in four of each group of 96 catheters that were incubated at 37 and 42°C. Three of the 16 different catheters accounted for all eight instances of separation. During incubation at 37°C, one 12-gauge Deseret Angiocath separated on the fourth day, two 16-gauge Quik-Caths separated on the fifth day, and one 14-gauge Quik-Cath separated on the sixth day. Incubation at 42°C resulted in separation of one 12-gauge Deseret Angiocath on the second day, one 16-gauge Quik-Cath on the fifth day, one 12-gauge Deseret Angiocath on the sixth day, and one 14-gauge Quik-Cath on the seventh day.

**Discussion**

The results of our study support the hypothesis that catheter embolization may result from faulty factory bonding of shaft to hub. The data also indicate that separation of shaft from hub is dependent on the type of catheter, the temperature of the catheter, and the length of time that the catheter is subjected to a given temperature. In the incident described in this case report, all these factors probably contributed to catheter embolization. The catheter at fault in the case report was one of the types found to be susceptible to shaft–hub separation after a number of days at 37°C. Held in place by a dressing over an area of high blood flow, the catheter presumably assumed a temperature at or near body temperature for approximately 48 hours. Other factors that might have contributed to the dissolution of the bond include the actions of bacteria and enzymes at the insertion site; the importance of these factors has not been investigated.

In view of the seriousness of catheter embolization, to prevent its occurrence measures have been proposed. These measures include modifications of the needle used to insert the catheter, use of heparin covers to protect the needle point, immobilization of a joint crossed by the catheter, use of tubing in which the exposed end is larger than the lumen of the vessel, use of collodion over the exposed catheter, and taping or suturing the catheter shaft as well as the hub. However, when a sterile dressing of antibiotic ointment and gauze is applied, the use of collodion, tape, or suture may not be entirely effective or practical. When such a dressing is used over a short catheter, sterility is violated by the use of nonsterile tape and slipping of the catheter out of the anchoring suture is predisposed to by the use of ointment. Therefore, it appears that use of a one-piece catheter with an exposed portion larger than the lumen of the vessel would be less likely to cause catheter embolization than catheters of bonded hub–shaft construction.

In summary, the data presented here indicate that the shaft–hub bond of some catheters is not reliable. When such catheters are used, secure fastening of the catheter shaft with tape or suture, although not ideal, should be used to reduce the risk of embolization.

**References**


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**Blood Warmers as a Source of Solution-conducted Leakage Currents**

**David G. Björaker, M.D.*

Intracardiac electrodes and catheters are recognized as possible conductive pathways of microshock fibrillatory currents. Although careful design and scrupulous maintenance of equipment associated with invasive catheters will minimize risk of an electrical mishap, equipment not meeting leakage standards may inadvertently be used. The purpose of this paper is to present data, obtained in investigation of a clinical situation, regarding commercial blood warmers as a source of potentially dangerous leakage currents from a fluid pathway.

**Report of a Case**

A 14-year-old girl, ASA physical status II, was admitted to the neurosurgical service with the diagnosis of cauda equina tumor for lumbar laminectomy. Neuroleptanalgesia was maintained with droperidol, fentanyl, nitrous oxide, oxygen, and d-tubocurarine with controlled ventilation and an endotracheal tube. Shortly after the anesthetist began whole-blood replacement, a 60-cycle signal as seen on a previously noise-free ECG display.
Table 1. Leakage Currents from the Fluid Paths of Ungrounded Blood Warmers

<table>
<thead>
<tr>
<th>Warmer</th>
<th>Heating Manifold</th>
<th>Range of Maximum Leakage Currents (μA)</th>
<th>Number of Units Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Normal Polarity</td>
<td>Reversed Polarity</td>
</tr>
<tr>
<td>Fenwal BW-2</td>
<td>Fenwal 4C2416 bag*</td>
<td>47–82</td>
<td>62–68</td>
</tr>
<tr>
<td>Hematherm 500</td>
<td>Abbott #4665 coil</td>
<td>23–33</td>
<td>50–52</td>
</tr>
<tr>
<td>McGaw</td>
<td>Abbott #4665 coil</td>
<td>11–51</td>
<td>10–20</td>
</tr>
<tr>
<td>Hemokinetherm</td>
<td>Abbott #4665 coil</td>
<td>19–27</td>
<td>19–26</td>
</tr>
<tr>
<td>Model 3200</td>
<td>Gorman Rupp Blood</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>Gorman Rupp</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model DW-1000</td>
<td>Warming Set DWC-100*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Drip chamber filled.

Since repositioning of the electrodes and changing the lead selector did not provide significant improvement, the situation was reluctantly accepted. Subsequently, it was noticed that turning off a plastic stopcock placed in the peripheral intravenous line through which the blood was being administered stopped the 60-cycle ECG noise. Cardiac arrhythmias did not occur.

The blood was administered through an Abbott no. 4665 blood-warming coil installed in a Hematherm 500 warmer. The warmer was subsequently found to have a defective chassis–ground connection. The intravenous administration set and warming coil were free of fluid leaks.

The fact that the electrical current was introduced into the patient when the warmer was apparently functioning caused us to question 1) whether the current level would have been sufficient to cause fibrillation if the fluid circuit had been connected to a central venous catheter, 2) whether this situation could occur with non-malfunctioning blood warmers, and 3) whether this current could be generated by similar grounding faults in other available blood warmers.

