

Experimental paper

The resuscitation blanket: A useful tool for “hands-on” defibrillation[☆]Tao Yu^{a,b}, Giuseppe Ristagno^a, Yongqin Li^a, Joe Bisera^a, Max Harry Weil^{a,c}, Wanchun Tang^{a,b,c,*}^a Weil Institute of Critical Care Medicine, Rancho Mirage, CA 92270, United States^b Department of Emergency Medicine, the Second Affiliated Hospital of Sun Yat-sen University, Guangzhou, China^c Keck School of Medicine of the University of Southern California, Los Angeles, CA, United States

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ABSTRACT

Aim of study: We investigated the safety, feasibility and efficacy of a resuscitation blanket designed with the intent to protecting the rescuer from the risk of receiving electrical current during defibrillation which, would allow for uninterrupted chest compressions.

Methods: Fifteen pigs weighing between 22 and 40 kg were investigated with an established model of cardiac arrest and CPR. CPR was performed with the interposition of the blanket between the rescuer's hands and the chest of the animal. Defibrillation voltage and current over the blanket were measured. Hemodynamics, including coronary perfusion pressure (CPP), end-tidal CO₂ (EtCO₂) and 50% successful defibrillation threshold (DFT50) were measured and compared during CPR with and without the blanket. **Results:** Leakage through the blanket was nominal. Voltages of 42.0, 56.6 and 105 V and mean leakage currents of 1.1, 1.4 and 3.3 μA were measured above the blanket for 150, 200 and 360 J defibrillation shocks. CPP and EtCO₂ in the animals during chest compression with the resuscitation blanket were not significantly different compared to those measured without the blanket. However, when the blanket was not utilized, CPP decreased ($P < 0.05$) during the 15-s hands-off interruption prior to defibrillation. Defibrillation threshold was significantly lower when the blanket was used.

Conclusion: The resuscitation blanket is a safe and useful tool which protects the rescuer from hands-on defibrillation shocks, allowing for uninterrupted chest compressions, and therefore improving defibrillation success.

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1. Introduction

Sudden cardiac arrest is one of the leading causes of death in the United States and Europe.^{1–3} As many as 400,000 Americans and 700,000 Europeans experience cardiac arrest each year.⁴ Despite major efforts to improve outcomes from sudden cardiac death, the victim survival outcome of between 2% and 10% remains dismal.^{5,6}

The quality of cardiopulmonary resuscitation (CPR) with uninterrupted chest compression has been considered the most important intervention for improving outcomes of cardiac arrest.⁷ In order to minimize interruptions of chest compression, the most recent guidelines for CPR have changed the defibrillation algorithm from the sequence of up to three shock attempts to a single-shock and increased the compression–ventilation ratio to 30:2 for adult victims.⁴ More recently, bystanders have been advised to

perform compression-only CPR on victims who experience out-of-hospital sudden cardiac arrest. Ventilations have therefore been abandoned in order to further minimize the interruptions in chest compression.⁸

Even a 10-s interruption in chest compression has been reported to cause major compromises in the success of resuscitation outcomes.^{9,10} In our previous investigations,^{9,10} we have also proved that interruptions in precordial compression of more than 10s resulted in declines in coronary perfusion pressure (CPP) and delays in restoring threshold values of CPP. CPP is recognized as an indicator of the success of resuscitation.^{11,12} Therefore, the “hands-off” intervals compromise the immediate success of defibrillation and ultimate survival after cardiac arrest.^{13–15}

Automated external defibrillators (AEDs) have been key devices in 21st century public health success stories, improving survival rates of victims presenting with ventricular fibrillation (VF) in settings of rapid AED response.^{16–20} However, the extent of the improvement does not meet expectations.^{21–23} It is suspected that the mandatory hands-off time imposed by the AED itself is not short enough to bring about the full benefit of a rapid defibrillation response.²⁴ Animal and clinical evidence suggests that minimizing the hands-off interval between precordial compressions and additional defibrillation shocks may have a profound effect on survival

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Fig. 1. The resuscitation blanket on a manikin.

