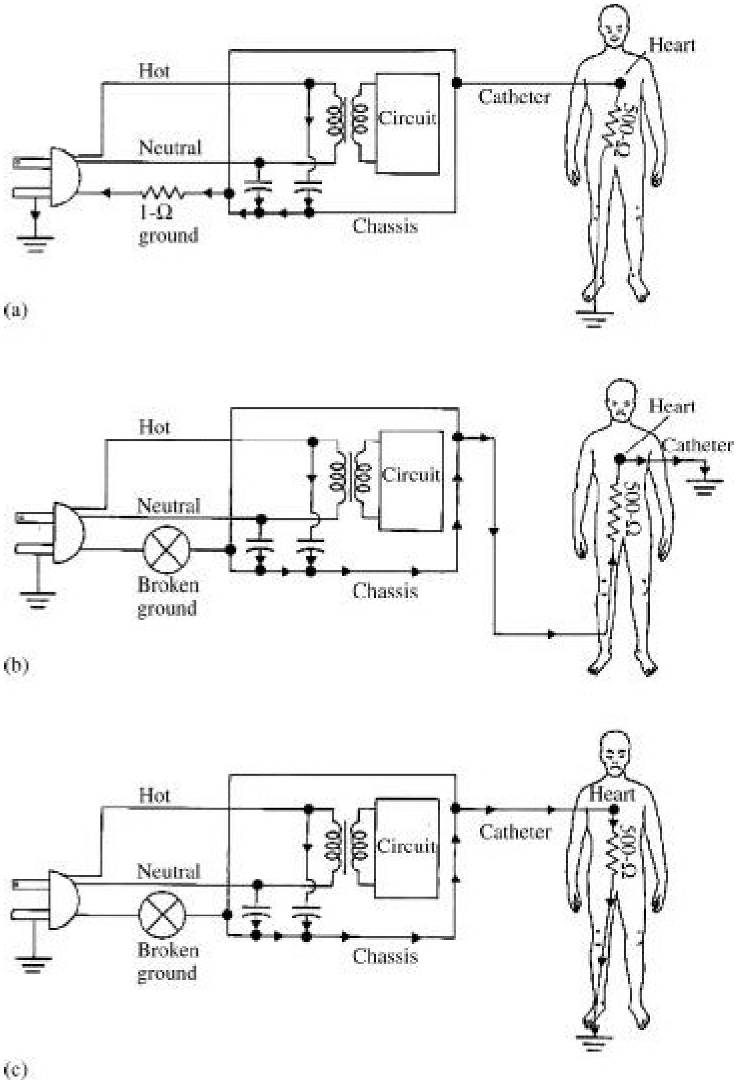

**Figure 14.11** **Microshock leakage-current pathways** Assume 100 μA of leakage current from the power line to the instrument chassis, (a) intact ground; 99.8 μA flows through the ground, (b) broken ground; 100 μA flows through the heart, (c) broken ground; and 100 μA flows through the heart in the opposite direction.

## CONDUCTIVE SURFACES

The source that produces the microshock current need not be leakage current from line-operated equipment. Small potentials between any two conductive surfaces near the patient can cause a microshock if either surface makes contact with the heart and the other surface contacts any other part of the body. An example is given later in this section.

## CONDUCTIVE PATHS TO THE HEART

Specific types of electric connections to the heart can be identified. The following clinical devices make patients susceptible to microshock.

1. Epicardial or endocardial electrodes of externalized temporary cardiac pacemakers
2. Electrodes for intracardiac electrogram (EGM) measuring and stimulation devices
3. Liquid-filled catheters placed in the heart to
   a. Measure blood pressure
   b. Withdraw blood samples
   c. Inject substances such as dye or drugs into the heart

It should be emphasized that a patient is in danger of microshock only when there is some electric connection to the heart. The internal resistance of liquid-filled catheters is much greater (50 k$\Omega$ to 1 M$\Omega$) than the resistance of metallic conductors in pacemaker and EGM electrode leads. Internal resistance of the body to microshock is about 300 $\Omega$, and the resistance of the skin can be quite variable.

In dogs, the surface area of the intracardiac electrode is an important determinant of minimal fibrillating current (Roy *et al.*, 1980). Figure 14.12 shows that as catheter electrodes get smaller, so does the total current needed to fibrillate. This means that current density at the tip of the intracardiac electrode is the important microshock parameter. Smaller catheter electrodes may have larger internal resistance.

**EXAMPLE 14.2** From Figure 14.1, find the current required for arm-to-arm VF. Assume that all this current passes through the area of the heart (about $10 \times 10$ cm). Calculate the current density through the heart. How does this compare with the lowest value current density from Figure 14.12?

**ANSWER** Figure 14.1 shows minimal current for VF by macroshock of 75 mA. For $10 \times 10$ cm cross-sectional area, the current density $J = 75,000\,\mu\text{A}/10,000\,\text{mm}^2 = 7.5\,\mu\text{A/mm}^2$. Figure 14.12 shows for 90 mm$^2$ a current for VF of 1000 $\mu$A, or $J = 1000\,\mu\text{A}/90\,\text{mm}^2 = 11.1\,\mu\text{A/mm}^2$. This comparison supports the view that macroshock and microshock cause VF by the same mechanism.

