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Improved Electrodes for Electrical Defibrillation of Rats

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Experimental induction of ventricular fibrillation in animals yields valuable information about this deadly arrhythmia. Human adult or pediatric defibrillators and their paddles can be used easily in larger animals such as dogs and pigs, but these animals are more difficult to house and handle, and available biochemical assays may be limited. In contrast, rats are easy and relatively inexpensive to house and handle, and numerous biochemical tests are available. However, in most cases, even pediatric electrodes are impractical for use in rats. Proper placement of defibrillation electrodes on the thorax requires that the electrical axis of the heart be situated between the defibrillator paddles. The most common approach to defibrillation in rats uses 2 electrodes: one is built into a board that underlies and touches the rat's back, and another is positioned manually on the anterior thorax. The aim of this study was to produce electrodes that are 1) easy to handle, 2) specifically designed for rats, 3) efficiently deliver defibrillation shocks along the electric axis of the heart, and 4) can be used for both in vivo defibrillation and on isolated heart preparations.

Because ventricular fibrillation is a pathologic condition that can easily cause death, much research addresses discovering its causes and optimizing its treatment. However, despite the vast research on isolated hearts and in various animals, the causes and mechanism of this deadly condition are not yet fully understood.[1,14]

The use of larger animals in this research offers several advantages, including the availability of suitable instrumentation from human practice and ease of catheterization. The pig[11,15] and dog[7] are used frequently in these types of studies, but these animals are costly to house, feed, and maintain in conditions suitable for experiments. Nonetheless, defibrillation equipment designed for human adults and children can be used in these species without adaptation.

Although small laboratory animals such as rodents offer other benefits for cardioelectrophysiology research, classic defibrillator paddles for human adults or children[6–8,12] are impractical for use in rats. They are difficult to attach to fur-covered skin, and their surfaces are too large for the rat thorax. When laboratory rats or rabbits are used[4,10,14] for in vivo or in vitro[4,13] experiments, the defibrillation electrodes must be custom-designed and most often involve 2 electrodes, one that is built into an underlying board (which touches the dorsal thorax when the animal is dorsally recumbent) and another that is applied to the ventral thorax. However, the problem with this design is that it requires firm fixation of the limbs to the underlying board for appropriate stabilization of the animal during delivery of the defibrillation shock. In a different but invasive approach, Jones and colleagues[6] subcutaneously inserted small gold-plated electrodes (0.8 cm diameter) on the left and right thorax to defibrillate rats. Here we propose an improved design for defibrillation electrodes in rats that sufficiently stabilizes the animal's body to minimize movements during shock delivery, is noninvasive, and defibrillates along the electrical axis of the heart.

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Materials and Methods

All the animal experiments described herein comply with *European Convention for the Protection of Vertebrate Animals used for Experimental and Other Scientific Purposes*[3] and the experimental protocol was approved by the Timisoara University of Medicine and Pharmacy Board for Animal Experimentation. In our study we used a total number of 15 male Sprague-Dawley rats, weighting 400 to 450 g. The animals were obtained from a facility (Pius Branzeu Center for Laparoscopic Surgery and Microsurgery, Timisoara, Romania) that certified them to be free of *Mycoplasma* spp., adventitious viruses, respiratory or enteric bacteria and ecto- and endoparasites. The animals were housed under conditions of controlled temperature (20 °C) with a 12:12-h light dark cycle and had ad libitum access to autoclaved rat chow (Rat Diet, Purina Lab Diet, St Louis, MO) and water.

Animal model of ventricular fibrillation. To induce ventricular fibrillation in rats, we used an ischemia–reperfusion model[2] in which the heart fibrillates upon reperfusion. Each rat was anesthetized with an intraperitoneal injection of 60 mg/kg ketamine and 6 mg/kg xylazine and then was placed in dorsal recumbency on a heated plate to maintain a constant body temperature of 37 °C (monitored continuously with a rectal thermometer). The rat then was intubated and ventilated throughout the procedure at 80 to 100 respirations/min with 100% humidified oxygen to maintain blood CO_2 and O_2 concentrations and pH within normal ranges. The carotid artery was cannulated with a 24-gauge catheter for blood collection and blood pressure monitoring.[9]

Briefly, left thoracotomy between the fourth and fifth intercostal spaces was performed, the pericardium sectioned, and the heart surface exposed. The left coronary artery was identified between the left atrium and the emergence of the aorta and was reversibly ligatured for 30 min with a plastic occluder. Occurrence of cyanosis downstream of occlusion point confirmed ligature of the artery and its disappearance

