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Experimental paper

Hemodynamic improvement of a LUCAS 2 automated device by addition of an impedance threshold device in a pig model of cardiac arrest☆

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ABSTRACT

Introduction: The combination of the LUCAS 2 (L-CPR) automated CPR device and an impedance threshold device (ITD) has been widely implemented in the clinical field. This animal study tested the hypothesis that the addition of an ITD on L-CPR would enhance cerebral and coronary perfusion pressures.
Methods: Ten female pigs (39.0 ± 2.0 kg) were sedated, intubated, anesthetized with isofluorane, and paralyzed with succinylcholine (93.3 μg/kg/min) to inhibit the potential confounding effect of gasping. After 4 min of untreated ventricular fibrillation, 4 min of L-CPR + an active ITD or L-CPR + a sham ITD was initiated and followed by another 4 min of the alternative method of CPR. Systolic blood pressure (SBP), diastolic blood pressure (DBP), diastolic right atrial pressure (RAP), intracranial pressure (ICP), airway pressure, and end tidal CO_2 ($ETCO_2$) were recorded continuously. Data expressed as mean mmHg ± SD.
Results: Decompression phase airway pressure was significantly lower with L-CPR + active ITD versus L-CPR + sham ITD (−5.3 ± 2.2 vs. −0.5 ± 0.6; $p < 0.001$). L-CPR + active ITD treatment resulted in significantly improved hemodynamics versus L-CPR + sham ITD: $ETCO_2$, 35 ± 6 vs. 29 ± 7 ($p = 0.015$); SBP, 99 ± 9 vs. 93 ± 15 ($p = 0.050$); DBP, 24 ± 12 vs. 19 ± 15 ($p = 0.006$); coronary perfusion pressure, 29 ± 8 vs. 26 ± 7 ($p = 0.004$) and cerebral perfusion pressure, 24 ± 13 vs. 21 ± 12 ($p = 0.028$).
Conclusions: In pigs undergoing L-CPR the addition of the active ITD significantly reduced intrathoracic pressure and increased vital organ perfusion pressures.

1. Introduction

Quality of cardiopulmonary resuscitation (CPR) is critical to improving survival rates with favorable neurological function.[1] Even when optimally performed, blood flow generated by manual chest compressions is, at best, less than 25% of normal.[2,3] Mechanical chest compression devices have been developed to improve the quality of CPR by replacing manual compressions. The LUCAS device consistently compresses the chest at a rate of 100/min and a depth of 5 cm and provides three pounds of upward force with each decompression. Animal studies with the Lund University Cardiopulmonary Assist System (LUCAS) have shown improved organ perfusion pressures, enhanced cerebral blood flow, and higher end-tidal CO_2 during CPR compared with the use of manual compressions.[4–6]

Similarly, the impedance threshold device (ITD) has also been shown to improve overall CPR hemodynamics including cerebral and coronary perfusion pressure. It works by impeding inflow

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of respiratory gases during the decompression phase of CPR, thereby generating a greater negative intrathoracic pressure with each chest recoil. This, in turn, enhances venous return and lowers intracranial pressure thereby enhancing cardiac and cerebral perfusion[7,8].

As in the case of standard manual CPR, we hypothesize that when an active ITD is added on L-CPR, cerebral and coronary perfusion pressures will improve.

2. Methods

This study was approved by the Institutional Animal Care Committee of the Minneapolis Medical Research Foundation of Hennepin County Medical Center. All animal care was compliant with the National Research Council's 1996 Guidelines for the Care and Use of Laboratory Animals. All studies were performed by a qualified, experienced research team in Yorkshire female farm bred pigs weighing 39 ± 2 kg. A certified and licensed veterinarian assured the protocols were performed in accordance with the National Research Council's guidelines.

2.1. Preparatory phase

The surgical preparation, anesthesia, data monitoring, and recording procedures used in this study have been previously described.[9] Under aseptic surgical conditions, we used initial sedation with intramuscular ketamine (10 mL of 100 mg/mL, Ketaset, Fort Dodge Animal Health, Fort Dodge, Iowa) followed by inhaled isoflurane at a dose of 0.8–1.2%. Pigs were intubated with a size of 7.0 endotracheal tube. The animal's temperature was maintained at normothermia, with a warming blanket (Bair Hugger, Augustine Medical, Eden Prairie, Minnesota). Central aortic blood pressure was recorded continuously with a micromanometer-tipped catheter (Mikro-Tip Transducer, Millar Instruments, Houston, TX) placed in the descending thoracic aorta via the femoral artery using a modify Seldinger technique. A second Millar catheter was inserted in the right atrium via the right external jugular vein. An ultrasound flow probe (Transonic 420 series multichannel, Transonic Systems, Ithaca, NY) was placed in the left common carotid artery to quantify carotid blood flow (mL/min). After creating a burr hole, an intracranial bolt was positioned at the right parietal aspect of the cranium. A Millar catheter was then inserted into the parietal lobe to measure intracranial pressure (ICP).

