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Experimental paper

Discriminating the effect of accelerated compression from accelerated decompression during high-impulse CPR in a porcine model of cardiac arrest☆

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ABSTRACT

Aim of the study: Piston based mechanical chest compression devices deliver compressions and decompressions in an accelerated pattern, resulting in superior haemodynamics compared to manual compression in animal studies. The present animal study compares haemodynamics during two different hybrid compression patterns to a standard compression pattern resembling that of modern mechanical chest compression devices.
Method: In 12 anaesthetized domestic pigs in ventricular fibrillation, coronary perfusion pressures (CPP) and cerebral cortical blood flow (CCBF) was measured, and transesophageal echocardiography (TEE) was performed. Two hybrid compression patterns, one with accelerated trapezoid compression and slower sinusoid decompression (TrS), and one with slower sinusoid compression and accelerated trapezoid decompression (STr), were tested against a standard accelerated trapezoid compression–decompression pattern (TrTr) in a cross-over randomised setup.
Results: There were 7% (1, 14, $p = 0.046$) lower CCBF and 3 mmHg (1, 5, $p = 0.017$) lower CPP with the TrS compared to TrTr pattern. No significant difference between STr and TrTr pattern in either CCBF, 6% (−3, 15, $p = 0.176$) or CPP, 0 mmHg (−2, 3, $p = 0.703$) was present. Our TEE recordings were insufficient for haemodynamic comparison between the different compression–decompression patterns. Despite standardized sternal piston position and placement of the pigs, TEE revealed varying degree of asymmetrical heart chamber compression in the animals.
Conclusion: Both cardiac and cerebral perfusion benefited from accelerated decompression, while accelerated compression did not improve haemodynamics. The evolution of mechanical CPR is dependent on further research on mechanisms generating forward blood flow during external chest compressions.

1. Introduction

A critical link in the chain of survival during cardiac arrest is providing effective chest compressions to reestablish sufficient cerebral and coronary perfusion. Recent clinical studies have demonstrated poor chest compression quality during cardiopulmonary resuscitation (CPR),[1,2] and several studies have documented an association between this poor CPR quality and survival.[3–5]

While human rescuers deliver manual chest compressions in a roughly sinusoid manner, mechanical chest compressions devices may be constructed to perform more specific and optimal compression–decompression patterns. New piston based devices such as the Lund University Cardiopulmonary Assist Device (LUCAS®, JoLife AB, Lund, Sweden) and the High-Impulse Thumper® (Model 1007, Michigan Instruments, Grand Rapids, MI, USA) delivers chest compressions–decompressions in an accelerated fashion resembling a trapezoid pattern, and both have demonstrated superior haemodynamics in animal studies.[6,7]

In a previous experimental animal study we found that haemodynamics during mechanical CPR were influenced by changes in

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the compression–decompression pattern.[8] In that study, an accelerated trapezoid compression–decompression pattern generated superior cerebral blood flow compared to the more human like slower sinusoid pattern, when compression rate, depth and duty cycle were unchanged. To investigate which phase of the compression cycle that profit from the accelerated piston movement, we compared two hybrid compression–decompression patterns to a standard trapezoid compression–decompression pattern resembling that of modern mechanical chest compression devices. Since the mechanisms responsible for forward blood flow during CPR in human are controversial, we used continuous transesophageal echocardiography (TEE) in an attempt to directly visualize the heart function during CPR in our porcine model of cardiac arrest.

2. Materials and methods

The experiments were conducted in accordance with “Regulations on Animal Experimentation” under The Norwegian Animal Welfare Authority Act and approved by Norwegian Animal Research Authority.

2.1. Animal preparation

Fifteen healthy domestic female pigs (31 ± 1.6 kg) were fasted over night with free access to water. They were sedated in the pens with an intramuscular injection of ketamine (40 mg kg^{-1}) before a catheter was inserted into an ear vein and anaesthesia induced with propofol (3 mg kg^{-1}) and fentanyl (8 μg kg^{-1}). The pigs were placed supine in a U-shaped trough with the limbs secured to prevent lateral displacement of the chest during CPR. Following a tracheotomy, anaesthesia was maintained with inhaled desflurane (8%) in a semi-closed ventilation circuit and a continuous intravenous infusion of fentanyl (20–40 μg kg^{-1} h^{-1}). The animals were mechanically ventilated (Hewlett Packard) with oxygen supplemented air (24%) at a positive end-expiratory pressure (4 mmHg) and minute ventilation adjusted to maintain an end tidal carbon dioxide (ETCO$_2$) level of 4.5–5.5 kPa, measured by a gas monitor (Datex Capnomac Ultima^{TM}, Helsinki, Finland). They received a continuous infusion of physiological saline (30 ml kg^{-1} h^{-1}) and urine output was drained through a cystostoma. Temperature was measured intra-abdominally and maintained above 38 °C with a hot air blanket.