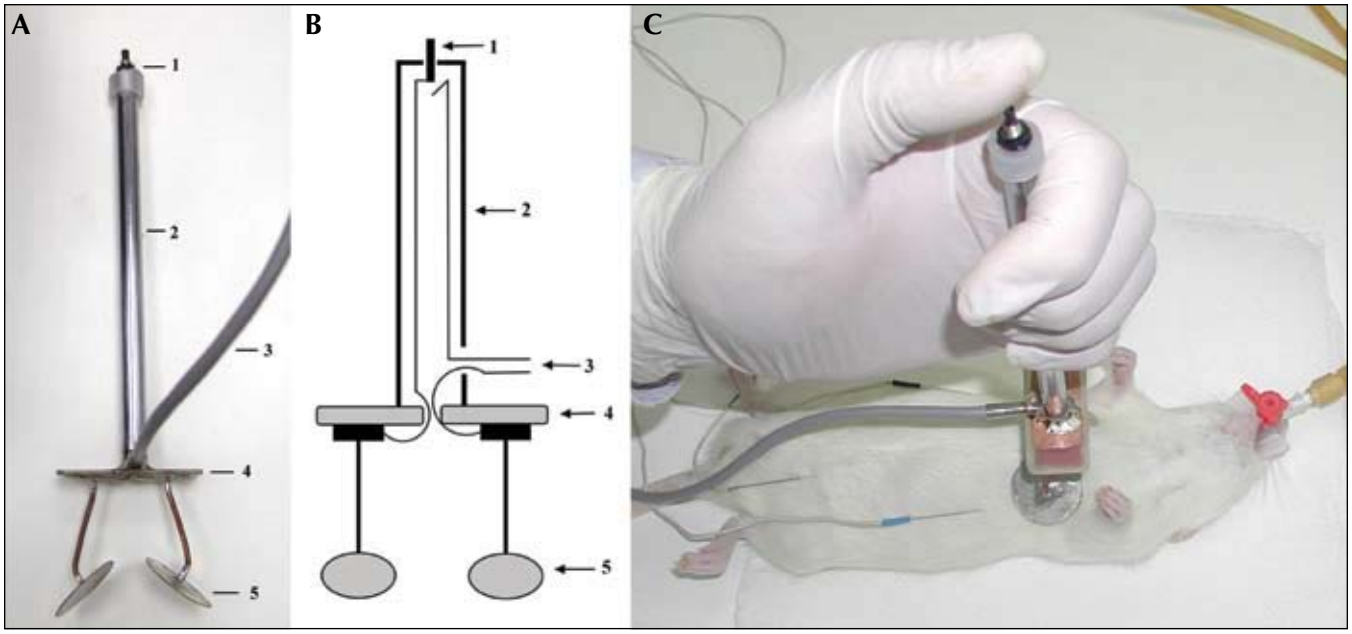

Figure 1. (A) Defibrillating electrodes. 1, on/off switch; 2, handle; 3, wires; 4, insulator; 5, electrode pads. (B) Schematic diagram of the defibrillating electrodes. 1, on/off switch; 2, handle; 3, wires; 4, insulator slab; 5, electrode pads. (C) Electrodes on the animal's thorax.

confirmed reperfusion. As soon as ventricular fibrillation occurred, the electrodes were applied to the thorax and the shock delivered. For this study all successfully resuscitated animals were kept alive. To minimize the pain during recovery, the animals received 10 mg/kg paracetamol (Perfalgan, Bristol-Myers Squibb, Rueil Malmaison, France) intravenously at the end of the procedure and were treated with the same drug, administered in the drinking water at a concentration of 2 mg/ml, for 3 d after procedure.

Electrode design. The defibrillating electrodes are shown in Figure 1 and comprise 2 electrode plates connected to an insulator slab that is welded to a handle with an on/off switch (Figure 1 A, B). Each electrode consists of a round stainless steel plate (radius, 0.8 cm) that is welded to a 4-cm copper wire; the opposite side is applied to the thorax. The copper wires for each electrode are welded separately to the insulator and are connected to the wires that come from the condenser. The metal handle also is welded to the insulator plate and has an on/off switch at the other end. With one hand on the handle, the investigator can place both electrodes in the correct position on the rat's thorax and can use his/her thumb to trigger the discharge (Figure 1 C). The copper wires are quite flexible and allow changes in the electrodes' orientation to accommodate various rib cage shapes and sizes. In addition, the investigator's hand holds the electrodes firmly in place on the rat's thorax, thus preventing displacement of intravenous catheters, endotracheal tubes, and so on during the ensuing muscular spasm. The electrodes grip the rat thorax like tongs, holding it in place while delivering the defibrillating shock, and the position of the electrodes on the animal's thorax can easily be adjusted to optimize shock delivery. Application of echocardiography gel on the electrode plate facilitates electrical conductivity. With only minor adjustment, the electrodes can be attached to any commercial defibrillator.