In addition to isoflurane and ketamine, all animals received an intravenous heparin bolus (100 units/kg), an infusion of succinylcholine (93.3 μg/kg/min), and an infusion of 1 L of saline. All animals were ventilated with room air using a volume-control ventilator (Narcomed, Telford, Pennsylvania), a tidal volume of 10 mL/kg and a respiratory rate adjusted to continually maintain a $PaCO_2$ between 38 and 42 mmHg and PaO_2 around 80 mmHg (blood oxygen saturation >95%), as measured from arterial blood gas (Gem 3000, Instrumentation Laboratory). Surface electrocardiographic tracings were continuously recorded. All data were recorded with a digital recording system (BIOPAC MP 150, BIOPAC Systems, Inc., CA, USA). End tidal CO_2 ($ETCO_2$), tidal volume, minute ventilation, and blood oxygen saturation were continuously measured with a respiratory monitor (Cosmo Plus, Novametrix Medical Systems, Wallingford, CT).

2.2. Measurements and recording

Aortic pressure, right atrial pressure, ICP, $ETCO_2$, and carotid blood flow were continuously recorded. Coronary perfusion pressure (CPP) was calculated as the difference between right atrial pressure and diastolic aortic pressure during the decompression phase of CPR. Cerebral perfusion pressure (CePP) was calculated as the difference between mean aortic pressure and mean ICP. Ultrasound-derived carotid blood flow was reported in mL/min.

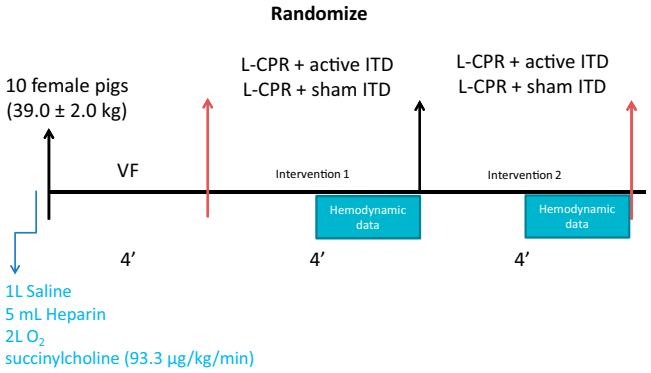

Fig. 1. Study protocol.

2.3. Experimental protocol

After the surgical preparation was complete, oxygen saturation on room air was greater than 95%, and $ETCO_2$ was stable between 38 and 42 mmHg for 5 min, ventricular fibrillation was induced by direct intracardiac current via a temporary pacing wire. The ventilator was disconnected from the endotracheal tube. As described below in the protocol mechanical CPR was performed using the LUCAS 2™ (Physio-Control, Redmond, WA) compression system at a rate of 100 compressions/min with a 50% duty cycle. According to randomization order, either an impedance threshold device with a resistance of 16 cmH2O (ITD, ResQPOD™, Advanced Circulatory Systems, Roseville, MN) or a sham ITD with no inspiratory resistance was attached to the endotracheal tube. Asynchronous positive pressure ventilations were delivered with 2 L/min of O_2 with a manual resuscitator bag. The tidal volume was maintained at 10 mL/kg determined by measuring the inspiratory tidal volume using the Cosmo Plus described above, and the respiratory rate was 10 breaths/min.

The protocol was as follows: after 4 min of untreated ventricular fibrillation, 10 pigs were block randomized on a crossover design to receive either L-CPR + active ITD for 4 min then L-CPR + sham ITD for 4 min or to the same interventions in reverse order (Fig. 1). Hemodynamic data were recorded continuously during the protocol and specific data elements were analyzed during the final 2 min of each intervention to allow for the animal to stabilize after the change of CPR method. Arterial blood gas samples were collected during the baseline and then after 3.5 min of CPR during each intervention. After 8 min of CPR, animals were sacrificed with a 10 mL injection of 10 M potassium chloride.

2.4. Statistical analysis

Data are expressed as mean ± standard deviation (SD). Mean values were compared with the Student's paired *t* test. To assess for the potential of a carry-over effect based upon randomization order a Student unpaired *t* test was performed comparing mean CPP and CePP values during the first intervention period versus the second period. Normality of data was tested using the Kolmogorov Smirnov test. All statistical tests were two-sided, and a *p* value of less than 0.05 was required to reject the null hypothesis. Statistical analysis was performed using IBM SPSS Statistics 21.