on the chassis of the machine while the other side of the resistor is connected to the powerline ground (usually the third slot or ground slot in a three-prong wall outlet). The measurement of this leakage current should then be repeated after reversing the way in which the powerplug is inserted into the wall receptacle.

Earlier studies have indicated that alternating currents as low as 180 microamperes are sufficient to produce ventricular fibrillation in man. With these data in mind we have arbitrarily chosen 10 microamperes as the maximal leakage of current that can safely be allowed to flow between two different grounds of powerline-operated equipment. This safety limit, which is twenty-fold lower than the lowest fibrillatory current we have noted to cause ventricular fibrillation in man, will probably prevent the accidental induction of ventricular fibrillation in the vast majority of clinical situations. If a current in excess of 10 microamperes is measured flowing through the 1,000 ohm resistor, the grounding of the machine is inadequate, and steps should be taken to remedy the situation.

It is important to understand the necessity for using a resistor while measuring the voltage. Measurements of voltage without a resistor to complete the ground circuit (open circuit voltages) can be large in magnitude and tend to give a falsely high impression of the amount of current available from the ground circuit of a piece of equipment. However, measurements of voltage made for calculating the leakage current through the 1,000 ohm resistor tend to be much less because the internal resistance of the ground

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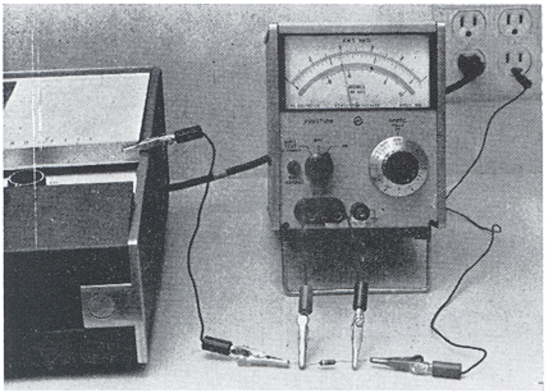

FIG. 1. *Apparatus for determining leakage of currents.* The vacuum tube voltmeter is connected in parallel with a 1,000 ohm resistor. One side of the resistor is connected to the chassis of the electrocardiograph, and the other side is connected to a powerline ground (the ground slot in a wall receptacle). Leakage currents are calculated utilizing Ohm's law and the voltage measured across the 1,000 ohm resistor.

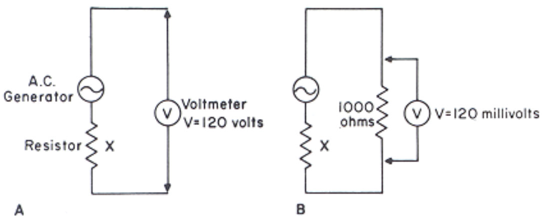

FIG. 2. *Equivalent ground circuit.* The equivalent ground circuit consists of an A.C. generator and an internal resistance of unknown magnitude (resistor X). *In panel A*, measurement of the ground voltage gives a high voltage (V) since no current is flowing in the circuit. *In panel B*, the ground circuit is completed by using a 1,000 ohm resistor representing the patient. The voltage measurement now reads considerably less because a significant voltage is dropped across the internal resistance, X.

circuit sometimes plays a significant role in limiting the available current.

Equivalent Ground Circuit

To illustrate the importance of both the internal resistance and the necessity for using the 1,000 ohm resistor, analysis of an equivalent circuit representing the ground circuit is helpful (Fig. 2). The ground circuit that supplies the leakage current can be represented by a circuit consisting of an A.C. generator (voltage source) and a resistor (internal resistance of the ground circuit) in series with this generator. If the generator supplies 120 v. and the series resistor is 1 million ohms, the open circuit voltage measured between the resistor and the generator will be 120 v. Since no current is flowing in the circuit, no voltage can be dropped across the resistor and the full generated voltage is measured. However, if a patient or a 1,000 ohm resistor is inserted in parallel with the generator and the series resistor so as to complete the circuit, current can flow, and the voltage across the patient will drop to 120 mv., corresponding to a current of 120 microamperes.

This apparent voltage paradox can be explained by application of Ohm's law ($V = IR$, where V = voltage, R = resistance, I = current). Since the total resistance of the circuit is 1.001 million ohms, the current flowing in the ground circuit will be

$$I = \frac{V}{R} = \frac{120 \text{ volts}}{1.001 \times 10^6 \text{ ohms}}$$

$$= 120 \times 10^{-6} \text{ microamperes.}$$

The voltage measured across the patient, in this case represented by a 1,000 ohm resistor, will then be

$$V = IR = 120 \text{ microamperes} \times 1000 \text{ ohms} = 120 \text{ mv.}$$

The safety of the machine is thus controlled by the internal resistance inherent in the electrical design; and a seemingly high open circuit voltage (120 v.) will actually allow only a small current (120 microamperes) to flow through the patient. This current is still larger than the standard set (10 microamperes) and hence should be considered dangerous.

Since prior knowledge of the internal resistance in the ground circuits of powerline-operated equipment is not usually known, the necessity of evaluating the approximate current available to the patient is obvious. This measurement is easily made, and can be incorporated into a routine procedure for evaluating the safety of electrically operated equipment.

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