Hazards of Electric Shock in Cardiology*

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Because of recent advances in instrumentation, the clinical cardiologist may expose his patient to ventricular fibrillation during routine diagnostic or therapeutic procedures. The purpose of this discussion is to review some of the principles that are helpful in understanding the genesis of electrically induced ventricular fibrillation and to emphasize the potential dangers associated with commonly used diagnostic and therapeutic maneuvers. Specifically, the potential hazards associated with cardiac catheterization, intracardiac electrocardiography, cardiac pacing, pericardiocentesis and cardioversion will be discussed.

Basic Concepts

The danger of causing ventricular fibrillation in patients exists whenever there is a significant difference in the potential between an electrical source and the heart, and when there is a low resistance path of current which allows the delivery of a concentrated current directly to the heart. In 1934 King[1] demonstrated that ventricular fibrillation is most likely to ensue if current is delivered during the vulnerable period of the cardiac cycle, which corresponds to the initial portion of the T wave on the standard electrocardiogram. Previous studies have demonstrated that 150 microamperes (60 c.p.s alternating current) can cause the human heart to fibrillate.[2] Thus, all safety considerations and precautions should be directed toward eliminating the possibility of exposing patients to currents in the microampere range. Analysis of currents available from ungrounded but functioning hospital equipment indicates that currents of this magnitude are available from electrocardiographs, cardiac monitors, portable x-ray machines and from oxygen tents.[2]

Electrical Resistance and Current Density: A brief review of Ohm's law and some of its ramifications will serve to emphasize the role that low resistance paths of current play in exposing patients to fibrillatory currents. Ohm's law ($E = IR$ or $I = E/R$) states that the current (I), which is responsible for initiating ventricular fibrillation electrically, is proportional to the ratio between the voltage (E) and the resistance (R) of the electrical circuit. Thus, large voltages provide little current if a large resistance is present. Current density, which is defined as the current per unit of cross-sectional area of the conductor through which the current flows, also plays a role in determining whether or not the heart will fibrillate. For any given current, the smaller the electrode the greater the current density will be; the greater the current density the greater the possibility of inducing ventricular fibrillation.[2–4]

Analysis of the role of resistance and current density illustrates why only small quantities of electricity would enter the heart if a 1 v. potential existed between an electrode on the right leg and an electrode on the left shoulder, as shown in Figure 1. The intervening body tissues act as an almost infinite number of resistors which prevent significant quantities of current from reaching the heart. These "resistors" also serve to distribute the current widely through the chest, thus preventing significant current density in the heart.

The importance of low resistance paths of current in the genesis of ventricular fibrillation is emphasized in the following situation: If a

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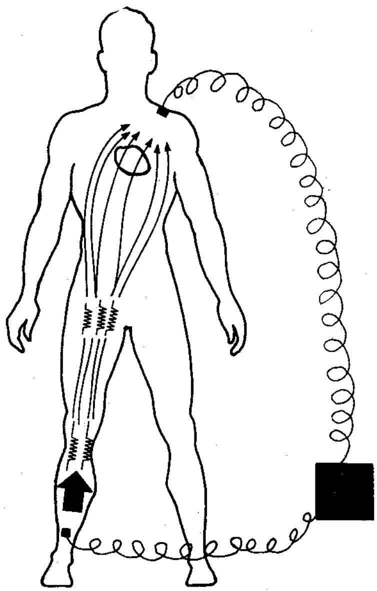

Fig. 1. If a potential exists between electrodes on the right leg and left shoulder, fibrillatory currents will not enter the heart because the body tissues act as an infinite number of resistors. The resistors dissipate the current (indicated by arrows) and prevent significant current density in the heart.

1 v. potential exists between an electrocardiographic electrode on the right leg and an intracardiac Lehman catheter filled with physiologic saline, the resistance of the system will be approximately 301,000 ohms. The saline-filled catheter is a relatively poor conductor and provides a 300,000 ohm resistance; the heart and body tissues provide 1,000 ohms. Under these circumstances the current delivered to the heart would be 3.3 microamperes. This current is unlikely to cause fibrillation.

$$I = \frac{E}{R} = \frac{1 \text{ volt}}{301{,}000 \text{ ohms}} = 3.3 \text{ microamperes}$$

However, if the same 1 v. potential existed between an electrocardiographic electrode and an intracardiac electrode catheter with a resistance of 70 ohms, the total resistance of the system would be 1,070 ohms instead of 301,000 ohms. The electrode within the catheter makes it a relatively better conductor than the saline-filled Lehman catheter, and the current delivered to the heart would be 935 microamperes.

$$I = \frac{E}{R} = \frac{1 \text{ volt}}{1{,}070 \text{ ohms}} = 935 \text{ microamperes}$$

This current is in excess of that known to cause ventricular fibrillation in man. The catheter has bypassed the protective resistance of the body tissues, and the low resistance of the electrode catheter has allowed current to be delivered directly to the heart. The small area of the electrode on the electrode catheter has allowed the production of a high current density with this relatively low current.