***Microshock via Ground Potential Differences*** An example of microshock illustrates the need for a single reference ground point of each patient in

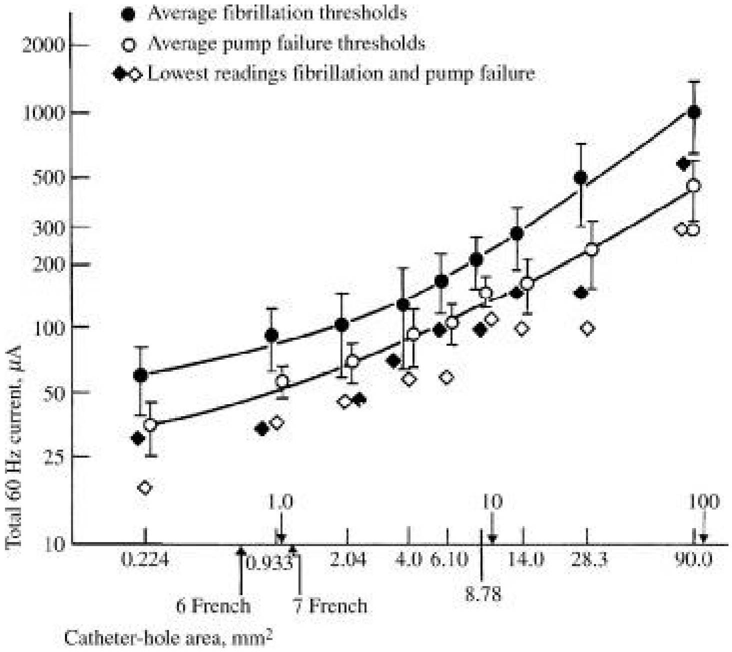

**Figure 14.12** Thresholds of VF and pump failure versus catheter area in dogs. (From O. Z. Roy, J. R. Scott, and G. C. Park, "Ventricular Fibrillation and Pump Failure Thresholds Versus Electrode Area," *IEEE Transactions on Biomedical Engineering*, 1976, 23, 45–48. Reprinted with permission.)

critical-care areas and the need for a 40 mV limit on the difference in potential between conductive surfaces in these areas.

Figure 14.13 shows a patient in the intensive-care unit (ICU) who is connected to an ECG monitor that grounds the right-leg electrode to reduce 60 Hz interference. In addition, the patient's left-ventricular blood pressure is being monitored by an intracardiac saline-filled catheter connected to a metallic pressure sensor that is also grounded. Assume that these two monitors are connected to grounded three-wire wall receptacles on separate circuits that can come from a central power-distribution panel many meters away. A microshock can occur when any device with a ground fault that does not open the circuit breaker is operated on *either* circuit.

Figure 14.13(a) shows the scheme of this hazard; Figure 14.13(b) shows an equivalent circuit. Suppose that a faulty electric floor polisher, which is dusty and damp, allows 5 A to flow to the distribution panel on the ground wire. The floor polisher functions properly, so the fault is not noticed by the operator. The ground wire could easily have a 0.1 Ω resistance, so 500 mV could appear across the patient between the ECG-monitor ground and the pressure-monitor ground. If the resistance of the patient's body and of the liquid-filled catheter is less than 50 kΩ, a current in excess of the 10 μA safe limit could flow. Of course, more current would flow if the ground

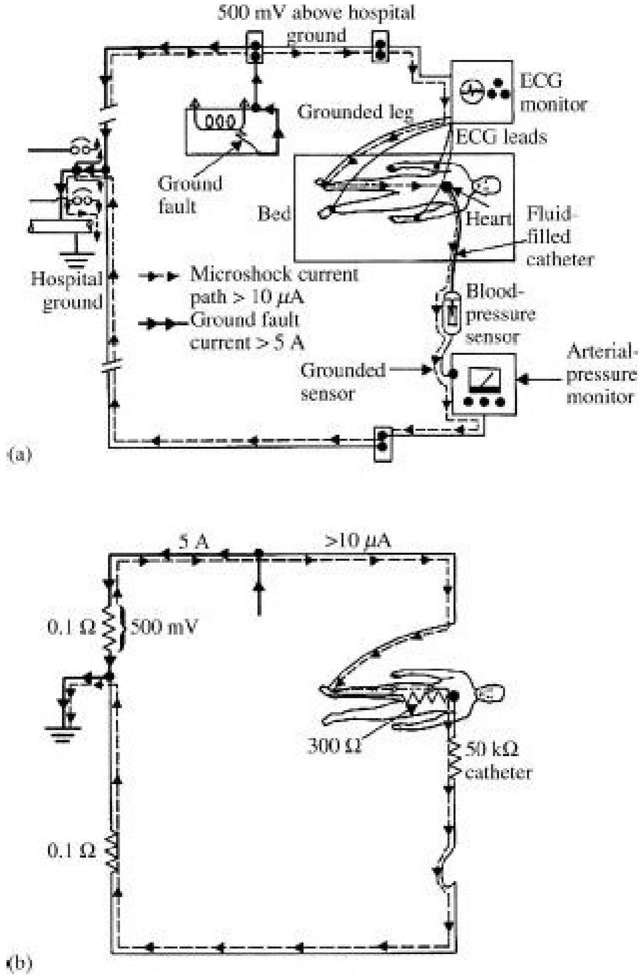

**Figure 14.13** (a) Large ground-fault current raises the potential of *one* ground connection to the patient. The microshock current can then flow out through a catheter connected to a different ground. (b) Equivalent circuit. Only power-system grounds are shown.

resistance or fault current were higher or if the catheter resistance were lower. If a grounded pacing catheter were to be used instead of the liquid-filled catheter in this example, then much smaller differences in ground potential would exceed the safe limit.

Most low-voltage hazards can be avoided if the grounds of all devices used in the vicinity of each patient are connected to a single patient-grounding point. This also prevents faults at one patient's bedside from affecting the safety of other patients. Modern pressure sensors and ECG monitors provide electrical isolation for all patient leads.