Two 7F micro-tip pressure transducer catheters (Model SPC 470, Millar Instruments, Houston, TX, USA) were inserted; one through the left carotid artery and advanced just above the aortic valve for continuous arterial pressure monitoring, and another to the right atrium via the right external carotid vein. A 7.5F Swan-Ganz catheter (Edwards Lifesciences, Irvine, CA 92614, USA) was inserted into the right atrium via the right femoral vein and a fluid filled polyethylene catheter was inserted into the aorta from the right femoral artery, both for blood gas monitoring. An ultrasound flow meter probe (model 3SB880, Transonic Systems Inc., Ithaca, NY, USA) was applied to the right carotid artery. All visible branches of the right common carotid artery, except the internal carotid artery, were ligated. All invasive catheters were introduced using a cut down technique.

A craniotomy and duratomy were performed approximately 10 mm anterior to the coronal suture and 15 mm to the left lateral side of the sagital suture to place a laser Doppler flowmetry probe (Model 407, Perimed AB, Stockholm, Sweden) on the surface of the cerebral cortex. Care was taken to avoid placing the probe directly over visible vessels and it was held in place at the cortical surface by a probe holder (Model PH 07-4, Perimed AB, Stockholm, Sweden) secured with dural sutures. The burr hole was sealed with bone wax and the probes cord were looped and fixed to the skin with suture to minimize movement artefacts. Readings were collected as arbitrary perfusion units that reflect volume flow in the part of the cerebral cortex just below the probe, and expressed as a percentage of the baseline measurements.

A T6 Multiplan transesophageal echocardiographic probe (5.0 MHz, Model 6T, GE Medical Systems, Milwaukee, WI, USA) was advanced into the distal oesophagus to the level of the heart and connected to a Vivid7 Dimension (GE Medical Systems, Milwaukee, WI, USA) echocardiograph including a standard three lead surface EKG. Pressure and flow signals were sampled using PC-based real time data acquisition hardware (NI SCXI-1000, NI PCI-6036E, National Instruments Company, Austin TX, USA) supported with VI logger (National Instruments Company, Austin TX, USA).

Following the experiments, autopsies were performed to verify the position of all catheters and to do a rudimentary check for thoracic or abdominal compression injuries.

2.2. Mechanical CPR

Chest compressions were delivered with a custom made servo controlled mechanical chest compression device (PigSaver, Laerdal Medical, Stavanger, Norway) designed to provide a wide array of different compression characteristics including different compression–decompression patterns. In the present study compression rate and depth were fixed at 100 min^{-1} and 5 cm, with a duty cycle of 50%. The device was pre-programmed to provide three different compression–decompression patterns (Fig. 1); the standard accelerated trapezoid down and upstroke (TrTr), as well as two hybrid patterns, one combining a trapezoid down stroke with a slower sinusoid upstroke (TrS) and an opposite with sinusoid down stroke and trapezoid upstroke (STr).

2.3. Experimental protocol (Fig. 2)

After completion of the surgical instrumentation, fentanyl administration was discontinued followed by a period of stabilization before blood gases, baseline registration of all haemodynamic variables and an echocardiographic examination was performed. Ventilation, desflurane anaesthesia and fluid infusion were then discontinued, and ventricular fibrillation (VF) was induced by a trans-thoracic current (90 V AC for 3 s). Cardiac arrest was confirmed by ECG and blood pressure changes. The pigs were left for 3 min in untreated VF followed by 1 min of continuous TrTr chest compressions with interposed ten bag ventilations per min (100% O$_2$). The vertical position of the compression piston was thereafter adjusted to a new zero position to correct for initial changes in the chest configuration. As showed in Fig. 2, 4 min runs with the three different compression–decompression patterns were performed in a cross-over randomised setup, followed by a final run repeating the initial pattern in order to monitor the effect of time on the experiment.

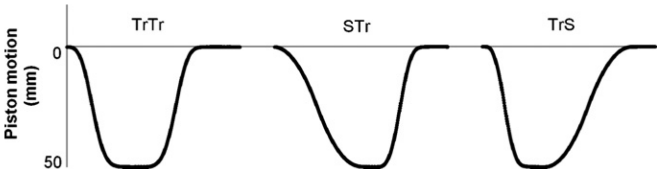

Fig. 1. Tracings of the piston motion during one complete compression decompressions cycle with each of the three patterns tested. STr, sinusoid down stroke combined with trapezoid upstroke; TrS, trapezoid down stroke combined with sinusoid upstroke; TrTr, trapezoid down and upstroke.