for cases of prolonged cardiac arrest, with variations of even a few seconds producing large survival differences.^{7–10}

Advances in AED technology have recently implemented devices to minimize interruptions in chest compressions, substantially shortening the hands-off intervals. Advances in signal filtering technology may enable automated rhythm analysis to proceed during CPR without stopping chest compression.^{25,26} The new charging methods and the voice prompting algorithm are also optimized to shorten the hands-off interruption.²⁷ In the future, the evolution of AEDs would allow the rescuer to perform chest compression without hands-off interruption. However, the currently available commercial AED models still impose wide variations in the hands-off interval, necessitated by differences in AED voice prompting, electrocardiogram analysis capabilities, and defibrillator charge times.^{28,29}

To minimize the hands-off interruption, new methods should be developed to protect the rescuers from electrical shock while performing uninterrupted chest compression.⁹ To address these needs, we have developed a new tool for shielding the rescuer. It is called the “resuscitation blanket”. The resuscitation blanket is made from light weight insulating materials which have stable physical characteristics, such as high dielectric strength and outstanding resistance to flame. The resuscitation blanket lies between the victim’s thorax, and chest electrodes and the rescuer’s hands (Fig. 1).

In the present swine study, we investigated the safety and efficacy of utilizing the resuscitation blanket during uninterrupted chest compression while delivering defibrillation shocks. We hypothesized that the resuscitation blanket is safe and through its use may contribute to the improvement of the patient’s hemodynamics and ultimately defibrillation success.

2. Methods and results

These studies were approved by the Institutional Animal Care and Use Committee of the Weil Institute of Critical Care Medicine. All animals received humane care in compliance with the Principles of Laboratory Animal Care formulated by the National Society for Medical Research and Guide for the Care and Use of Laboratory Animal prepared by the Institute of Laboratory Animal Resources and Published by the National Institutes of Health (NIH publication 0-309-05337-3, revised 1996). The animal laboratories of Weil Institute of Critical Care Medicine are fully accredited by the American Association for Accreditation of Laboratory Animal Care (AAALAC) International.

2.1. Animal preparation

A total of 15 male domestic pigs weighing between 22 and 40 kg were used in these studies. Animals were fasted overnight except for free access to water. Anesthesia was initiated by intramuscular injection of ketamine (20 mg/kg) and completed by ear vein injection of sodium pentobarbital (30 mg/kg). Additional doses of sodium pentobarbital (8 mg/kg) were injected at intervals of approximately 1 h to maintain anesthesia. A cuffed endotracheal tube was advanced into the trachea. Animals were mechanically ventilated with a volume-controlled ventilator (MA-1, Puritan-Bennett, Carlsbad, CA) with a tidal volume of 15 mL/kg and FiO₂ of 0.21. End-tidal PCO₂ (EtCO₂) was monitored with an infrared analyzer (01R-7101A, Nihon Kohden, Tokyo, Japan). Respiratory frequency was adjusted to maintain EtCO₂ between 35 and 40 mmHg. For measurement of mean aortic pressure (MAP), a fluid-filled 8-Fr angiographic catheter (6523; USCI C.R. Bard, Salt Lake City, UT) was advanced from the right femoral artery into the thoracic aorta. For the measurement of the right arterial pressure (RAP), a 7-Fr, thermodilution-tipped catheter (Abbott Critical Care 41216, North Chicago, IL) was advanced from the right femoral vein and flow-directed into the pulmonary artery. The positions of the catheters were confirmed by characteristic pressure morphology and fluoroscopy. Measurements of aortic and right atrial pressure allowed for estimation of CPP, which is the difference between diastolic pressure in the aorta and the diastolic pressure in the right atrium. For measurements of ECG, three adhesive electrodes were applied to the shaved skin of the right and left upper and lower limbs.

2.2. The rescuer

The three rescuers were experienced healthcare providers trained by AHA basic life support courses. During CPR, all of the rescuers performed chest compression guided by a CPR prompter (iCPR, ZOLL Medical Corporation, Chelmsford, MA). All of the rescuers were queried whether during hands-on defibrillation they felt discomfort during the electrical shock, paresthesia, sensory or movement loss, etc. These data were recorded. For investigation of possible skin damage (superficial burn injury), the hands of rescuers were checked after each hands-on defibrillation.

