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Experimental paper

The Effect of Head Up Cardiopulmonary Resuscitation on Cerebral and Systemic Hemodynamics☆

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ABSTRACT

Aim: Chest compressions during cardiopulmonary resuscitation (CPR) increase arterial and venous pressures, delivering simultaneous bidirectional high-pressure compression waves to the brain. We hypothesized that this may be detrimental and could be partially overcome by elevation of the head during CPR.

Measurements: Female Yorkshire farm pigs (n = 30) were sedated, intubated, anesthetized, and placed on a table able to elevate the head 30° (15 cm) (HUP) and the heart 10° (4 cm) or remain in the supine (SUP) flat position during CPR. After 8 minutes of untreated ventricular fibrillation and 2 minutes of SUP CPR, pigs were randomized to HUP or SUP CPR for 20 more minutes. In Group A, pigs were randomized after 2 minutes of flat automated conventional (C) CPR to HUP (n = 7) or SUP (n = 7) C-CPR. In Group B, pigs were randomized after 2 minutes of automated active compression decompression (ACD) CPR plus an impedance threshold device (ITD) SUP CPR to either HUP (n = 8) or SUP (n = 8).

Results: The primary outcome of the study was difference in CerPP (mmHg) between the HUP and SUP positions within groups. After 22 minutes of CPR, CerPP was 6 ± 3 mmHg in the HUP versus -5 ± 3 in the SUP (p = 0.016) in Group A, and 51 ± 8 versus 20 ± 5 (p = 0.006) in Group B. Coronary perfusion pressures after 22 minutes were HUP 6 ± 2 vs SUP 3 ± 2 (p = 0.283) in Group A and HUP 32 ± 5 vs SUP 19 ± 5, (p = 0.074) in Group B. In Group B, 6/8 pigs were resuscitated in both positions. No pigs were resuscitated in Group A.

Conclusions: The HUP position in both C-CPR and ACD + ITD CPR significantly improved CerPP. This simple maneuver has the potential to improve neurological outcomes after cardiac arrest.

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Introduction

Given the majority of patients treated with conventional cardiopulmonary resuscitation (C-CPR) never wake up after cardiac arrest, new treatment approaches are needed. C-CPR is not efficient, providing only 15-30% of normal blood flow to the brain and heart, in part because refilling of the heart is dependent upon the generation of an intrathoracic vacuum during the decompression phase that draws blood back to the heart.[1–5] During C-CPR each chest compression results in an immediate increase in the arterial system and right heart. The right-sided pressures are transmitted to the brain via the paravertebral venous plexus and jugular veins.[6] This increase in blood volume and pressure increases intracranial pressure (ICP), thereby reducing cerebral perfusion. In addition, the simultaneous rise of arterial and venous pressure with C-CPR generates contemporaneous bi-directional high pressure compression waves that bombard the brain within the closed-space of the skull. This could cause additional damage to the already ischemic brain tissue during C-CPR.

Newer methods of CPR have been developed that increase cerebral and cardiac perfusion, lower ICP, and improve short and long-term outcomes, such as the combination of active compression decompression (ACD) CPR and an impedance threshold device (ITD).[9,10] Despite such advances most patients still have a poor outcome.[7,9]

We previously reported elevation of the head in a porcine model by tilting the entire body upwards for 5 minutes improves cerebral perfusion with the combination of an automated C-CPR device and an ITD. With head up tilt CPR, gravity drains venous blood from the brain to the heart, resulting in a decrease in ICP and thereby reducing resistance to forward brain flow.[8] In addition, head up CPR reduces the likelihood of right and left-sided high pressure waves simultaneously compressing the brain. Head up CPR also augments the refilling of the heart after each compression by the redistribution of venous blood from the brain and potentially redistribution of blood within the lungs and right heart. While head up tilt CPR may represent a significant advance, tilting the entire body upward could reduce coronary and cerebral perfusion during prolonged resuscitation, as pooling of blood in the abdomen and lower extremities will occur. It is known that the average duration of CPR is prolonged for many patients in cardiac arrest.[9]

Building upon the porcine whole body head up tilt CPR study,[8] we tested the hypothesis that cerebral perfusion pressure (CerPP) will remain elevated over 22 minutes of CPR with the head and shoulders elevated 30° (HUP) compared with the supine position (SUP) in two CPR groups A) C-CPR and B) ACD + ITD CPR

Materials and Methods

Study Ethics

Approval for the study was obtained from the Institutional Animal Care Committee of the Minneapolis Medical Research Foundation. Animal care was compliant with the National Research Council's 1996 Guidelines for the Care and Use of Laboratory Animals, and a certified and licensed veterinarian assured protocol performance was in compliance with these guidelines.

