

ORIGINAL RESEARCH

Hemodynamic efficacy of a motor-driven automatic device performing simultaneous sternothoracic cardiopulmonary resuscitation compared to standard cardiopulmonary resuscitation in an animal model of cardiac arrest

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Abstract

The aim of this study was to investigate hemodynamic effects and resuscitation outcomes of simultaneous sternothoracic cardiopulmonary resuscitation (SST-CPR) with a prototype of a motor-driven automatic device, comparing to manual standard CPR (S-CPR), in an animal model of ventricular fibrillation (VF). 20 male pigs were randomized to receive standard CPR (S-CPR group) or CPR with an automatic SST-CPR device (A-CPR group) after 5 minutes of VF. Five minutes of basic life support CPR was performed, followed by 10 minutes of advanced life support CPR. Hemodynamic variables including systolic blood pressure (SBP), diastolic blood pressure (DBP), coronary perfusion pressure (CPP), and end-tidal carbon dioxide tension (ETCO₂), and resuscitation outcomes including rate of restoration of spontaneous circulation (ROSC) and 2-hour survival were compared between two groups. Ten animals among the A-CPR group and 8 animals among the S-CPR group were included in the final analysis. SBP was higher in the A-CPR group than in the S-CPR group during CPR ($p = 0.046$). The DBP, CPP and ETCO₂ were not different between two groups ($p = 0.412$, 0.585 , and 0.243 , respectively). ROSC rate was 38% in the S-CPR group and 10% in the A-CPR group ($p = 0.275$). The 2-hour survival rate was 25% in the S-CPR group and 0% in the A-CPR group ($p = 0.183$). In a swine model of cardiac arrest, CPR with a prototype of a motor-driven automatic SST-CPR device, compared with standard CPR, produced higher systolic blood pressure, but there was no difference in diastolic pressure, coronary perfusion pressure, ROSC rate and 2-hour survival rate.

Keywords

Cardiac arrest; Cardiopulmonary resuscitation; Life support

1. Introduction

Incidences of sudden cardiac arrest are among the major medical issues worldwide and are associated with high fatality. The prompt provision of high-quality cardiopulmonary resuscitation (CPR), early defibrillation, and optimal post-cardiac arrest care is a mainstay of treating cardiac arrest. Despite advances in resuscitation science and emergency medical systems, survival in case of out-of-hospital cardiac arrests remains quite low due to the lack of an effective method for maintaining artificial circulation during CPR [1].

Although minor modifications have been made to the method, in terms of the depth and rate, over the last 50 years, manual external chest compression has been used as a standard method of artificial circulation in its original form [2–4]. However, manual external chest compression

cannot maintain sufficient blood flow to maintain adequate perfusion to the tissue during cardiac arrest. The blood flow generated by chest compressions is only about one-third of the normal cardiac output [5, 6]. In addition, difficulty in achieving consistent quality in performing chest compressions is frequently observed during resuscitation [7, 8].

Mechanical CPR devices have been introduced in clinical practice, and have several advantages over manual chest compressions. Mechanical CPR devices provide consistent chest compressions, regardless of the rescuer. The types of mechanical CPR devices range from those that simply compress the chest, such as Thumper™, to devices that are capable of performing alternative CPR, such as LUCAS™ and AutoPulse™ [9–11]. Although mechanical CPR devices have not proven to increase survival rates, they are used widely in the clinical field [12, 13]. Simultaneous sternothoracic CPR (SST-CPR) is an

alternative method of CPR, which performs the simultaneous exploitation of sternal compression with a piston and thoracic constriction with a strap, in a cycle [14]. Previous animal studies, which used a prototype of the device performing SST-CPR, proved it to be superior to standard CPR, in terms of hemodynamic efficacy and survival rate [15]. Recently, we developed a battery-powered, motor-driven mechanical device performing SST-CPR (X-CPR™, CU medical systems, Inc., Wonju, Republic of Korea). The purpose of this study was to compare the hemodynamic effects and resuscitation outcomes of SST-CPR with a prototype of a motor-driven automatic device and standard CPR in an animal model of cardiac arrest.

2. Materials and Methods

2.1 Device description

The automatic SST-CPR consists of two parts: a CPR-performing apparatus and a backboard (Fig. 1). The CPR performing apparatus is composed of a piston, a chest strap, actuating and controlling parts, and a supporting frame. The piston and actuating and controlling parts are mounted on the supporting structure. The piston is a rectangular bar, used to compress the sternum. The chest strap is to constrict the chest circumferentially. It surrounds the thorax when combined with the CPR-performing apparatus and the backboard. The piston pulls the chest straps attached to both sides of the piston as much as the compression depth when compressing the sternum, so the chest constriction occurs twice the depth of chest compression. The up-and-down motion of the piston is driven by a battery-powered motor. The parameters of the piston-driven chest compressions are adjustable. The compression depth of the sternum can be controlled from 0 to 6 cm, and the compression rate can be controlled from 0 to 110 compressions per minute (CPM). The actuating and controlling parts provide the electronic control of the device. The supporting frame is connected to the backboard and serves to support the piston and actuating and controlling parts. When the supporting frame and the backboard are combined, the chest strap on both sides is connected to each other. The backboard includes an apparatus to control the length of the thoracic strap automatically according to the size of the chest.

2.2 Animal experiment

Domestic male Yorkshire pigs, weighing 35–48 kg, aged 8–11 weeks, from a single-source breeder were used in the study. The pigs were housed in a temperature (18–25 °C) and humidity (40–60%) controlled room. The experimental procedures and protocols were carried out in compliance with ARRIVE guidelines [16].

