DC defibrillator failure

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Since the development of the DC pulse defibrillator[1] and its synchronous use as a cardioverter,[2] professional acceptance has brought this type of defibrillator into widespread use.[3] Generally, it has replaced the original 60-cycle AC defibrillator developed by Kouwenhaven.[4] Patterns of failure for the DC defibrillator have not, at this time, been described. This report concerns a case of DC defibrillator failure, initially thought to be due to myocardial damage. Had not the actual cause been found in the defibrillator, a fatality easily could have occurred.

Defibrillator failure

In a recent procedure for left coronary artery endarterectomy and bifurcation pericardium patch graft (left coronary to anterior descending and circumflex arteries), difficulty was encountered during the defibrillation. The operation was carried out with the patient maintained on pump support from the right ventricular outflow to the femoral artery,[5] esophageal temperature maintained at 32° C., and the ventricles electrically fibrillated. After the patch graft was completed and the patient was rewarmed to esophageal temperatures of 37° C. on pump support, five internal 30 watt-second countershocks, followed by five 40 watt-second discharges, failed to defibrillate the heart. With each discharge, coincident skeletal muscle jerk occurred and the fibrillating ventricle appeared to momentarily go into arrest and then promptly resume its fibrillation. A second defibrillator and internal paddles were brought onto the field—a single 30 watt-second discharge promptly restored sinus rhythm. This persisted through an uneventful postoperative recovery.

At examination of the current output from the defibrillator causing the difficulty, without the paddles, oscilloscopic current wave forms obtained from the unit indicated a normal output. The internal paddles were then examined. From Fig. 1 it can be seen that the wires to these paddles were broken in three places. A complete break in the wire occurred at each paddle handle and a third within the wire a short distance from the paddles. During the ten attempts at defibrillation mentioned, there was no sign of electrical arcing, either by sight or sound.

Pattern of failure

This experience was extremely disturbing in two ways. We regard difficulty defibrillating as an ominous prognostic sign, particularly following coronary surgery where an area of localized myocardial anoxia may be suspect as the focus continuing the fibrillation. We had believed, also, that

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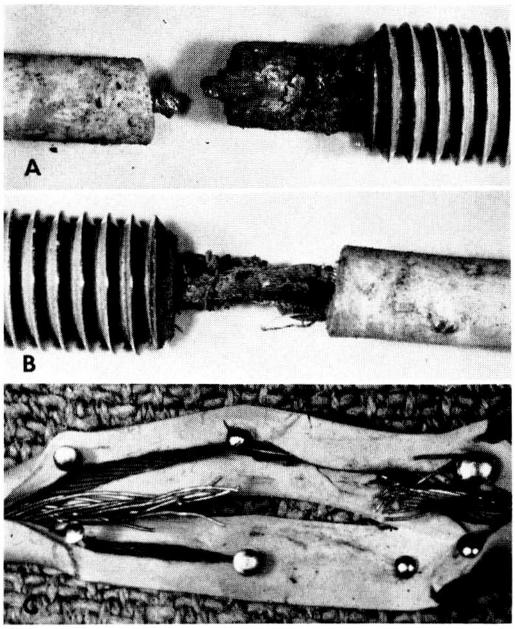

Fig. 1. Photograph of defective internal paddles shows wires broken in three places.

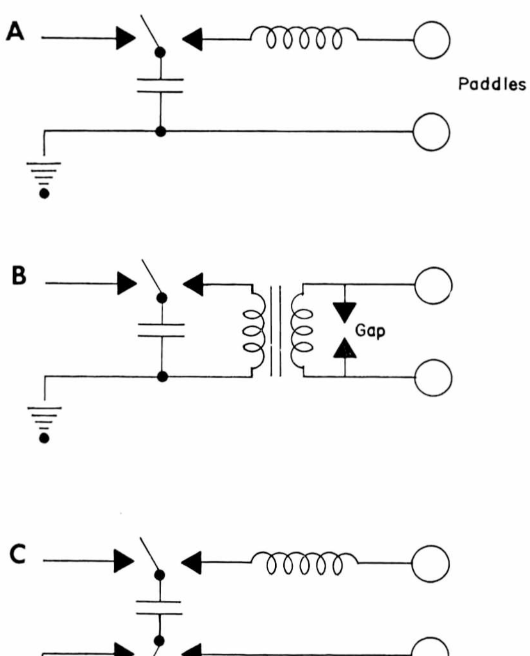

Fig. 2. Circuit diagram of the three basic types of defibrillators. *A*, Grounded paddle. *B*, Transformer isolation. *C*, Double-pole relay isolation.

if muscle jerk occurred with defibrillation after adequate capacitor charge indication, the defibrillator was operating satisfactorily. The latter we now know is not true. It should be brought to the attention of those using DC defibrillators, for defibrillation or cardioversion, that the presence of muscle jerk at the time of discharge is *no indication* that the defibrillator is working properly.