Grounding Equipment: Since many of the incidents of electrically induced fibrillation stem from grounding problems, it may be helpful to review the reason for and the importance of grounding equipment. In general, a ground or ground system is a common conductor or series of conductors connected to a common point. The purpose of the ground circuit is to insure a uniform reference point from which differences in electrical potential can be developed. For convenience, the earth is considered true ground and is used as a common ground for power line circuits.

Electrical potential is brought from generators to the wall receptacle by means of two lines, one of which is a ground line. This ground line is connected to one of the slots in the wall receptacle, which is considered the ground slot. The other slot, which is in a sense a high potential slot, can be considered the "hot" slot. When a plug is placed in a wall receptacle, the potential that exists between the "hot" slot and the ground slot is delivered to a piece of equipment. If there is sufficient leakage to the chassis from capacitors, resistors and transformers within the equipment, a significant potential can be developed between the chassis and true ground. This potential may serve as a source of fibrillatory current.

To eliminate this potential between chassis and true ground, several measures can be taken. The equipment may be designed so that the chassis is completely isolated from the power sources in the equipment, and no stray potentials can reach it (Fig. 2A). Because this requires careful and frequently expensive modifications in equipment design, complete isolation is seldom realized in routine hospital equipment. As an alternative the equipment may be designed so that the ground side of the power sources in the equipment is connected to the chassis (Fig. 2B). The chassis is then connected to the ground circuit of the power line through the ground prong of the plug. For this arrangement to assure no potential on the chassis, the ground plug must enter the

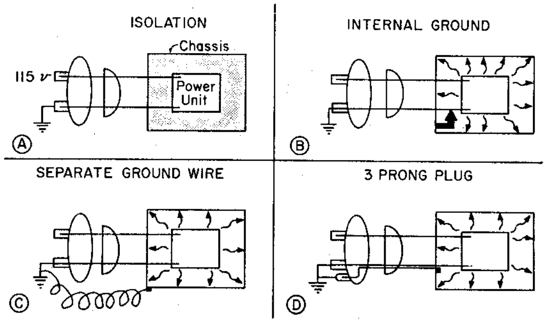

FIG. 2. *Four methods of eliminating electrical potential from the chassis of equipment.* A, current leakage from the power unit to the chassis (indicated by curved arrows in B, C and D) is prevented by careful isolation. B, the chassis has been connected to the ground side of the power line (right angle arrow). C, a separate wire has been run from the chassis to a ground point. D, the chassis is connected to the third prong of a three prong plug, which is connected to the power line ground.

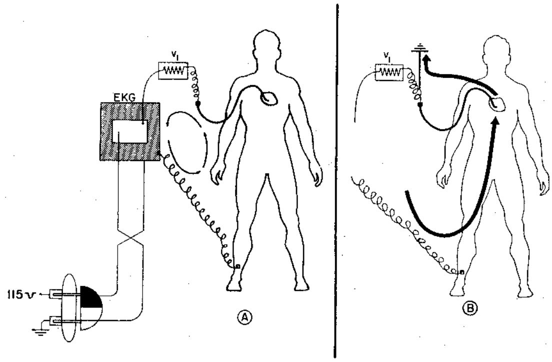

FIG. 3. *Potential danger of intracardiac electrode catheter.* A, an electrocardiograph plug has been incorrectly placed in a wall receptacle so that the grounded prong of the plug enters the "hot" slot of the wall receptacle. This allows the development of a high potential on the chassis and the right leg electrode. Current does not flow to the electrode catheter in the heart because of the high resistance in the V lead circuit. A small signal current will flow between the patient and the electrocardiograph (indicated by the arrows). B, the high resistance of the V lead circuit has been bypassed by grounding the terminal of the electrode catheter. A fibrillatory circuit (arrows) can flow from the chassis of the ungrounded electrocardiograph through the right leg electrode to the grounded electrode catheter.

ground slot of a correctly wired wall receptacle. If the plug is incorrectly placed in the wall receptacle, and the ground prong enters the 115 v. or "hot" slot, the chassis may be at the high potential carried in the power line. The use of a coded plug, constructed so that the ground prong can only enter the ground slot, will prevent incorrect placement of the plug in the wall receptacle. However, if the connection between the chassis and the ground circuit of the plug has been broken or the wall receptacle has been incorrectly wired, the coded plug will not eliminate the potential from the chassis.

