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Experimental paper

Tilting for perfusion: Head-up position during cardiopulmonary resuscitation improves brain flow in a porcine model of cardiac arrest☆

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ABSTRACT

Introduction: Cerebral perfusion is compromised during cardiopulmonary resuscitation (CPR). We hypothesized that beneficial effects of gravity on the venous circulation during CPR performed in the head-up tilt (HUT) position would improve cerebral perfusion compared with supine or head-down tilt (HDT).

Methods: Twenty-two pigs were sedated, intubated, anesthetized, paralyzed and placed on a tilt table. After 6 min of untreated ventricular fibrillation (VF) CPR was performed on 14 pigs for 3 min with an automated CPR device called LUCAS (L) plus an impedance threshold device (ITD), followed by 5 min of L-CPR + ITD at 0° supine, 5 min at 30° HUT, and then 5 min at 30° HDT. Microspheres were used to measure organ blood flow in 8 pigs. L-CPR + ITD was performed on 8 additional pigs at 0°, 20°, 30°, 40°, and 50° HUT.

Results: Coronary perfusion pressure was 19 ± 2 mmHg at 0° vs. 30 ± 3 at 30° HUT ($p < 0.001$) and 10 ± 3 at 30° HDT ($p < 0.001$). Cerebral perfusion pressure was 19 ± 3 at 0° vs. 35 ± 3 at 30° HUT ($p < 0.001$) and 4 ± 4 at 30° HDT ($p < 0.001$). Brain–blood flow was 0.19 ± 0.04 ml min^{-1} g^{-1} at 0° vs. 0.27 ± 0.04 at 30° HUT ($p = 0.01$) and 0.14 ± 0.06 at 30° HDT ($p = 0.16$). Heart blood flow was not significantly different between interventions. With 0, 10, 20, 30, 40 and 50° HUT, ICP values were 21 ± 2, 16 ± 2, 10 ± 2, 5 ± 2, 0 ± 2, −5 ± 2 respectively, ($p < 0.001$), CerPP increased linearly ($p = 0.001$), and CPP remained constant.

Conclusion: During CPR, HDT decreased brain flow whereas HUT significantly lowered ICP and improved cerebral perfusion. Further studies are warranted to explore this new resuscitation concept.

1. Introduction

Generation of adequate non-invasive circulatory support during CPR remains a complex physiological challenge, with competing demands to provide sufficient venous return to refill the heart after each compression and enough circulation to the brain to preserve neurological function.[1–3] Blood flow is highly dependent on the refilling of the heart during the decompression phase and the vascular resistance.

Closed-chest standard (S) manual cardiopulmonary resuscitation (CPR) has traditionally been performed in the 0° supine position. Stimulated by the need to develop better techniques to transport patients in high-rise apartment buildings in small elevators with ongoing CPR in Korea, an international research collaborative was established to examine the impact of CPR in more vertical positions. Little is known about the potential benefit of tilting the head upward or downward during CPR, especially when

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using CPR mechanical devices known to enhance circulation and provide high quality CPR.[4,5] We hypothesized that use of mechanical adjuncts known to enhance circulation during CPR would improve outcomes when the head and body are tilted upward vs. supine CPR or with feet up and head down.

2. Method

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 39.3 ± 0.5 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.[3,6,7] Under aseptic surgical conditions, initial sedation was achieved with intramuscular ketamine (10 mL of 100 mg/mL) followed by inhaled isoflurane at a dose of 0.8–1.2%. Pigs were intubated with a 7.0 French endotracheal tube. The animal's temperature was maintained between 36.5 and 37.5 °C with a warming blanket (Bair Hugger, Augustine Medical, Eden Prairie, MN). Central aortic blood pressure was recorded continuously with a electronic-tipped catheter (Mikro-Tip Transducer, Millar Instruments, Houston, TX) placed in the descending thoracic aorta. 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 measure carotid blood flow ($ml\,min^{-1}$). After creating a burr hole, a Millar catheter was then inserted into the parietal lobe to measure intracranial pressure (ICP). In pigs used for the microsphere studies (see below), a second femoral artery cannulation was performed and a 7F pigtail catheter was positioned in the left ventricle under fluoroscopic guidance. All animals received an intravenous heparin bolus (100 units/kg). Animals were fasted overnight and received normal saline solution to maintain the mean right atrial pressure between 3 and 5 mmHg. The animals were ventilated with room air, using an anesthesia machine (Narkomed, Telford, PA), with a tidal volume of 10 mL/kg and a respiratory rate adjusted to continually maintain an end tidal CO_2 ($ETCO_2$) of 40 mmHg and O_2 saturation of >92%. Arterial blood gases (Gem 3000, Instrumentation Laboratory) were obtained at baseline, and 3 min after each change of CPR position. Surface electrocardiographic tracings were continuously recorded. All hemodynamic data including aortic pressure, right atrial pressure, $ETCO_2$, ICP, and carotid blood flow were continuously monitored and recorded with a digital recording system (BIOPAC MP 150, BIOPAC Systems, Inc., CA, USA). Coronary perfusion pressure (CPP) was calculated as the difference between aortic pressure and right atrial pressure during the CPR decompression phase.[8] Cerebral perfusion pressure (CerPP) was calculated as the difference between mean aortic pressure and mean ICP. Ultrasound derived carotid blood flow velocity was reported in $ml\,min^{-1}$. $ETCO_2$, tidal volume, minute ventilation, and blood oxygen saturation were continuously measured with a respiratory monitor (COSMO Plus, Novametrix Medical Systems, Wallingford, CT).