2.3. Statistical analysis

Continuous values are presented as mean ± SD or as medians and ranges. ANOVA or the Mann–Whitney test was used to compare scale variables when appropriate. All of the statistical analyses were performed with the use of the SPSS version 14.0 (SPSS Inc., Chicago, IL). For all statistical analyses, $P < 0.05$ was considered significant.

2.4. Investigating the safety of the resuscitation blanket

These initial series of studies evaluated the capability of the resuscitation blanket to shield the rescuer from voltage and current delivered by an AED during chest compression.

For this purpose, a domestic pig weighing 40 ± 4 kg was surgically prepared as described above and ventricular fibrillation (VF) was induced by delivering a 1–2 mV AC current through a 5-Fr pacing catheter (EP Technologies, Inc., Mountain View, CA) which had been advanced into the right ventricle.⁹ Precordial defibrillation electrodes were applied to the apex-anterior positions as currently utilized with AEDs. The resuscitation blanket was placed between the pig’s chest and the rescuer’s hands. For the measurement of voltage leakage, a sensor was placed above the resuscitation blanket over the heart. The experiments were performed in a university

Table 1
Measurements from 15 hands-on shocks during external defibrillation.

Shock energy (J) (n = 5)	Voltage delivered (V) (n = 5)	Current delivered (A) (n = 5)	Voltage over the blanket (V) (n = 5)	Mean leakage current (μ A) (n = 5)	Impedance of blanket ($M\Omega$) (n = 5)
150	1610	32.2	42.0 \pm 5.4	1.1 \pm 0.2	30.8 \pm 8.9
200	1835	36.7	56.6 \pm 21.8	1.4 \pm 0.5	34.1 \pm 22.1
360	1995	39.9	105.0 \pm 35.1	3.3 \pm 0.6	11.3 \pm 7.6

Values are expressed as mean \pm SD.

affiliated research laboratory with consistently maintained humidity and temperature.

After 2 min of untreated VF, manual chest compression was performed by the rescuer whose hands were placed on the top of the resuscitation blanket. One minute later, a defibrillation shock was delivered during chest compression without “hands-off” interruptions with the aid of a biphasic defibrillator (CodeMaster XL, Heartstream Operation, Hewlett Packard, Seattle, WA). This procedure was repeated 15 times (5 at each of the 3 energy levels, 150, 200 and 360 J), with an interval of 10 min between ROSC and the subsequent induction of VF. The different energy levels were randomly assigned over the 15 procedures. Voltage leakage was continuously measured and recorded on a PC-based data acquisition system supported by CODAS hardware/software (Computer Acquisition System, Cambridge, MA)³⁰ at a frequency of 10,000 Hz. The total energy delivered was calculated by the integration of the voltage.

The data on the 15 shocks delivered during chest compression while using the resuscitation blanket are shown in Table 1. Biphasic 150 J shocks yielded voltages of 1610 V together with a defibrillation current of 32.2 A to the pigs. When a defibrillation shock of 200 J was employed, voltage and current increased to 1835 V and 36.7 A. When the shock delivered was increased to 360 J, voltage and current delivered were 1995 V and 39.9 A. The voltage over the blanket was, 42.0, 56.6 and 105 V, respectively, for 150, 200 and 360 J defibrillation shocks, while the mean current leakage over the blanket and passing to the rescuer was 1.1, 1.4 and 3.3 μ A. The impedance of the resuscitation blanket (i.e., the rescuer circuit impedance) as calculated by dividing the recorded voltage leakage and current, was 30.8, 34.1 and 11 $M\Omega$. The total of the 15 maximal current leakage values are shown in Fig. 2.