A more certain way of grounding the chassis of equipment involves the use of either a separate ground wire or a three prong plug. Connection of a separate ground wire from the chassis to an object that is presumed to be at true ground level, such as a water pipe, has certain disadvantages (Fig. 2C). Water pipes or other metal objects are frequently not at true ground level. Even if the eventual grounding point is at true ground level, the cumbersomeness of the separate wire may discourage its use, or the ground wire may be easily dislodged from the grounding point. A three prong plug which contains a separate wire connecting the chassis to the power line ground by means of a third prong on the plug is most likely to insure that the chassis is at ground level (Fig. 2D). Because of these considerations a correctly wired three prong plug affords the best means of grounding equipment in the vast majority of situations.

CLINICAL SITUATIONS

CARDIAC CATHETERIZATION

It has been amply confirmed by recent case reports[5–8] that it is more than a theoretical possibility that the cardiac catheter may serve as the vehicle for the delivery of fibrillatory currents to the heart. The source of the electrical potential may be poorly grounded recording or monitoring devices that come in contact with patients in the catheter laboratory. Ventricular fibrillation has undoubtedly been prevented in many instances because of the relatively high resistance afforded by the usual saline-filled nylon or Teflon® catheter. The introduction of low-resistance electrode catheters for the recording of intracavitary electrocardiograms or the detection of intracardiac shunts and the frequent use of low-resistance guide wires have eliminated the safety factor formerly provided by the high-resistance catheters.

Electrode Catheters: The development of a small, easily manipulatable electrode catheter in conjunction with the use of inhaled hydrogen has popularized the use of an electrode catheter and deserves further comment. The exploring catheter, which is connected to the V lead of an electrocardiograph, can be used to document the nature of unusual arrhythmias or, in combination with the inhalation of hydrogen, to demonstrate the location of left to right shunts.[9–11] Because of the simplicity of the technic it is being used in many laboratories and undoubtedly will be applied to ward and office situations as well.

The method, however, carries certain potential dangers which must be recognized and controlled. Figure 3 illustrates how this technic can initiate ventricular fibrillation. If the electrocardiograph is correctly grounded, there is little danger (Fig. 3A). However, if it is not grounded and the electrocardiograph plug has been incorrectly placed in the wall receptacle so that its ground prong enters the "hot" slot of the wall receptacle, a significant potential can exist between the indifferent electrode on the right leg and the electrode catheter. The potential exists because the indifferent right leg electrode is directly or indirectly connected to the chassis of the electrocardiogram, which, in turn, is connected to the "hot" slot of the wall receptacle through the incorrectly placed electrocardiograph plug. Indirect connections occur between the indifferent electrode and the chassis of the electrocardiograph because of leakage through transformers, capacitors and resistors within the apparatus.

If the electrode catheter has been connected to the V lead of the electrocardiograph, a small signal current is detected, and the intracavitary electrocardiogram is recorded. The situation is still relatively safe because the V lead circuit in the electrocardiograph contains a 5 to 10 million ohm resistor. This high resistance limits the current flowing between the indifferent right leg electrode and the intracardiac electrode. However, if the catheter or the clip lead connecting the catheter to the V lead is grounded, the high resistance afforded by the V lead circuit is bypassed, and a fibrillatory current may enter the heart (Fig. 3B). There are almost innumerable ways of inadvertently grounding the catheter in a ward or laboratory situation. We have consistently caused ventricular fibrillation in dogs by having one person touch the end of the catheter or the clip lead with one hand and a grounded piece of equipment with the other hand.

To prevent ventricular fibrillation under these circumstances (1) the electrocardiograph should be checked periodically by an electrician to detect any electrical faults in the apparatus. Gross evidence of potential dangers, such as defective wiring or persistent 60 c.p.s. artifact, demand an immediate safety check. (2) The machine should always be grounded, preferably with a three-pronged plug. (3) The connection between the electrode catheter and the V lead should be protected with an insulator such as a firmly fitting rubber sleeve before the catheter is introduced into the vein. Other reasonable precautions have been outlined previously.[12]

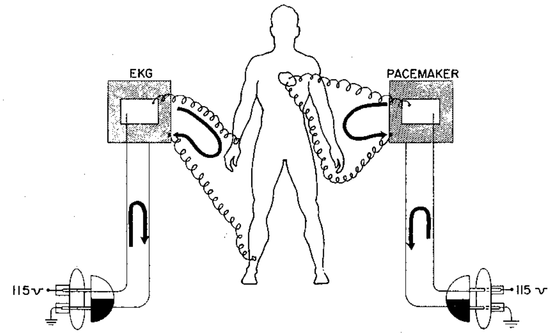

FIG. 4. *Correct arrangement of line-powered pacemaker equipment.* The solid arrows indicate the current paths present when an electrocardiograph and a line-powered pacemaker are correctly plugged into wall receptacles. The currents travel in a path from the power line to each machine and from each machine to the patient. There is no current path between the two machines, and fibrillatory currents will not enter the heart.