Defibrillator design and construction. The structure of our test defibrillator is depicted in Figure 2 A. Basically the energy is stored in the condenser (100 µF, 500 V) and is released by the on/off switch (S2, Figure 2 A) through the 2 electrodes (E1 and E2, Figure 2 A). The curve showing energy accumulation in the condenser is displayed in Figure 2 B and is of a typical shape. The curve of the electrical discharge is a damped sinusoidal monophasic waveform (Figure 2 C). The condenser is programmed to recharge automatically after each shock delivery. The defibrillator has a display that indicates the charge level of the condenser; once the threshold is surpassed, the machine is ready to deliver the shock. Before the defibrillator is turned off, the residual electrical charge accumulated in the condenser is discharged through switch S1 (Figure 2 A) which is attached to a resistor.

ECG recording. ECG recording was performed as described previously,[5] with 3 electrodes placed on the rat: 2 of them symmetrically on the lower thorax (the active electrodes that record the first derivative waveform), while the ground electrode was placed on the lower abdomen. The signals were recorded with a RFT Biomonitor (VEB Messgeratewerk, Zwonitz, Germany) and printed on paper.

Energy recordings. Energy measurements were made with a 2-channel digital real-time oscilloscope (TDS 210, Tektronix Texas LLC, Richardson, TX). The curve of energy accumulation in the condenser (Figure 2 B) was measured at the condenser terminals while the shock discharge was tested on a 50-ohm resistor (Figure 2 C).

Results

The electrodes we designed efficiently deliver a defibrillation shock. They can be applied to the rat thorax in the desired positions (Figure 1 C) and secure the animal during defibrillation. Figure 3 illustrates the sequence of events during defibrillation of ventricular fibrillation upon reperfusion and restoration of normal sinus rhythm after shock delivery. Upon reperfusion of the heart, a bout of ventricular fibrillation occurred; immediately the electrodes were applied and the shock delivered. Upon induction of ventricular fibrillation the mean arterial pressure dropped to less than 10 mm Hg but after successful resuscitation, it returned to values exceeding 60 mm Hg. We considered successful resuscitation to be the return of spontaneous rhythm with an average arterial pressure of 60 mm Hg for at least 5 min.