2.5. Investigating the hemodynamics during chest compression with and without the resuscitation blanket

VF was induced in six domestic pigs weighing 40 \pm 4 kg by occlusion of the left anterior descending (LAD) coronary artery, as previously described.²⁴ After 5 min of untreated VF, pigs were randomized to receive chest compression with the resuscitation

blanket (n = 4) or without the blanket (n = 2). In animals in which the blanket was used, a 5-s hands-off interruption was observed for rhythm analysis after 2 min of CPR. Chest compression was then resumed and a single 150 J defibrillation shock was attempted 10 s later without interruption in chest compression. In the animals in which the blanket was not utilized, after 2 min of CPR, a 15-s hands-off interruption prior to defibrillation was observed for rhythm analysis and rescuer safety.

There were no significant differences in baseline characteristics between the two groups. During the 2 min of CPR, CPP and EtCO₂ in the animals receiving chest compression with the resuscitation blanket were not significantly different compared to those measured in the animals receiving chest compression without using the resuscitation blanket (Fig. 3).

During the 5-s interruptions in CPR for rhythm analysis, CPP significantly decreased in all animals compared to the pre-interruption level ($P < 0.05$). When precordial compression was restarted during the 10 s prior to defibrillation in the animals receiving chest compression with resuscitation blanket, CPP was promptly restored and maintained to the pre-interruption levels before and during defibrillation. In animals treated with chest compression without the blanket, CPP continued to decrease before the delivery of the defibrillation shock. CPP was substantially different in the two groups during the last 10 s prior to and during the defibrillation attempt (Fig. 4).

2.6. Investigating the defibrillation threshold of hands-on defibrillation while utilizing the resuscitation blanket

We examined the effects of defibrillation delivered during manual compression on the measurement of the 50% defibrillation threshold (DFT50) while using the resuscitation blanket.

VF was electrically induced and untreated for 10 s in 8 domestic male pigs weighing between 22 and 31 kg. Manual chest compression was performed for 25 s with the protection of the resuscitation blanket. A biphasic electrical shock of variable energies ranging from 30 to 150 J was randomly delivered by a M-series defibrillator (ZOLL Medical Corp., Chelmsford, MA) during the compression

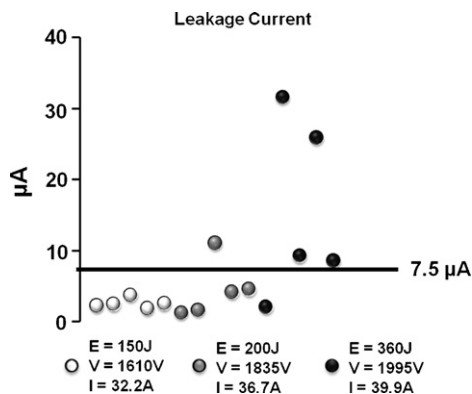


Fig. 2. Leakage current measured in 15 defibrillation shocks during hands-on chest compression with resuscitation blanket.

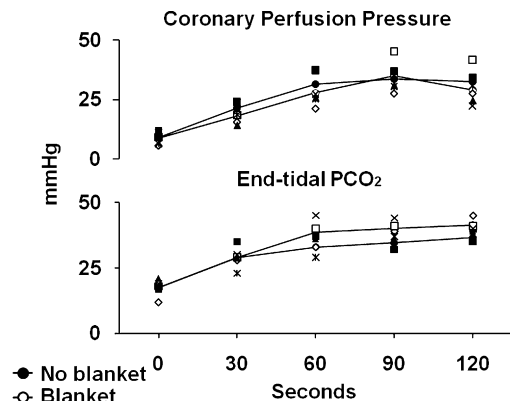


Fig. 3. Coronary perfusion pressure and end-tidal CO₂ pressure during CPR with and without the resuscitation blanket.

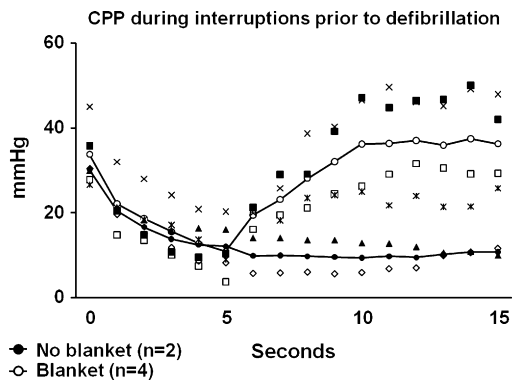


Fig. 4. Coronary perfusion pressures in animals utilizing CPR with and without the resuscitation blanket during the 15-s interruptions prior to defibrillation shock.