CARDIAC PACING

The supportive measures used to prepare a patient with complete heart block for implanta tion of a pacemaker may expose the patient to fibrillatory currents.[13–16] Before pacemaker implantation, cardiac pacing is often maintained by an external line-powered pacemaker and an intracardiac electrode catheter or myocardial electrodes. Little danger arises from the use of the line-powered pacemaker per se, but the use of this unit in combination with other pieces of electrical apparatus may lead to the delivery of fibrillatory currents.

The danger of inducing ventricular fibrillation is present whenever two or more pieces of line-powered equipment are connected to the patient. If these pieces of equipment have different potentials from their chassis relative to the common power line ground, fibrillatory currents may be available. The low-resistance intracardiac or myocardial electrodes allow currents to be shunted from the equipment directly into the heart. If the chassis of all equipment is at the same potential, there will be no current leakage into the heart.

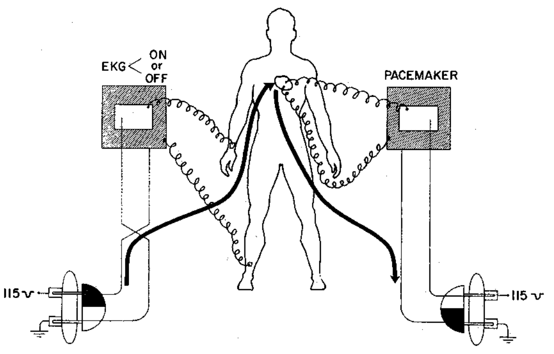

FIG. 5. *Potential danger of line-powered pacemaker equipment.* The solid arrows represent a dangerous current path from the right leg electrode to the heart, which may exist when the electrocardiograph is improperly grounded. The plug of the electrocardiograph is reversed so that there is a difference in potential between the chassis of the electrocardiograph machine and the pacemaker. Current can flow from one chassis to the other via the right leg electrode and the heart. Note that the electrocardiograph can be on or off for this to happen.

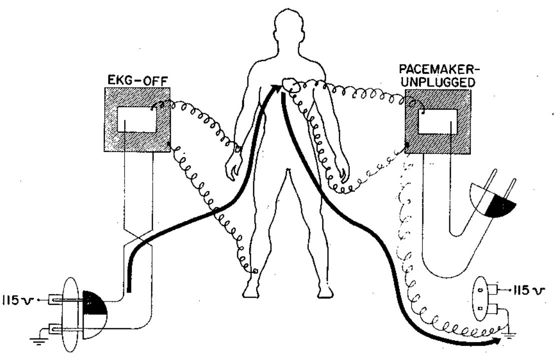

FIG. 6. *Potential danger of line-powered pacemaker equipment.* A potentially dangerous current path can exist from the right leg electrode to the heart when an ungrounded electrocardiograph is off and the pacemaker is unplugged but grounded by a separate ground wire. The plug of the electrocardiograph is reversed, allowing the chassis and the right leg electrode to have a high potential. Current can flow from the right leg electrode through the heart to ground by means of the separate ground wire connected to the unplugged pacemaker.

Figure 4 illustrates a safe operating situation in which an electrocardiogram is being taken on a patient who is being paced by a line-powered pacemaker. The electrocardiographic equipment has been chosen for illustration since it is frequently used to monitor such patients and, if used improperly, is an excellent source of fibrillatory currents. Both the electrocardiograph and the pacemaker have been properly connected to the wall receptacle. The ground prongs of the plugs are in the ground slots of the wall receptacles, and the "hot" prongs of both machines are in the "hot" slots of both wall receptacles. The indifferent right leg electrode is grounded to the chassis of the electrocardiograph, which, in turn, is either directly or indirectly connected to the ground circuit of the wall power receptacle. Current will flow from the electrocardiograph to the power line ground, as is true in the pacemaker. There is a small signal current flowing between the patient and the electrocardiograph and the pacemaker and the patient, but there is no current path between the two machines.

