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Successful Defibrillation in Water: A Preliminary Study

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Abstract— **Mild hypothermia (32-34° C) treatment alleviates vital organ damage after cardiac arrest. A new cooling device, the Thermosuit^{TM} operates by applying of a thin layer of water directly to the body surface. Hypothermic patients may experience sequential fibrillation. Therefore, we examined whether defibrillation could be administered safely and effectively in water. A 35 kg swine was anesthetized and placed inside the Thermosuit^{TM} system. This consists of a water containing surround and pumping system. Conventional AED disposable defibrillation electrodes were applied to the animal's chest. Fibrillation was created by applying a 50-volt signal to a pacing wire introduced into the heart. Following a 30-second period of fibrillation, defibrillation was attempted using Medtronic AED 1000 defibrillator. Defibrillation voltage and current were measured. There were three test cases: dry in the system, wet in the functioning system, and damp. Cooling water in the system was contaminated with saline to simulate potential conditions in clinical application. In each fibrillation–defibrillation sequence, the heart was restarted successfully; this required less than 220 joules. Only a small difference was measured in the overall defibrillation voltage and current as applied to the electrodes for the different cases. Thus, underwater defibrillation is safe and can be performed effectively.**

Keywords: hypothermia, defibrillation, water, Current measurements (water).

I. INTRODUCTION

Prior studies have shown that resuscitative mild hypothermia (approximately 3-5 C° below normal body temperature) can reduce the level of damage to vital organs, including the brain [1,4,5]. A new form of hypothermia treatment, the Thermosuit^{TM} [6] consists of the circulation of a thin layer of water over the surface of the body. Patients receiving such treatment are often post resuscitative and may experience sequential fibrillation. However, defibrillation in a wet environment is not generally advised [7]. Thus, in the present study an appropriate method to defibrillate a subject while wet and immersed during cooling in the Thermosuit^{TM} is investigated. We examined whether defibrillation could be administered safely and effectively.

II. METHODS

A 35 kg domestic swine was anesthetized and placed inside the animal version of the Thermosuit^{TM} system. This consists of a plastic tub in which the patient lays down supine, a top sheet covering his body up to the neck and a separate pumping system which circulates of a thin layer of 0-2 °C ice-water directly on the subject's skin. The whole body is contained in tub. The volume of water needed for this pig was 20 Liters and the ice slurry was pumped at a 1L/min flow rate. Arterial blood pressure, ECG, pulmonary artery temperature and defibrillation voltage and current were measured.

Data was digitized and collected on a laboratory computer system. In addition, a pacing wire was introduced into the right ventricle. Conventional AED disposable defibrillation electrodes were applied to the animal's chest (one on the upper surface and the other on the side of the chest). A Grass stimulator induced ventricular fibrillation (VF) by applying a 60Hz 50 volt signal to the pacing wire. Following a 30 second period of fibrillation, defibrillation was attempted using Medtronic AED 1000 defibrillator. During the actual defibrillation shock, two current probes (Pearson, Inc) placed in series with the electrode pads, measured transient voltage and current signals. One current probe measured the AED current. The other probe measured the AED voltage by monitoring current through a calibrated resistor. Both probes were connected to a calibrated 15 gain circuit to amplify the signals collected by the probes and an Analog to Digital Converter (ADC). The signals were then recorded at an acquisition frequency of 7.5 kHz. There were several test cases: dry, with the animal in the suit but no cooling water present, wet with the system fully functioning and damp with the animal's skin wet but not completely covered with water. Cooling water in the system was contaminated with saline solution (2 Liters in a total of 20) to simulate potential conditions in clinical application (such as blood or urine contamination of the cooling water).

Statistical methodology

All above data were analyzed to assess the safety and effectiveness of the Thermosuit^{TM} when used during AED-

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induced defibrillation. Descriptive statistics including mean, standard deviation, median, and ranges were generated for each parameter. The 2-tailed t-test was used to measure the level of significance between variables.