Failure of this defibrillator prompted our evaluating eight additional DC defibrillators manufactured by five different companies. All but one defibrillator had been in use for 1 year or more in four different Seattle hospitals.

Defibrillator types

The nine defibrillators manufactured by five different companies may be broken down into three basic types, illustrated in Fig. 2.

Type A utilized one grounded paddle. It is the type initially developed by the author and also used by Lown in cardioversion. Three such defibrillators made by two manufacturers were tested. The advantage of this type of defibrillator is its simplicity. A disadvantage of the grounded paddle system is the possible shock hazard to attending personnel. If personnel are grounded but the defibrillation chassis with which they are in contact is not, shocking may occur.

Type B utilizes transformer isolation which does not provide complete transient isolation from ground. Three defibrillators, made by three different manufacturers, employ this type of circuitry, which permits a relatively inexpensive low voltage capacitor to discharge through a low voltage relay, stepping the voltage up to the required amount through the transformer. This type of transformer-isolated defibrillator presents a problem in that if the discharge switch is thrown without a load between the paddle, a bypass spark-gap is required to prevent excessively high build-up of voltage in the transformer and breakdown of the secondary transformer isolation. In addition, if the spark-gap is too small, arcing occurs at high watt-second settings and the full energy is not dissipated through the electrodes, but through the spark-gap.

Type C is a truly isolated system, utilizing a high voltage capacitor, vacuum relay, and a good quality, low-resistance inductor. This method is more expensive; however, it is the only type of defibrillator which provides true, complete isolation. True isolation is provided when no voltage appears between either of the electrode paddles and ground when a discharge switch is depressed. This type of defibrillator, because of the above features as well as an automatic ground indicator, is believed to be superior in terms of safety to the operating personnel over the preceding two types.

Types of failure

Failure in Type A defibrillators. The defibrillator described as failing during the coronary endarterectomy was of this original type. In Fig. 3 we see wave forms develop by two defibrillators of this type. Fig. 3, *A* shows that wave form originally described

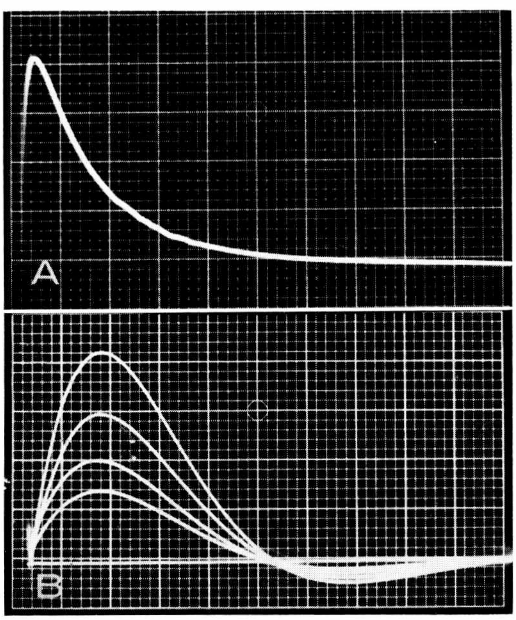

Fig. 3. *A*, Critically dampened wave form. Horizontal time, 2 msec. per centimeter. *B*, Non-critically dampened wave form. 50-100-200-400 watt seconds. Horizontal, 1 msec. per centimeter. Vertical, 10 ampers per centimeter.

by the author and first utilized in DC pulse defibrillation of a human being. The wave form shown in Fig. 3, *B* is that described by Lown. Both of these defibrillators indicate the charge energy on the capacitor by a watt-second meter, calibrated in watt-seconds. Failure of an adequate charge on the capacitor is immediately detected by the meter not coming up to proper watt-second setting. This brings out the desirable feature of a meter readout, permitting one to rapidly assess that adequate energy is stored on the capacitor; with discharge, the meter falls to zero, indicating that the capacitor has been discharged. In the mechanism of failure described, the meter does not safeguard against an open lead (one or more) in the defibrillating paddles. The high voltage energy can be dissipated in an arc in the electrode wires. This cannot be heard if the insulation and shielding remain intact. Sufficient energy will pass between the electrodes to cause muscle response, but the grossly distorted wave form will not defibrillate. We have observed broken leads as the only cause for defibrillator failure in the Type A instrument. There have been, however, several reports of accidental shocking when the defibrillator is improperly grounded and personnel have their hands on the cage of the defibrillator and are themselves grounded.