Figure 5 illustrates how the combined use of a line-powered pacemaker and an electrocardiograph can deliver fibrillatory currents directly to the heart. The electrocardiograph plug has been reversed so that the ground prong is in the "hot" slot of the wall receptacle. The pacemaker plug is correctly placed in the wall receptacle so that the ground prong of the plug enters the ground slot in the receptacle. Because the electrocardiograph plug has been reversed, a significant potential exists between the right leg electrode and the power line ground through the chassis of the electrocardiograph. The pacemaker electrode in the heart is at true ground level because the pacemaker plug is correctly attached to the wall receptacle. Thus, the current generated by the potential between the right leg electrode and the intracardiac electrode can be delivered to the heart. The potential difference between the right leg electrode and the intracardiac catheter is present whether the electrocardiograph is on or off. Thus, if ungrounded, the machine is just as dangerous whether it is on or off.

What is true for the electrocardiograph is equally true for any machine that carries a high potential when ungrounded, or, more specifically, when there is any difference between the grounds of the machine and the pacemaker. Analysis of the current available from ungrounded functioning hospital equipment has indicated that electrocardiographs, cardiac monitors, portable x-ray machines and oxygen tents are capable of delivering currents in the fibrillatory range.[2]

The speed that is often necessary in the care and monitoring of patients with complete heart block frequently prevents a careful evaluation of the shock hazards to the patient. Figure 6, which is based on a case of accidental fibrillation described by Noordijk et al.,[16] illustrates how unsuspected fibrillatory cur-

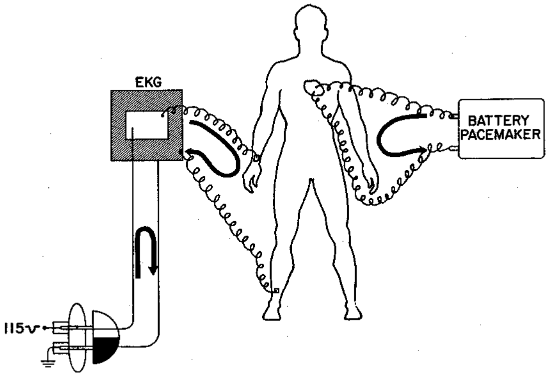

FIG. 7. *Battery-operated pacemaker.* The power source of a battery-operated pacemaker is isolated from the power line. This prevents current leakage between the pacemaker and the electrocardiograph. Even if the electrocardiograph is ungrounded, fibrillatory currents will not enter the heart.

rents can be introduced to patients. In this case the electrocardiograph attached to the patient was turned off. The cardiac pacemaker was not even plugged into the wall receptacle, but the pacemaker had been grounded by a separate ground wire. Because the electrocardiograph plug had been plugged into the wall receptacle incorrectly, a significant potential existed between the indifferent right leg electrode and the heart. Because the chassis of the pacemaker and thus one of the intracardiac electrodes which had been grounded to the chassis was connected to ground by the separate wire, a significant potential existed between the right leg electrode and the grounded electrode in the heart. Thus, a fibrillatory current was allowed to flow through the heart.

Prevention of Fibillatory Currents: These dangerous situations can be prevented if all equipment coming in contact with the patient who is being stimulated by a line-powered pacemaker and intracardiac electrodes is at the same ground potential in respect to the power line ground. Unfortunately, either because of human error or unsuspected mechanical faults, this principle cannot always be adhered to. The time-honored method of grounding apparatus by running a separate ground line to a water pipe does not necessarily place a piece of apparatus at the same potential as the power line ground. Excessive resistance either in the ground wire or the water pipe itself may prevent the establishment of a common ground. The use of coded or three prong plugs, correctly wired, goes far toward placing all equipment at the same ground potential, but it does not guarantee this. Not all rooms in all hospitals have three-prong wall receptacles, which leads to the careless use of two-prong adaptors. This obviously negates the virtues of a three-prong plug. Because of sporadic changes in hospital construction, wall power receptacles in the same room may be attached to grounds of different potential.

Battery Operated Pacemakers: In view of these practical limitations to implementing the ideal concept of common grounding of equipment, we have chosen to use battery-operated pacemakers whenever intracardiac electrodes are being employed.* Furman et al.[15] have instituted this policy after they encountered 3 cases of accidentally induced ventricular fibrillation. Figure 7 shows that the battery-operated pacemaker is totally isolated from the wall power receptacle. The current path exists only between the heart and the battery-operated pacemaker. Inadvertent reversing of the electrocardiograph plug in the wall receptacle will not eventuate in the passage of a fibrillatory current through the heart. It should be emphasized that the connection between the intracardiac electrodes and the battery-operated pacemaker must be carefully insulated against the possibility of coming in contact with any pieces of equipment or personnel that are grounded. If the electrocardiograph is ungrounded, and a grounded person or piece of apparatus should come in contact with the terminals of the intracardiac electrodes, a fibrillatory current can flow from the chassis of the electrocardiograph through the heart.