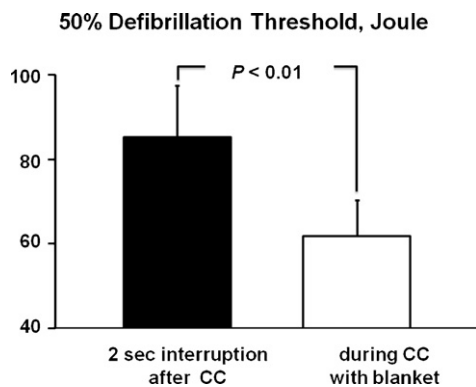


Fig. 5. Fifty percent defibrillation threshold measured when defibrillation was delivered after a 2-s interruption in discontinued chest compression (CC) or during the compression phase of chest compression with resuscitation blanket ($P < 0.01$).

phase of chest compression or 2 s after interruption of chest compression. After restoration of spontaneous circulation (ROSC) animals were permitted to stabilize hemodynamically for 4 min, and then the sequence was repeated. The defibrillation threshold is obtained by measuring V50 and E50. V50 and E50 where the peak shock voltages and total delivered energy, respectively, were required to produce a 50% likelihood of successful defibrillation. An up-and-down protocol with three reversals was used in this study to estimate V50 and E50.^{31–34} For each porcine model, the order of two predetermined coupling phases was randomized using a randomization schedule based on a predetermined random permutation of 2.³⁵

No significant differences in CPP prior to the delivery of the shock were observed between the 2 groups. The DFT50, however, was significantly lower ($P < 0.01$) in the pigs to which defibrillation was delivered during chest compression with the blanket (Fig. 5).

A total of 259 defibrillation shocks (hands-on defibrillation) were delivered in these 3 serial studies. The rescuers did not have any abnormal sensations, including discomfort during shock, paresthesia, sensory or movement loss, etc. No skin damage caused by the hands-on defibrillation was found.

3. Discussion

This study showed that, at least in a laboratory environment, there is only minimal voltage and current leakage through the blanket during defibrillation shocks. Thus, use of the blanket is safe during hands-on defibrillation. The study showed that the blanket does not impede CPR hemodynamics and does lower the defibrillation threshold when shock is synchronized with the compression stroke.

The electrocution of rescuers has been recognized as a possible hazard relating to external defibrillation during CPR.³⁶ The possible risks to the rescuer from accidental defibrillation include the development of a lethal arrhythmia, nerve damage, cutaneous burns, muscle damage, and secondary trauma from tetanic muscle contractions.³⁷ Thus far, medical literature has not reported any rescuer or bystander serious injury from receiving an inadvertent shock while in direct or indirect contact with a patient while performing CPR.³⁸ The resuscitation blanket is made of a “nonconducting” material which presents an impedance of more than 10 MΩ. It reduces the voltage leakage, filtering the majority of the dangerous defibrillation current to the rescuer, and therefore allows the performance of precordial compression without hands-off interruptions during the delivery of an electrical shock. In our studies, the blanket successfully insulated the rescuer from the current leakage. The current delivered to the animals was more than 30 A, but the maximal leakage of current to the rescuer was only in the μA range, far below the safety limit.^{39,40}