Study design and measurements

The techniques for surgical preparation, protocol for anesthesia, and data monitoring and recording procedures used in this study have been previously described.[5,10,11] Yorkshire female farm pigs, with average weight 39.3 ± 0.5 kg, were fasted overnight and were acclimatized for at least 2 days in the research facility prior to study. Each animal received intramuscular ketamine (10 mL of 100 mg/mL) for initial sedation, and were then transferred from their holding pen to the surgical suite and intubated with a 7-8 French endotracheal tube. Anesthesia with inhaled isoflurane at 0.8%-1.2% was then provided, and animals were ventilated with room air using a ventilator (Narkomed, Telford, PA) with tidal volume 10 mL/kg. Arterial blood gases were obtained at baseline. The respiratory rate was adjusted to keep oxygen saturation above 92% and end tidal carbon dioxide ($ETCO_2$) between 36 and 40 mmHg. Central aortic blood pressures were recorded continuously with a micromanometer-tipped catheter (Mikro-Tip Transducer, Millar Instruments, Houston, TX) placed in the descending thoracic aorta via femoral cannulation at the level of the diaphragm. A second Millar catheter was placed in the right external jugular vein and advanced into the superior vena cava, approximately 2 cm above the right atrium for measurement of right atrial (RA) pressure. Carotid artery blood flows were obtained by placing an ultrasound flow probe (Transonic 420 series multichannel, Transonic Systems, Ithaca, NY) in the left common carotid artery for measurement of blood flow. Intracranial pressure (ICP) was measured by creating a burr hole in the skull, and then insertion of a Millar catheter into the parietal lobe. All animals received a 100 units/kg bolus of heparin intravenously and received a normal saline bolus for a goal right atrial pressure of 3-5 mmHg. $ETCO_2$ and oxygen saturation were recorded with a CO_2SMO Plus® (Novametrix Systems, Wallingford, CT).

Continuous data including electrocardiographic monitoring, aortic pressure, RA pressure, ICP, carotid blood flow, and $ETCO_2$ was recorded. Cerebral perfusion pressure (CerPP) was calculated as the difference between mean aortic pressure and mean ICP. Coronary perfusion pressure (CPP) was calculated as the difference between aortic pressure and RA pressure during the decompression phase of CPR. All data was stored using a computer analysis program (BioPac; BioPac Systems Inc,

Ventricular fibrillation (VF) was induced with delivery of direct electrical current from a pacing wire placed in the right ventricle. C-CPR and ACD + ITD CPR were performed with an automatic piston device (Pneumatic Compression Controller; Ambu International, Glostrup, Denmark) as described previously.[12] C-CPR was performed at a rate of 100 compressions/min, with a 50% duty cycle and depth of 25% of anteroposterior chest diameter. During C-CPR, the chest wall was allowed to recoil passively. ACD + ITD CPR was also performed at a rate of 100 per minute, and the chest was pulled upwards after each compression with a suction cup on the skin at a decompression force of approximately 20 lb [2,12] An ITD, (ResQPOD, Zoll Medical, Chelmsford MA) was placed on the endotracheal tube. If randomization called for HUP CPR, the head and shoulders of the animal were elevated at 30° (Fig. 1). In HUP, the thorax was elevated approximately 4 cm and the head 15 cm. In SUP, the head and heart were horizontal and at the same level relative to each other. While transitioning from SUP to HUP, CPR was not interrupted. Positive pressure ventilation was delivered with room air (FiO_2 of 0.21) with a tidal volume of 10 mL/kg and respiratory rate of 10 breaths per minute. If the animal was noted to gasp during resuscitation, time at first gasp was recorded. Succinylcholine was administered at a dose of 3 mg (0.075/kg) to inhibit gasping after the third gasp.

Experimental procedures

After 8 minutes of untreated VF, 2 minutes of automated CPR were performed in the 0° supine (SUP) position. Pigs were then randomized to CPR with 30° head up (HUP) versus SUP without interruption for 20 minutes. In group A, all pigs received C-CPR, randomized to either HUP or SUP, and in Group B, all pigs received ACD + ITD CPR, again randomized to either HUP or SUP. After 22 total minutes of CPR, pigs were then placed in the SUP