Vulnerable Period of Cardiac Cycle: The possibility has been raised that any type of pacemaker, whether it be battery-operated or line-operated, carries with it certain hazards of electric shock for reasons different from those that have been discussed. It has been suggested that the delivery of an electrical stimulus from the pacemaker during the vulnerable period of the cardiac cycle may induce ventricular fibrillation. It has been clearly demonstrated in animals that delivery of current during this

* Preliminary evaluation of a recently developed line-powered pacemaker which contains strategically located isolation transformers indicates that this form of line-powered pacemaker can be completely isolated from ground. Such an isolated line-powered pacemaker has the safety features of a battery-operated unit and is not subject to the risk of battery failure.

period will consistently induce ventricular fibrillation.[1,17] Lillehei and his associates[18] believe that this possibly could happen in human beings with implantable pacemakers, but Chardack and others[18] disagree. They point out that in the dog, currents of close to six times those used with standard clinical cardiac pacemakers are necessary to induce ventricular fibrillation. Although there are inadequate data at the present time to settle this issue completely, the practical facts of the matter are that implantable pacemakers have prolonged the useful life of innumerable patients, and there are few, if any, documented cases in which the pacemaker can be indicted unequivocally as a cause of ventricular fibrillation.

PERICARDIOCENTESIS

The electrocardiographic method of monitoring pericardiocentesis suggested by Bishop et al.[19] has undoubtedly prevented inadvertent cardiac puncture during pericardiocentesis and has become a standard procedure in many hospitals. The technic utilizes the V lead of a standard electrocardiograph which is connected to the pericardiocentesis needle. If the needle touches the epicardium, the operator is immediately warned of this by the development of a current of injury on the electrocardiogram being recorded during the procedure.

Since the needle would appear to provide a low resistance path of current to the heart, an analysis of the hazards of electric shock associated with this technic is in order. In certain ways the inherent hazards are analogous to those attending the use of an electrode catheter, but there are significant differences. If the electrocardiograph is correctly grounded, there is little danger. Even if the electrocardiograph is not grounded and a significant potential exists between the indifferent right leg electrode and the needle, a margin of safety is provided by the 5 to 10 million ohm resistor in the V lead circuit of the electrocardiograph. Because of this high resistance, an inconsequential current will flow from the indifferent right leg electrode to the exploring pericardiocentesis needle.

Figure 8 illustrates why electrocardiographic monitoring of the pericardiocentesis is relatively safe, even when the high resistance provided by the V lead circuit is mistakenly bypassed by grounding the pericardiocentesis needle or the clip lead connecting the needle to the V lead. In Figure 8A the electrocardiograph plug has been incorrectly placed in the wall receptacle so that there is a significant potential between the right leg electrode and the pericardiocentesis needle. The needle to the V lead assembly has been grounded, thus bypassing the high resistance in the V lead circuit. The needle is touching the heart, and there are no intervening body tissues touching the needle. Under these circumstances a fibrillatory current can flow through the heart. However, during pericardiocentesis the needle will touch not only the heart, but of necessity it will be in contact with the intervening tissues of the chest wall, as shown in Figure 8B. The body tissues provide another margin of safety by acting as multiple resistors which serve to decrease markedly the amount and density of current entering the heart, even if the electrocardiograph is ungrounded and the high resistance of the V lead circuit has been bypassed.

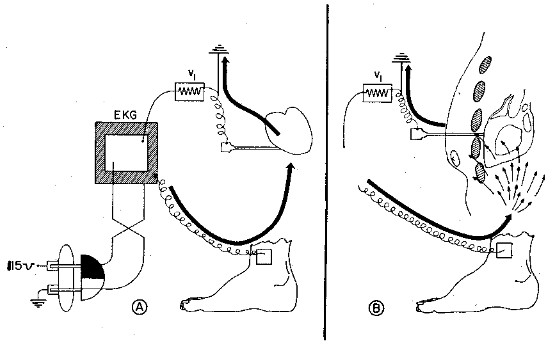

FIG. 8. *Potential danger of pericardiocentesis.* This figure illustrates the protective effect of body tissues during the electrocardiographic monitoring of pericardiocentesis. The electrocardiograph is incorrectly plugged into the wall receptacle, placing a significant potential on the right leg. The connection between the needle on the heart and the V lead circuit is grounded, thus bypassing the protective high resistance in the V lead circuit. A, a fibrillatory current (arrows) can flow through the heart. B, a fibrillatory current will not flow through the heart because the tissues of the chest wall have served as multiple resistors which dissipate and shunt current away from the heart.