Impedance mean during defibrillation

To compare the impedances during defibrillation, we examine the overall trend of the impedance during a defibrillation shock (Figure 1). The impedance waveform is the same basic shape in the three tested conditions. As seen in Figure 1, the shape consists of two plateaus separated by a notch. For each condition, we arbitrarily chose the impedance values centered on the first plateau. We picked 5 samples before and after the central sampled value of the plateau. Those 11 impedance values and their corresponding voltage and current values were used to compute average impedance for each condition.

III. RESULTS

In each fibrillation –defibrillation sequence the heart was restarted successfully, this normally required less than 220 joules. For each condition, especially for the dry and wet conditions, conversely to our expectations figures 2 through 4 were very similar in shape and values. There was only a small impedance difference measured in the overall defibrillation voltage and current as applied to the electrodes for each of the several cases. However, we calculated that the impedance values for the damp and wet (saline) against dry conditions (table 1) were significantly different. ($p<0.05$). The corresponding current values were also significantly different ($p<0.01$). Only the voltage values were significantly similar ($p>0.05$).

IV. DISCUSSION

Common sense might suggest that defibrillation under conductive water would not be possible. However we demonstrate here, that it is effective and likely to be safe.

It was expected that the overall impedance as seen at the AED electrodes would be less when water covered the body. This is based on the belief that the water would tend to short circuit the AED signal. This would require more current from the defibrillator in total since some would flow in the water bath. If this happens it is expected, based on parallel resistances, that the overall impedance would be less. This was found to be true, but the difference between dry and wet conditions was only slight as seen the above table. The small difference explains why a substantial current still flows in the subject’s body as opposed to the surrounding water.

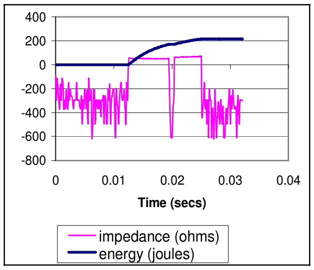

Figure 1. Impedance and energy during defibrillation –dry

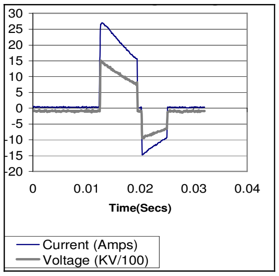

Figure 2.Current and voltage during defibrillation– dry

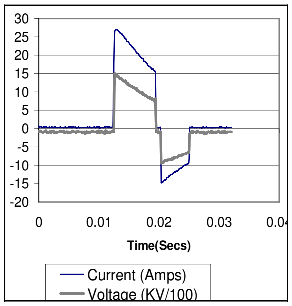

Figure 3. Current and voltage during defibrillation –damp

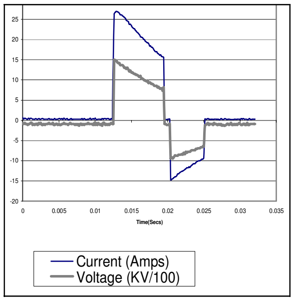

Figure 4.Current and voltage during defibrillation wet - with saline (under water)

condition	dry			damp			saline		
	U (10kv)	I (amps)	Z (Ω)	U (10kv)	I (amps)	Z (Ω)	U (10kv)	I (amps)	Z (Ω)
Mean	10.79	21.2	50.88	10.41	22.71	45.83	10.5	22.7	46.25
Std	0.54	0.9	0.95	0.62	1.01	0.81	0.47	1.01	0.82
p				0.15	0.001	0	0.19	0	0

Table 1. AED electrode impedance values during defibrillation

Since this report is based on several observations in a single animal, more controlled data needs to be collected to further elucidate the mechanisms as well as provide an operator safe methodology to defibrillate subjects in this setting.

V. CONCLUSION

Safe defibrillation under water is possible and can be performed effectively. Further investigations are needed to model the impedance in the water during a defibrillation shock.

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