New evidence suggests that it might be even electrically safe for the rescuer to continue chest compressions during defibrillation in the certain well defined circumstances (i.e., if self-adhesive defibrillation electrodes are used and examination gloves are worn).⁴⁰ However, the electrical protection efficacy of the medical examination gloves during defibrillation is still questionable.^{41,42} When gloves were utilized as a protective tool during defibrillation, the measured mean current leakage to the rescuer was more than 280 μA and the maximal current leakage was more than 900 μA.⁴⁰ These values were substantially higher when compared to those measured during defibrillation while utilizing our resuscitation blanket. According to the occupational and medical electrical safety standards mandated in compliance with IEC 950, the maximum allowable current leakage is 3500 μA for non-handled equipment and 750 μA for handled equipment.³⁹ The IEC 60601-1 guidelines for medical equipment are more rigorous, owing to the potential exposure to patients, with the safety limit of 500 μA.⁴⁰ From our measurements, the mean current leakage was less than 4 μA and the maximal leakage current was only 31.9 μA when the resuscitation blanket was used. We have completed 259 defibrillation shocks during precordial compression with the blanket, and the rescuers were safe and without discomfort or injuries. The resuscitation blanket appears therefore to be the best tool for usage by rescuers to avoid hands-off interruptions to allow for defibrillation attempts.

Threshold levels of CPP have been identified as the leading predictor of the success of ROSC^{43–46} and are related to the optimal quality of chest compression. EtCO₂ has also emerged as an indicator of the effectiveness of chest compressions.^{47–50} It is highly correlated with, and therefore can be taken as an indirect approximate measurement of pulmonary blood flow during CPR and therefore of cardiac output produced by chest compressions. In the present study, during the 2 min of CPR performed with the blanket, CPP and EtCO₂ were not significantly different when compared to those measured in animals that received CPR without the blanket. The use of the resuscitation blanket during precordial compression therefore did not compromise the quality or the effectiveness of chest compression.

During hands-off intervals, declines in CPP and delays in restoring threshold values of CPP⁹ were observed.^{9,10,12} Even short interruptions in chest compression of less than 5 s caused decreases in aortic diastolic pressure and CPP,^{51,52} which required as many as 7 chest compressions for restoration to pre-interruption level. In the present study, we simulated a 5-s rhythm analysis plus other 10 s hands-off interruptions during chest compression based on the data of the hands-off interruptions mandated by currently available commercial AEDs.²¹ When the resuscitation blanket was utilized, chest compression was resumed and continued during

defibrillation after a 5-s interruption for rhythm analysis. This allowed restoration of CPP to a threshold level which predicts successful resuscitation prior to attempted defibrillation. When the resuscitation blanket was not utilized, the 15-s hands-off interval for rhythm analysis and rescuer's safety, instead, produced rapid reductions in CPP before defibrillation. Compared with the current hands-off practice, the blanket allows chest compressions during countershocks, thereby improving hemodynamics, and potentially improving survival from cardiac arrest.

With the development of AED technologies, the pre-shock pauses mandated by future AEDs will be shortened to 1–2 s during chest compression for delivering defibrillation shock. Unfortunately, our study showed that even though a 2-s pause does not substantially affect hemodynamics, it does substantially increase the defibrillation threshold. The exact mechanism is still unknown, the possible explanations are the compression pressure produced by manual chest compression empties blood from the heart chambers which may further reduce the defibrillation energy and current requirement. This is because blood is a good conductor and may have a "shunting effect" during defibrillation. Furthermore, heart deformation under CPR pressure may create a larger projection in the shocked electric field which may further reduce the DFT. One of the possible explanations is that the current study findings may well be a false positive. Further studies are needed to prove this hypothesis.

We recognize important limitations in the interpretation of the present findings. First, for safety reasons we have not measured the leakage of defibrillation current during precordial compression without the resuscitation blanket. Although lacking comparison, the present data proved the reliable safety of the blanket. Second, the investigators were not blinded to the employment of the resuscitation blanket. Third, to investigate the physical awareness during shock, all of the precordial chest compressions were performed by trained healthcare providers. Moreover, control of CPR quality was assured throughout all the experiments. Finally, in the present studies we focused mainly on evaluation of efficacy and safety of the resuscitation blanket, and resuscitation and survival outcomes remain to be investigated in further studies.

4. Conclusions

We conclude that the resuscitation blanket is a safe and useful tool which protects the rescuer from defibrillation shocks while performing CPR. The utilization of the resuscitation blanket allows "hands-on defibrillation", and therefore improves defibrillation success.

Conflicts of interest statement

The authors report no conflicts of interest.

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