The situation outlined in Figure 8 has been tested in dogs. If the needle which had been connected to a grounded V lead of an ungrounded electrocardiograph was placed directly on the epicardium after a thoracotomy, the heart promptly fibrillated. If, however, the needle was placed first through the skin and muscle and then allowed to touch the epicardium, the animal did not fibrillate. Furthermore, the protective effect of the intervening body

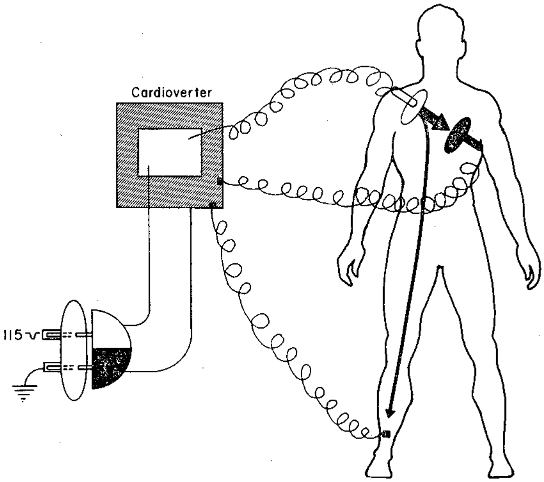

FIG. 9. *Potential danger of inducing skin burns during cardioversion.* Current can be delivered to the indifferent right leg electrode of the electrocardiographic monitoring circuit during cardioversion. One chest paddle may be considered the "hot" paddle; the black paddle is the ground paddle, which is at or near the same potential as the indifferent right leg electrode. Current (black arrows) will flow not only from the "hot" paddle to the ground paddle but also to the grounded right leg electrode.

tissues in this situation can be overcome by insulating the shaft of the needle which traverses the chest wall with a polyethylene sleeve. Under these circumstances the tissues are no longer in contact with the shaft of the needle; they can no longer act as resistors which shunt current away from the heart; and a fibrillatory current can be concentrated on the bare needle tip which touches the epicardium.

A review of these animal studies should introduce a note of caution in initiating certain modifications in pericardiocentesis technics. Commercially available needles which have an outer polyethylene or Teflon sleeve may initially appear desirable for pericardiocentesis. Once the needle tip is introduced into the pericardial space, the needle can be withdrawn, leaving the polyethylene or Teflon sleeve in the pericardial space, where it can be used to remove pericardial fluid. This may eliminate the danger of myocardial or coronary artery laceration. If such needles are used, it must be recognized that the margin of safety provided by intervening body tissues during the insertion of the needle has been eliminated, and extra care must be taken to insure the proper grounding of the electrocardiograph and insulation of the connection between the exploring needle and the V lead.

In summary, the electrocardiographic monitoring technic during pericardiocentesis is unlikely to introduce fibrillatory currents into the heart because of certain electrical and anatomic relationships, but this should not militate against proper grounding of the electrocardiograph and proper insulation of the connection between the needle and the V lead.

CARDIOVERSION

Conversion of arrhythmias to normal sinus rhythm (cardioversion) by programmed external D.C. countershock has become common practice.[20,21] The effectiveness and the safety of the procedure rests on two principles: (1) Transient complete depolarization of the heart is usually followed by the initiation of a coordinated wave of excitation which leads to the reinstitution of normal sinus rhythm; and (2) the heart will tolerate the countershock without developing fibrillation if the countershock is not delivered in the vulnerable period of the cardiac cycle. The vulnerable period for the induction of ventricular fibrillation corresponds to the period during the inscription of the initial portion of the T wave on the standard electrocardiogram.

Avoidance of Vulnerable Period: Commercial countershock instruments utilize a programming circuit so that the operator can choose the portion of the cardiac cycle in which he wishes to deliver the countershock and avoid the vulnerable period. The circuit operates by sensing an R wave of the simultaneously monitored electrocardiogram and then delivering the countershock at a specific interval after the R wave. The possibility exists that the operator may mistakenly choose a delay which will allow the delivery of the countershock during the vulnerable period. This can be avoided by checking before the external electrodes are applied to the chest to be certain that the countershock will be delivered at an appropriate time.

We have encountered a more subtle and less predictable danger that must be guarded against.[21] If, when the external electrodes are applied to the chest and the countershock circuit is engaged to fire, there is a sudden shift in the baseline of the monitoring electrocardiogram, the programming circuit may misinterpret the sudden shift as an R wave, and the countershock may be delivered during the vulnerable period, leading to ventricular fibrillation. Precautions directed toward preventing movement of the patient or the monitoring electrocardiographic electrodes prior to the delivery of the countershock will prevent this complication.

