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Experimental paper

Novel adhesive glove device (AGD) for active compression–decompression (ACD) CPR results in improved carotid blood flow and coronary perfusion pressure in piglet model of cardiac arrest☆,☆☆

Jai P. Udassi[a,d,*], Sharda Udassi[e], Andre Shih[f], Melissa A. Lamb[a], Stacy L. Porvasnik[d], Arno L. Zaritsky[b], Ikram U. Haque[c]

[a] Division of Pediatric Critical Care Medicine, Department of Pediatrics, University of Florida College of Medicine, Gainesville, FL, United States
[b] Department of Pediatrics, Children's Hospital of The King's Daughters, Eastern Virginia Medical School, Norfolk, VA, United States
[c] Division of Pediatric Critical Care, Department of Pediatrics, The University of Texas Health Science Center at Houston, TX, United States
[d] Division of Pediatric Cardiology, Congenital Heart Center, Department of Pediatrics, University of Florida College of Medicine, Gainesville, FL, United States
[e] Division of Pediatric Hospitalist Medicine, Department of Pediatrics, University of Florida College of Medicine, Gainesville, FL, United States
[f] Department of Anesthesiology, College of Veterinarian School, University of Florida, Gainesville, FL, United States

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ABSTRACT

Objective: ACD-CPR improves coronary and cerebral perfusion. We developed an adhesive glove device (AGD) and hypothesized that ACD-CPR using an AGD provides better chest decompression resulting in improved carotid blood flow as compared to standard (S)-CPR.
Design: Prospective, randomized and controlled animal study.
Methods: Sixteen anesthetized and ventilated piglets were randomized after 3 min of untreated VF to receive either S-CPR or AGD-ACD-CPR by a PALS certified single rescuer with compressions of 100 min^{-1} and C:V ratio of 30:2. AGD consisted of a modified leather glove exposing the fingers and thumb. A wide Velcro patch was sewn to the palmer aspect of the glove and the counter Velcro patch was adhered to the pig's chest wall. Carotid blood flow was measured using ultrasound. Data (mean ± SD) was analyzed using one way ANOVA and unpaired *t*-test; *p*-value ≤ 0.05 was considered statistically significant.
Results: Right atrial pressure (mm Hg) during the decompression phase was lower during AGD-ACD-CPR (−3.32 ± 2.0) when compared to S-CPR (0.86 ± 1.8, $p = 0.0007$). Mean carotid blood flow was 53.2 ± 27.1 (% of baseline blood flow in ml/min) in AGD vs. 19.1 ± 12.5% in S-CPR, $p = 0.006$. Coronary perfusion pressure (CPP, mm Hg) was 29.9 ± 5.8 in AGD vs. 22.7 ± 6.9 in S-CPR, $p = 0.04$. There was no significant difference in time to ROSC and number of epinephrine doses.
Conclusion: Active chest decompression during CPR using this simple and inexpensive adhesive glove device resulted in significantly better carotid blood flow during the first 2 min of CPR.

1. Introduction

Incomplete chest recoil during CPR leaves residual positive intrathoracic pressure that decreases return of venous blood to the right atrium and results in decreased coronary and cerebral perfusion.[1–3] A recent piglet cardiac arrest study showed that leaning of 10–20% during cardiopulmonary resuscitation substantially decreased coronary perfusion pressure, cardiac index and myocardial blood flow.[4] Different chest compression techniques[1,2] and devices[5] have been used to achieve better chest decompression during CPR in adults.

To perform ACD-CPR, the rescuer is required to actively lift the anterior chest wall during the decompression phase of CPR.[6,7] Higher cardiac output (CO), higher coronary and cerebral perfusion pressures[8–10] improved hemodynamics[6,11] and improved resuscitation rates, both in-hospital[12,13] and out-of-hospital[14] has been observed during ACD-CPR. ACD-CPR is performed with a hand-held suction cup device with a pressure gauge (Ambu CardioPump™),[6] or with LUCAS[5,15,16] a pneumatically driven mechanical piston device. ACD-CPR is not recommended for use in children due to lack of studies,[17] although it is an optional technique for adult CPR. There is no device available to apply this technique in infants and children.

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* Corresponding author at: Division of Pediatric Cardiology, Congenital Heart Center, Department of Pediatrics, University of Florida College of Medicine, PO Box 100296, UF HSC, Gainesville, FL 32610-0296, United States. Tel.: +1 352 273 5422; fax: +1 352 392 0547.
E-mail address: judassi@ufl.edu (J.P. Udassi).

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A previous study of single rescuer chest compression and decompression using a novel glove device (AGD-ACD-CPR) in an infant, child and adolescent manikin by health care providers showed that the use of our simple inexpensive adhesive glove device resulted in improved chest decompression without any excessive rescuer fatigue.[18]

This study of ACD-CPR in two-month-old piglets used a simple, inexpensive adhesive glove device (AGD) (1) to evaluate the feasibility of AGD to achieve ACD-CPR during cardiac arrest, (2) to assess the coronary perfusion pressure during CPR and cardiac function post ROSC and (3) to assess brain blood flow via ultrasound measurement of carotid flow during CPR. We hypothesized that ACD-CPR using our AGD would improve chest decompression compared to S-CPR and would result in better cardiac and brain blood flow.

2. Methods

This prospective randomized study was approved by the University of Florida Health Science Center Institutional Animal Care and Use Committee (IACUC) and followed the guidelines of the American Physiologic Society.