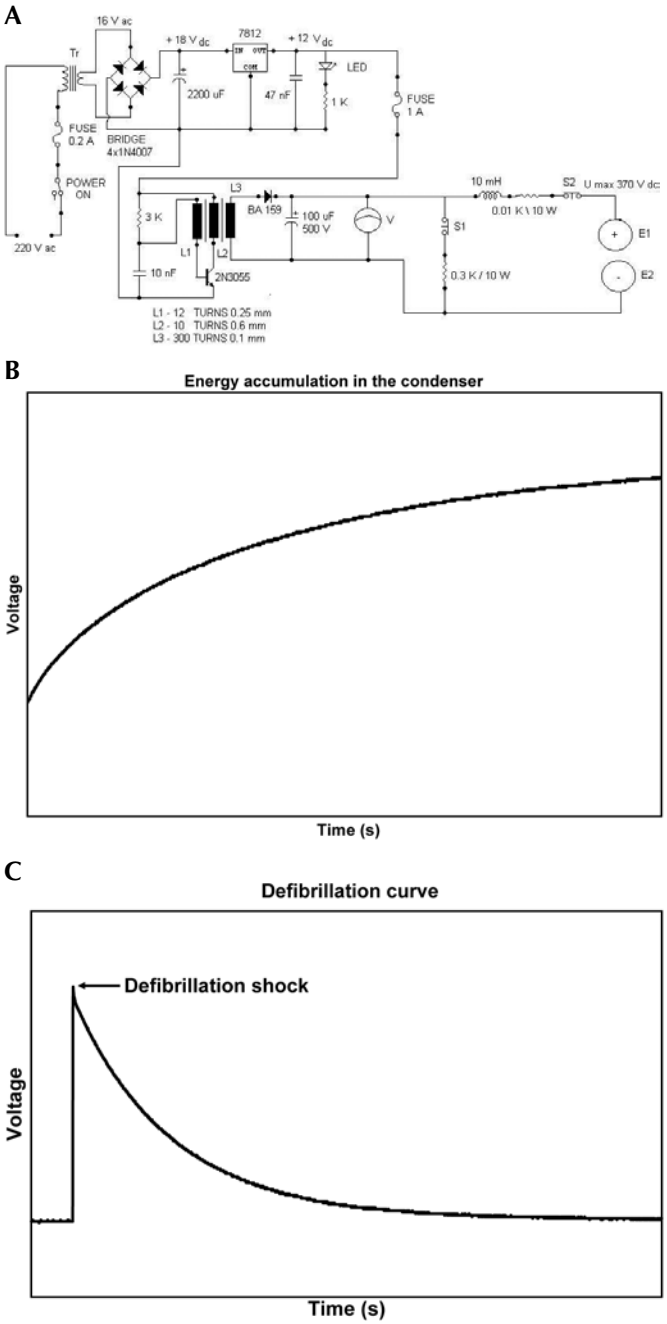

Figure 2. (A) Electronic scheme of the defibrillator. (B) Loading curve for the condenser. (C) Electrode discharge curve.

Of the 15 rats that were used in this study, 14 were resuscitated successfully; the remaining rat developed a nonresuscitable form of arrhythmia.

Discussion

The electrodes we have designed effectively deliver the electrical shock required to resuscitate a fibrillating rat heart.[1] When tested on fibrillating hearts early after onset of fibrillation, the electrodes delivered an electrical signal that stopped the arrhythmia and returned the heart to sinus rhythm. Unlike traditional rat paddles which are placed ventrally and dorsally,[4,10,14] these electrodes are placed on the ventral thorax in a position resembling that for defibrillation in humans. The new electrodes are easy to operate: a single investigator, using just one hand, can place them on the rat's ventral thorax in the desired position and use the on/off switch to deliver the defibrillation shock. By their design, the electrodes securely hold the animal during electrical discharge, thus preventing dislodging of endotracheal tubes and indwelling catheters. The animal need not be placed on a special underlying board for electroconversion; the design allows defibrillation to be delivered in many experimental setups. Unlike other approaches,[6] ours is noninvasive. The copper wires and pads of the electrodes are flexible enough to accommodate rats of various sizes. This system likely can be adapted with minimal effort to defibrillate guinea pigs and other small laboratory animals as well as isolated hearts of larger species (rabbits, piglets).

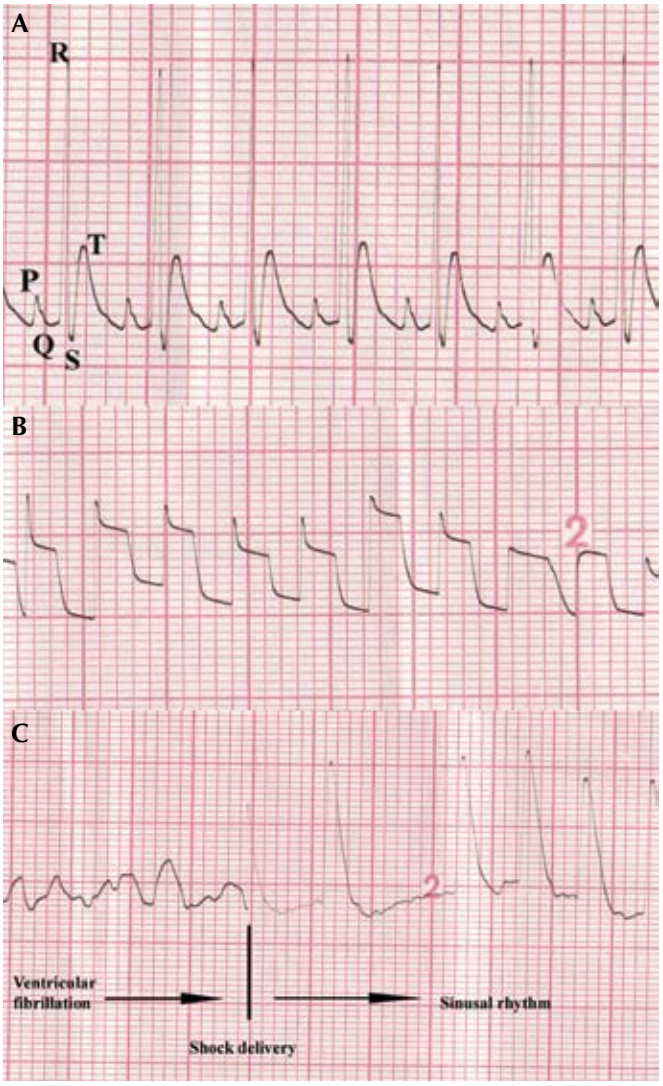

Figure 3. (A) Normal rat electrocardiogram, with clear P waves, QRS complexes, and T waves. (B) Electrocardiogram of rat showing a heart attack after ligature of the coronary artery. (C) Ventricular fibrillation upon reperfusion and restoration of sinus rhythm after shock delivery.

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