Minimizing Danger of Skin Burns: Cardioversion also can lead to skin burns at the site of the indifferent or grounding electrode of the electrocardiographic monitoring system, if one of the defibrillator paddles is grounded (as is true in at least one commercial defibrillator). The reason for this illustrated in Figure 9. One of the electrode paddles on the chest may be considered the "hot" paddle; the other electrode paddle, the ground paddle. The countershock flows from the "hot" to the ground paddle. However, during cardioversion there is another ground point as well as the ground paddle on the chest: the indifferent electrode which is the ground electrode for the electrocardiographic monitoring system. Current can and does flow not only to the ground paddle on the chest but also to the electrocardiograph ground electrode, which is usually placed on the right leg. This current flowing to the electrocardiograph ground electrode usually causes little trouble because of the brief duration of the current and because there is greater resistance between the indifferent electrode on the leg and the "hot" paddle on the chest than there is between the ground and "hot" paddles on the chest. However, if the ground electrode paddle is in poor contact with the chest, there will be an increase in resistance in the paddle circuit. The majority of the countershock current may be shunted to the ground electrode of the electrocardiograph causing skin burns.

If a needle is substituted for the usual indifferent electrode plate of the electrocardiograph on the right leg, the chance of inducing a skin burn is intensified. The needle overcomes the resistance of the skin and serves as a small focal point for the development of a high current density. In a postoperative patient in whom it was difficult to place the grounded chest paddle firmly against the skin because of tape, we have seen current arc to a grounded needle electrode in an extremity and cause a skin burn, the outline of which conformed perfectly to that of the needle (Fig. 10). This problem has been eliminated in at least two D.C. conversion units by isolating the countershock circuit from the ground circuit.

To minimize the chance of inducing skin burns, needle electrodes should be avoided, and the indifferent or grounding electrode of the electrocardiographic monitoring system should be placed on an extremity, as far away as posssible from the chest. The grounding electrodes of other pieces of equipment such as electroencephalographs which may be in contact with the patient should be disconnected before the countershock is delivered.

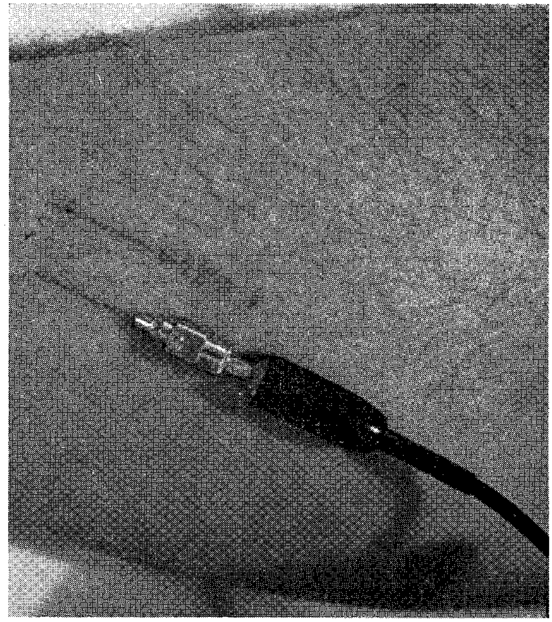

FIG. 10. *Skin burn on a patient's leg* at the site of the indifferent electrode of the electrocardiographic monitoring system. The burn conforms perfectly to the 24 gauge needle (shown for comparison below the burn) which was used as the terminal for the indifferent electrocardiographic lead. (See text and Fig. 8 for the explanation of the burn.)

SUMMARY

The danger of inducing ventricular fibrillation is present during certain commonly used diagnostic and therapeutic procedures. Electrode catheters employed for intracardiac electrocardiography, the detection of intracardiac shunts or cardiac pacing provide a current path of low resistance directly to the heart. In the presence of such paths, small voltages from improperly functioning or improperly used electrical equipment can generate fibrillatory currents. Proper grounding of all equipment coming in contact with patients will eliminate the danger of inducing ventricular fibrillation in the vast majority of cases. Since proper grounding is not always possible, battery-powered rather than line-powered pacemakers should be used in conjunction with myocardial electrodes or electrode catheters.

Electrocardiographic monitoring of pericardiocentesis is unlikely to cause ventricular fibrillation because the resistance within the V lead circuit of the electrocardiograph and the resistance of the body tissues act to prevent significant currents from entering the heart. Cardioversion, if improperly programmed, may cause ventricular fibrillation. Because certain D. C. cardioversion units have a grounded rather than an isolated countershock circuit, burns can be induced at the site of the indifferent electrode of the electrocardiographic monitoring circuit.

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