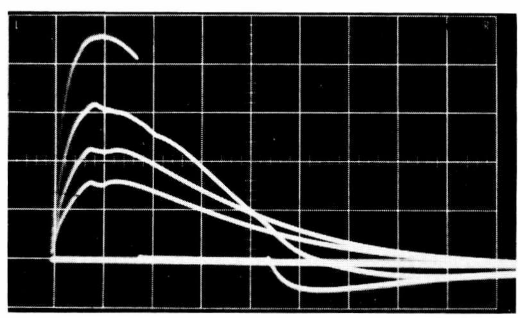

Fig. 4. Type B defibrillator failure caused by arcing across protective shunt spark-gap at 400 watt-seconds. 70 ohm load. 50, 100, 200, 400 watt-second discharge. Note, also, irregularities from pitted relay contacts at lower energy levels. Vertical, 10 amperes per centimeter. Horizontal, 1 msec. per centimeter.

Failure of Type B defibrillator. Failure of this type of defibrillator under test conditions has been observed in two areas. Fig. 4 shows failure at 400 watt-second settings produced by an arc forming at the spark-gap, effectively shorting the output. The wave form of Fig. 4 illustrates this. Fig. 5 illustrates the second type of failure produced by high current densities through the nonprotected contacts of the relay. By utilizing a very large capacity, low voltage capacitor, the manufacturer may also use a relay not designed for high voltage application.

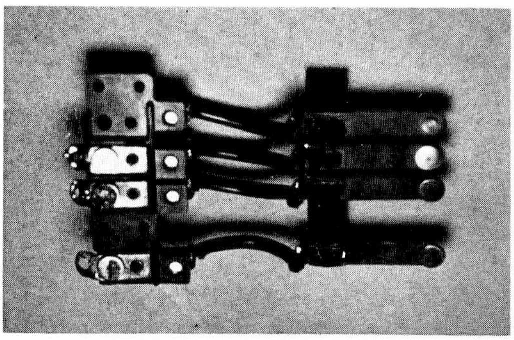

Fig. 5. Pitted contacts from relay in Type B defibrillator.

Unfortunately, the requirements for this relay, although less stringent for high voltage requirements, necessitates its operation at currents much higher than that of the high voltage relay, resulting in pitting of contacts. When this occurs, energy is dissipated in the resistance of the electrical contacts.

Failure in Type C defibrillator. Since this is the newest and theoretically the safest type of defibrillator, failures have not been seen in its short time of operation.

Failure mode

Attempting to reduplicate the actual defibrillator failure observed, we created spark-gaps of different lengths. When current wave forms were observed in series with the discharging defibrillator, we were surprised to see that, *if arcing occurred,* the amount of energy delivered between the electrodes was not significantly reduced. However, if arcing did not occur, no energy whatsoever was delivered to the paddles. Failure of the defibrillator to function after the coronary endarterectomy was not due directly to the breaks in continuity at the paddles' wires, but to carbonization and increasing series resistance in wires after arc

Fig. 6. Photograph of simple bolometer-type energy-dependent defibrillator tester.

formation. An arc, once formed, offers minimal energy absorption. Carbonization of wire and the resultant introduction of 70 ohms of series resistance will reduce the effective power output from the defibrillator by 50 per cent.

Whereas series arcing, per se, does not materially reduce a defibrillator's effectiveness, shunt arcing, as seen in the Type B defibrillator from too close setting of the transformer-protecting spark-gap and/or variation in environmental humidity, in effect short circuits out the defibrillator, destroying its effectiveness.

For rapid and simple testing of any DC type of defibrillator, we have developed a prototype tester, which is shown in Fig. 6. The defibrillator electrodes are placed on the two top metal discs of the tester, the tester is then set at zero. An energy level such as 400 watt-seconds is selected on the defibrillator, which is then discharged through the tester. The indicated reading in watt-seconds on the tester meter should be the same as the selected setting on the defibrillator. If it is lower, energy is being absorbed in the leads or the unit is defective. The tester operates on a bolometer principle and measures energy, independent of wave shape. A test may be completed in less than a minute on any type of DC defibrillator at any energy level, up to 400 watt-seconds.

The three types of defibrillator output failures reported here in nine instruments suggests that there are undoubtedly other unsuspected defective defibrillators in operation around the country. Reports of high failure rates during cardioversion may be related to reduced output from untested defibrillators. Skeletal muscle jerk occurring at the time of defibrillator discharge is no indication of proper defibrillator function. A simple energy-dependent test method is described.

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