METHODS

Physiologic saline solution-filled administration sets and warming coils or manifolds were installed in five varieties of clinically used blood warmers. A Beckman 39281 platinum electrode was placed in the fluid column at the point where an intravenous catheter would be connected in clinical use. A Tektronix DM502 digital multimeter was used to measure AC root mean square (rms) currents from electrode to ground as for National Fire Protection Association (NFPA) determination of leakage currents between patient leads and ground. Measurements were made with the chassis–ground connected and open and the polarities normal and reversed. The maximum rms leakage current during initial warm-up and the heating cycle was recorded.

RESULTS

Leakage currents were not detected (less than 0.1 microampere) when the chassis–ground connection was intact. With the ground line bypassed at the plug of the blood warmer, all the machines tested developed measurable leakage currents between the intravenous solution and ground (table 1). Four of the five types of warmers exceeded 20 μA current for open chassis–ground. The fifth type, of which only one was tested, had a leakage value between 10 and 20 μA.

Only the Hematherm 500 showed a leakage waveform other than a sine wave. Since the current to the heating elements flows only a portion of each electrical cycle, the leakage current, which was the first derivative of the wave form, included a spike each time the silicone-controlled rectifier supplied the elements.

DISCUSSION

Tentative NFPA standards limit leakage current to a 10-μA maximum for a fluid-filled intracardiac catheter during normal operation. The limit when a nonobvious fault occurs, as in the case reported, extended to 20 μA. Four of the five tested models exceeded this proposed guideline. Because of the sparsity of available information about fibrillation thresholds from endocardial electrodes in man, the NFPA rationale was based on the considerations that: 1) since epicardial fibrillation thresholds in man and dogs are similar, endocardial thresholds are probably also similar; 2) endocardial threshold current levels are lower than epicardial threshold current levels.1

Several investigators have now studied ventricular fibrillation thresholds in man at initiation of cardio-pulmonary bypass Whalen et al., using 4.9-mm² epicardial electrodes at the apex of the left ventricle and right ventricular outflow tract in four patients, found a mean current threshold of 583 μA, with a low value of 180 μA. Starmer and Whalen, using a 5-mm² similarly positioned epicardial electrode pair in six patients, found a mean threshold of 260 μA with a low value of 180 μA. Kugelberg studied 36 patients, 33 of whom fibrillated upon application of 12.6-mm² epicardial electrodes to the posterior wall of the left ventricle and 11 of whom fibrillated with a right ventricu-
lar endocardial 9-mm² pacemaker electrode. The mean value for epicardial current was 601 μA, with a minimum value of 100 μA; for endocardial current, 358 μA, with a minimum value of 100 μA. He subsequently recommended a safety limit of 50 μA. Of the 56 patients that Watson et al. studied by stimulating with epicardial electrodes, intramyocardial needles, or a right ventricular endocardial pacemaker electrode, the latter group had the lowest threshold currents. By extrapolation, Watson et al. predicted a minimum fibrillating current from 14 patients with a bipolar endocardial electrode to be 67 μA; from nine patients with a unipolar electrode, 141 μA. In two additional studies using right ventricular endocardial stimulation, Snider and Raftery et al. found fibrillation currents ranging from 180 to 520 μA and greater than 80 μA, respectively; however, the details provided were insufficient to elaborate. All the values reported were larger than the NFPA limits.

The apparent discrepancy between the human data and the suggested early guidelines may be partially resolved by considering electrode surface areas. Roy effectively demonstrated that small-orifice fluid-filled catheters require lower current flows for fibrillation than large-orifice catheters, which are comparable to the larger pacer electrodes. For the smallest catheter studied, which had a .224-mm² orifice, pump failure occurred in dogs at a mean value of approximately 35 μA and fibrillation occurred at about 75 μA. Therefore, the values observed in the human studies may be large, since the electrode surface areas were larger than the area of a typical central catheter used for fluid administration. A 16-g catheter has an orifice of approximately 1 mm².

Other determinants of ventricular fibrillation current thresholds have also been considered. Investigators agree that ventricular fibrillation by atrial stimulation occurs in the milliampere current range. In spite of a threefold variation in heart sizes of the dogs studied by Roy, unlike surface electrocution, organ size was not related to threshold current. Roy et al. demonstrated that high current thresholds with pulses of short duration were lowered to a plateau level when pulses exceeded 3 seconds in duration. The lower plateau levels for long pulses would apply to leakage current. Both Roy et al. and Green et al. distinguished between severe rhythm disturbances, which diminish pump function, and the occurrence of persistent fibrillation. The former occurred at lower levels of current flow but are of clinical importance.

Do the capacitance-coupled currents found in the survey constitute an example of the hazard of microshock electrocution? Fibrillation thresholds in patients may be lowered by electrolyte imbalances, acidosis, hypothermia, the presence of intracardiac catheters, underlying myocardial disease, high catecholamine levels, preoperative drugs (e.g., digitalis), and perhaps anesthetics. Although for most of these factors, in the context of microshock electrocution, adequate data are nonexistent, standards justifiably should allow a safety margin. For the reported patient to have sustained microshock electrocution 1) the patient's fibrillation threshold would have had to have been on the "sensitive" side of a statistical distribution of fibrillation thresholds, 2) the catheter acting as an electrode would have had to contact the ventricular myocardium, and finally 3) the grounding connection of the blood warmer would have had to fail.

This case of delivery of leakage current from an ungrounded blood warmer to a patient by an electrolytic pathway could have occurred with several commercially available units, but theoretically would have led to ventricular fibrillation only under unlikely circumstances. Blood warmers should always be used with the grounding pin of the three-wire plug connected. Routine preventive maintenance of apparently functioning equipment will further minimize this hazard.

References