Low energy level internal defibrillation during cardiopulmonary bypass

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Abstract. Low energy level internal direct current shocks were used to defibrillate the hearts of 168 patients during procedures performed on cardiopulmonary bypass. In all cases, the core temperature was greater than 32°C and care was taken to correct hypokalaemia and acid-base balance prior to defibrillation. In 78 patients (46%), defibrillation required 2 joules or less, and in 139 (82.7%) cases, defibrillation was effected with 4 joules or less. Only 4 patients required more than 10 joules to defibrillate the heart. This study shows that it is possible to defibrillate hearts during cardiopulmonary bypass with energy levels well below the 20–30 joule shocks commonly used. [Eur J Cardiothorac Surg (1989) 3: 273–275]

Key words: Defibrillation – DC cardioversion

The first report of a successful resuscitation using an electrical current originated from the Middlesex Hospital in 1775 [14]. A child was initially declared dead after falling from a window, but was subsequently revived by electrical shocks transmitted through the thorax. No details are given regarding the child’s heart rhythm or the source or strength of the applied electrical current, but this account of the use of electrical energy as a resuscitative measure predates all other work on this subject by more than a century and deserves recognition [11]. In 1899, Prevost and Batelli published their work showing that it is possible to convert ventricular fibrillation to synchronised beats by the application of a strong electrical current through the fibrillating heart [12]. Some 14 years later, Jex-Blake in the Goulstonian lectures on death by electrical currents and lightning suggested that this might be a treatment that could be applied with success to humans apparently killed by electrical currents. He pointed out that in the case of man, there was no experimental evidence to show what voltage or strength of current should best be employed in this method of resuscitation [7]. To a certain extent, this remains true today.

In 1962 Lown published his work on direct current (DC) defibrillation [9]. He concluded that this was a more effective and less damaging way to defibrillate the heart than alternating current. In his series, 65% of fibrillating dog hearts reverted to sinus rhythm with the application of an internal DC shock of 70 joules or less.

There is evidence that high energy electrical shocks damage the myocardium [2, 3, 5, 8]. Nevertheless, it is still common practice to use 20–30 joule shocks for internal defibrillation of hearts during cardiopulmonary bypass: some defibrillators cannot be set to deliver less than 10 joules. For this study, a standard Albury Lifeguard defibrillator was modified to permit a range of low energy shocks to be administered in order to determine the threshold required for internal defibrillation.

Patients and methods

A total of 391 patients underwent procedures on cardiopulmonary bypass during the period 1983–1985 under the supervision of one consultant surgeon. Of these, 168 required defibrillation and were included in the study. Ages ranged from 4 years to 77 years with a median age of 58 years. There were 118 males and 50 females. The surgical procedures undertaken in these patients are shown in Table 1.

In the coronary graft patients, hypothermia was induced during cardiopulmonary bypass, the core temperature was reduced to 28°C and cold cardioplegic arrest was utilised. The
Table 1. Surgical procedures undertaken in patients requiring defibrillation

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Patients</th>
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<tbody>
<tr>
<td>Coronary artery grafts</td>
<td>88</td>
</tr>
<tr>
<td>Mitral valve replacement</td>
<td>33</td>
</tr>
<tr>
<td>Aortic valve replacement</td>
<td>22</td>
</tr>
<tr>
<td>Double or triple valve replacement</td>
<td>4</td>
</tr>
<tr>
<td>Valve replacement plus coronary grafts</td>
<td>4</td>
</tr>
<tr>
<td>Left ventricular aneurysm repair</td>
<td>4</td>
</tr>
<tr>
<td>Repair ruptured ventricular septum</td>
<td>1</td>
</tr>
<tr>
<td>Correction of congenital defects</td>
<td>12</td>
</tr>
</tbody>
</table>

The aortic root was thereafter perfused with cold electrolyte solution throughout the period of cross clamp. In other procedures, ventricular fibrillation occurred either spontaneously or after elective electrical stimulation to induce it. In these cases, the median value of all the lowest core temperatures was 33°C (with a range from 32°C to 37°C). In all cases, defibrillation was attempted at a core temperature of 32°C or higher.