2.1. Animal preparation

Two-month-old (weight ~12 kg) farm piglets (University of Florida swine unit) of either sex were used in this study. Animals were initially sedated with an intramuscular injection of ketamine (15 mg/kg). Once the appropriate level of sedation was met, the animals were subjected to anesthesia with an induction of 5% isoflurane in 100% oxygen delivered by a nose cone followed by oral endotracheal intubation. Mechanical ventilation was achieved with a rate- and volume-regulated ventilator (Surgivet Vaporstic Anesthesia Machine, Smiths Medical, USA) and titrated isoflurane (1.5–3%). Initial ventilation was set at 12 respirations/min with tidal volume of 15 mL/kg. Rate and tidal volume were adjusted to maintain an end-tidal PCO_2 of ~40 mm Hg. The lowest concentration of anesthetic that prevented movement during surgical instrumentation was used. EKG leads were placed on the limbs to continuously monitor heart rate and rhythm.

Using standard cut-down techniques, the right carotid artery, left internal jugular (IJ) vein and bilateral femoral arteries were exposed. A 3 mm transonic flow probe (Animal Blood Flow Meter T206, Transonic Systems Inc., USA) was placed around the left carotid artery for blood flow measurements. A vascular introducer sheath (5 F and 15 cm) was placed in the left IJ and advanced to the upper portion of the right atrium for right atrial pressure measurements (fluid-filled catheter transducer). The same introducer sheath was used to advance a non-coated guide wire into the right ventricle for current delivery to induce ventricular fibrillation (VF). A 7 F triple lumen catheter was placed in the right femoral artery for invasive BP monitoring (fluid-filled catheter transducer). Correct catheter placement was verified by fluoroscopy. Heparin (50 units/kg) as a single bolus dose was given to all animals. All animals were given intravenous lactated Ringer's solution at maintenance.

2.2. Adhesive glove device description

The AGD consisted of a leather glove modified to expose the fingers and thumb allowing interlocking of the fingers and an adjustable strap for proper fit on the dorsum aspect of the glove. A Velcro patch was sewn to the palmer aspect of the glove. The counter Velcro patch was adhered to the animal chest wall using an adhesive pad (Fig. 1).

2.3. Experimental protocol

Subsequent to baseline data collection, VF was induced by an alternating current delivered to the RV. The presence of VF was confirmed by the characteristic EKG waveform and the precipitous fall in aortic pressure. Assisted ventilation was discontinued and the animals underwent a period of untreated VF for 3 min to simulate in-hospital resuscitation. After the initial untreated VF, animals were randomized by random number generator to one of the two CPR groups: AGD-ACD-CPR and S-CPR groups. Chest compressions were performed in all animals in both groups by same PALS certified health care provider blinded to data recording including aortic and right atrial pressure tracings. Ventilations were given by a second rescuer using an anesthesia bag attached to the ET tube. Aortic systolic pressure and right atrial pressures in systolic phase (during compression phase of cycle) were monitored and compared between the two techniques to make sure that the applied compression force was similar between the techniques. Mean right atrial pressure during the decompression phase of the cycle (diastolic RA pressure) and mean aortic pressure during the decompression phase (diastolic aortic pressure) were recorded. CPP was calculated by using the formula diastolic aortic pressure – diastolic RA pressure. Both CPP and carotid blood flow was averaged during the same first 2 min of chest compressions.

Chest compressions were given at a rate of 100 min^{-1} with compression to ventilation ratio of 30:2. In both groups animals were manually ventilated with an anesthesia bag attached to a 100% oxygen source. CPR was continued initially for 2 min and then paused for a rhythm check. If still in VF, defibrillation was attempted with 150J biphasic shock and CPR was continued for another cycle of 2 min. During this cycle an epinephrine bolus dose of 0.01 mg/kg (1:10,000) was given. At the end of 2 min of CPR, we checked the rhythm. If still in VF, another 200J shock was given. Return of spontaneous circulation (ROSC) was defined as a perfusing rhythm with a peak aortic systolic pressure of >60 mm Hg sustained for 1 min. CPR was continued per AHA (PALS) guidelines until ROSC or no ROSC within 20 min of CPR. Animals who achieved ROSC were connected to a mechanical ventilator and remained anesthetized during the ensuing 30 min post-resuscitation simulated intensive care period.

2.4. Measurements and data acquisition

The primary endpoint was achieving chest decompression as evident by a negative diastolic RA pressure, improved CPP and better carotid blood flow. Secondary endpoints were ROSC, other hemodynamic variables, number of shocks and epinephrine doses administered. Data was transferred to a bioamplifier by ADInstruments Power lab® Systems (Castle Hill, NSW 2154, Australia), which then sent real time continuous data to a laptop computer. Computer software (Chart pro V7.3 by ADInstruments Power lab® Systems; Castle Hill, NSW 2154, Australia) was used to record the data. The sampling rate for data collection was set at 100 data points/s. Trans-thoracic echocardiography (Sonos 7500, Philips Inc., USA) was performed to assess left ventricular ejection fraction at baseline and 30 min post ROSC. Venous and arterial blood gas analysis along with plasma concentrations of sodium, potassium, hematocrit, lactic acid and ionized calcium (iSTAT Blood Gas Analyzer, Windsor, NJ) were performed at baseline and 30 min post ROSC in all animals.

2.5. Statistical consideration

Data are reported as mean ± SD. All data analyses were conducted on the normalized data using PC-Sigma-stat (3.0). Normality and equality of data variances were assessed using the