After the surgical preparation was complete, oxygen saturation on room air was greater than 92%, and $ETCO_2$ was stable between 35 and 42 mmHg for 5 min, VF was induced by delivering direct intra-cardiac current via a temporary pacing wire positioned in the right ventricle. Mechanical CPR was performed using a LUCAS 1™ (Physio-Control, Redmond, WA) compression system at a rate of 100 compressions min^{-1} with a 50% duty cycle. The LUCAS backboard was bolted to a stretcher (Stryker Corporation. Kalamazoo MI) and the pig was tied by its legs to the stretcher as well. The stretcher was attached to a tilt table built to perform CPR with different study angles. In this way the pig, stretcher, and LUCAS could be moved simultaneously while L-CPR was ongoing. An impedance threshold device with a resistance of 16 cmH_2O (ITD-16, ResQPOD™, Advanced Circulatory Systems, Roseville, MN) was attached to the endotracheal tube. Asynchronous positive pressure ventilations with supplemental oxygen at a flow of 10 $l\,min^{-1}$ were delivered with a manual resuscitator bag. The tidal volume was maintained at ~10 mL/kg and the respiratory rate was 10 breaths min^{-1}. In addition, prior to inducing VF succinylcholine (93.3 mcg kg^{-1} min^{-1}) was administered intravenously to prevent spontaneous gasping during CPR.

Angle positions were confirmed after each change of position with a digital protractor (Mitutoyo Pro 360).

2.1.1. Protocol A

Hemodynamics and calculated coronary and cerebral perfusion pressures were the focus of Protocol A. After 6 min of untreated VF, CPR was initiated on 14 pigs with L-CPR + ITD in a 0° supine position for 3 min. This interval provided time for the hemodynamic parameters to stabilize after reperfusion. L-CPR + ITD continued thereafter without interruption for multiple sequential interventions as follows: 5 min epochs at 0°, 30° head up, and 30° head down position, an additional 2 min of L-CPR + ITD in the 30° head up position and then L-CPR alone, without the ITD, for 2 additional min while still in the 30° head up position. Pigs were then placed in the 0° supine position and defibrillated with up to three 275 joule biphasic shocks (Lifepak 15, Physio-control, Redmond, WA). Animals were then sacrificed with a 10 ml injection of saturated potassium chloride.

2.1.2. Protocol B

Cerebral and myocardial perfusion were assessed under different experimental CPR positions in Protocol B. Blood flow to the heart and brain was measured with microspheres injected into the left ventricle under baseline pre-VF conditions and during CPR as previously described.[9–11] In the current study 15 μm diameter neutron activated Lanthanum (^{140}La), Gold (^{198}Au), Ytterbium (^{175}Yb), and Lutetium (^{177}Lu) microspheres (STERIspheres™, BioPAL™: BioPhysics Assay Laboratory, Worcester, MA) were used. Microspheres were randomly assigned for each of the respective four interventions with one type of microsphere per intervention. Microspheres were injected into a total of 8 pigs during CPR under different experimental CPR positions. The microspheres were first injected into the left ventricle under stable baseline conditions 5 min prior to the induction of VF. Then, following 6 min of untreated VF CPR was performed continuously with L-CPR + ITD for the different time intervals and using the 3 different CPR positions as described in Fig. 1. After 4 min of CPR a second microsphere was injected while the pig remained in the 0° supine position. The pig was then tilted upwards to the 30° head up position and 1 min later a third microsphere was injected. After 4 min the pig was tilted downwards in the 30° head down position and 1 min later the last microsphere was injected. The number of microspheres injected for each intervention was computed as follow:

$$\mu = 1.2 \cdot 10^6 + ((1.9 \cdot 10^5) \cdot \omega)$$