**Defibrillator modification**

A diagrammatic representation of a DC defibrillator is shown in Fig. 1. A DC source is used to apply a voltage across a capacitor (C) to charge it. The DC source is driven by a comparator. This receives a voltage signal from the selector circuit which pre-selects the desired energy to be stored in the capacitor. A feedback voltage signal comes from the capacitor informing the comparator of the energy in store. When the two voltage inputs to the comparator are balanced, the power supply to the DC source is switched off and no further charging of the capacitor takes place. In our modification of the DC defibrillator, a resistance (R) was introduced into the selector circuit such that the voltage signal to the comparator was reduced to about \( \frac{1}{3} \) of the voltage applicable without the resistance. This resistor can be withdrawn from the circuit by the flick of a switch, allowing higher energy levels to be selected. The energy delivered by a DC defibrillator is approximately equal to the energy stored in its capacitor. This is proportional to the product of the capacitance of the plates and the square of the voltage applied across them (i.e. \( E = \frac{1}{2} CV^2 \), where \( E \) = energy stored; \( C \) = capacitance and \( V \) = voltage).

Thus by placing a resistance in the circuit to reduce the voltage to about \( \frac{1}{3} \) of its original value, it is possible to reduce the stored energy to approximately \( \frac{1}{9} \) of its predicted size. The voltage across the capacitor plates was independently checked to ensure that it agreed with the preselected energy level. For the range 1-4 joules, the energy stored did not vary from that selected by more than 0.1 joule and for the range 6-12 joules, the maximum variation was 0.4 joules. For all adult patients, the DC shocks were delivered by means of cardiac recorder defibrillating paddles each with a surface area of 48 cm².

**Defibrillation**

The first attempt at defibrillation was made with a 1 joule shock. If this was unsuccessful, larger shocks were applied until the heart defibrillated. The sequence of energy levels was 1, 2, 4, 6, 8, 9, 12, 15, 20 and 30 joules. If the heart fibrillated again, the defibrillation sequence was restarted at the previously successful energy level. Only the energy level ultimately successful in defibrillating the heart was recorded.

**Results**

The energy level required to defibrillate each of the 168 patients is shown in Fig. 2. Three patients required subsequent defibrillation after an initial successful shock. Two reverted at the same energy level as on the first defibrillation, but one patient required a 4 joule shock having initially defibrillated with 1 joule. In 78 (46%) cases, defibrillation was effected with 2 joules or less and 139 (82.7%) patients defibrillated with 4 joules or less. Only 4 patients required more than 10 joules to defibrillate.

**Discussion**

High energy electrical shocks are damaging to the myocardium. Reduced myocardial function and release of CPK [8] have been observed in isolated Langendorff perfused rabbit hearts after stimulation with energy densities in excess of 1.5 joules/cm². Dahl et al. [2] observed myocardial necrosis in dog hearts after transthoracic DC shocks and related the extent of necrosis to paddle size and the...
interval between shocks. Direct DC shocks in excess of 35 joules have been shown to cause sub-endocardial necrosis in dog hearts [3] whilst 30-joule shocks impair aerobic metabolism [5].

In clinical practice, indirect evidence of myocardial damage after DC conversion is obtained by the development of arrhythmias, ST segment elevation [1, 10], serum enzyme rises [4] and the occurrence of pulmonary oedema [6, 16]. Controversy remains as to whether multiple low energy shocks are more damaging than a single high energy shock. The lowest energy level which would safely defibrillate a human heart is not known. However it appears a reasonable principle to use a shock no larger than necessary. Tacker et al. [15] suggest starting at an energy level of 10 joules for internal defibrillation. In their study, the energy required to defibrillate a heart did not appear to correlate with heart weight, patient age, operative procedure or even duration of cardiopulmonary bypass.

We have shown that the majority of hearts will defibrillate with a shock of 4 joules or less once the acid/base balance has been optimised and the core temperature is in excess of 32°C. We would recommend the use of low energy DC shock to defibrillate hearts during cardiopulmonary bypass and the provision of equipment to achieve this. The likelihood of the need for cumulative shocks is small and many patients would be spared unnecessary high energy shocks.

References


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