2.3 Preparation of animals

The pigs were fasted overnight but allowed free access to water. Anesthesia was induced through the intramuscular injection of ketamine (30 mg/kg) and xylazine (2 mg/kg), followed by inhaled 3% isoflurane during preparation. Jaw tone was assessed throughout the procedure as an anesthetic



FIGURE 1. Automatic SST-CPR device (X-CPR). The main compression unit is positioned in the top of the device which is operated by a battery-powered motor. The strap is attached to both sides of the central piston.

depth indicator. Endotracheal intubation was performed with a cuffed endotracheal tube in the prone position. The placement of the endotracheal tube was confirmed by auscultation and measurement of end-tidal carbon dioxide (ETCO₂) levels (CO₂SMO, Philips Respironics, Murrysville, PA, USA). After intubation, the animals were placed in the supine position. The pigs were ventilated with room air, via a volume-controlled ventilator (MDS Matrix 3000, Orchard Park, NY, USA). The tidal volume was set at 10 mL/kg and ventilation rate at 18 breaths per minute. Electrocardiography (ECG lead II) was performed and ETCO₂ levels were monitored continuously.

Under aseptic conditions, an introducer sheath (7.5 Fr, Arrow International Inc., Reading, PA, USA) was inserted into the right femoral artery, as per the Seldinger method, and a micromanometer-tipped catheter (5 Fr, Millar Instruments, Inc., Houston, TX, USA) was introduced into the femoral sheath and advanced to the thoracic aorta to continuously record the arterial pressure [17]. After right cervical dissection, two introducer sheaths were placed in the right external and internal jugular veins. A micromanometer-tipped catheter (6 Fr, Millar Instruments, Inc., Houston, TX, USA) was introduced into the right atrium and a pacing electrode catheter (5 Fr, bipolar lead, Arrow International Inc., Reading, PA, USA) was positioned in the right ventricle. The catheter position was confirmed by characteristic pressure tracing from the cardiac chamber and a postmortem examination. Once the catheters were in place, a heparin bolus (100 units/kg, IV) was administered to prevent thrombosis. The mean right atrial (RA) pressure was maintained at approximately 5 mmHg through the administration of intravenous fluid. Electrode pads for defibrillation placed in the right upper quadrant and the left

lower quadrant of the chest. The pigs were stabilized at least 10 minutes before the baseline measurement was recorded.

2.4 Randomization and induction of ventricular fibrillation

After preparation, each animal was randomized into the standard CPR (S-CPR) group or the automatic CPR (A-CPR) group according to the results after the researcher opened the sealed, opaque envelope containing the results of randomization by one of the investigators. After the baseline measurement was done, ventricular fibrillation (VF) was induced by delivering 30–60 mA of electrical current, at 60 Hz for a duration of 5 seconds, to the endocardium, via the electrode in the right ventricle. The occurrence of VF was confirmed by the ECG waveform and the disappearance of arterial pressure. Once VF was induced, the endotracheal tube was disconnected from the ventilator and the pigs were observed for 5 minutes without any procedure or treatment.

2.5 Experimental protocol

After 5 minutes of VF, the animals received either S-CPR or A-CPR, according to the randomization result. During the first 5 minutes, the ratio of compressions to ventilation was maintained at 30:2 as in basic life support (BLS). For S-CPR group, manual chest compressions were performed by investigators according to the CPR guidelines [18]. All compressors were emergency physicians certified with the American Heart Association basic life support training program. Chest compression was performed at the center of the chest with a depth of about 5 cm and at a rate of 100 per minute following audio prompt from metronome. The compressors were switched every 2 minutes. For A-CPR group, the animal was placed on the backboard of the automatic SST-CPR device after induction of VF. Then, the automatic SST-CPR device was applied to the animals with the piston positioned in the center of the chest. During A-CPR, chest compression was set at a rate of 100/min and a depth of 5 cm (a thoracic constriction of 10 cm). Positive pressure ventilations were delivered with a resuscitator bag (silicone resuscitator 870150, Laerdal Medical, Stavanger, Norway). A tidal volume of approximately 300 mL per breath was delivered by a resuscitator bag. Two breaths were given within 6 seconds, after 30 continuous chest compressions. After 5 minutes of CPR, advanced cardiovascular life support (ACLS) was implemented and continued for 10 minutes. Continuous chest compressions were performed without interruption for ventilation, while asynchronous, intermittent, and manual ventilations were administered with the resuscitator bag at a rate of 10 ventilations per minute. Defibrillation was performed every 2 minutes with 2J/kg for the first shock and 4J/kg for subsequent shocks. One mg of epinephrine was administered into the right atrium every 3 minutes. All the resuscitation efforts were stopped if ROSC was not achieved after 10 minutes of ACLS. If ROSC was achieved, isoflurane inhalation was restarted. The animals were stabilized using vasopressors and survival was monitored for 2 hours. If an animal survived for 2 hours, then it was euthanized with an intravenous injection of potassium chloride.

2.6 Data measurements and resuscitation outcomes

Data were digitized with a digital recording system (Powerlab, AD Instruments, CO, USA). All parameters including systolic blood pressure (SBP), diastolic blood pressure (DBP), coronary perfusion pressure (CPP), right atrial pressure (RAP) and, $ETCO_2$ were continuously recorded during the experiment. CPP was calculated as the difference between the arterial pressure and right atrial pressures during the end-diastolic phase using an electronic subtraction unit. The primary outcome was measured by SBP to compare the hemodynamic effects in the two groups. The secondary outcomes were successful defibrillation, ROSC, and 2-hour survival. Successful defibrillation was defined as the termination of fibrillation with the return to an organized electrical rhythm at 5 seconds after defibrillation. ROSC was defined as the maintenance of a SBP of at least 60 mmHg for at least 10 consecutive minutes [19].

2.7 Statistical analysis

On the basis of a previous study reporting a 44 mmHg difference of SBP with standard deviation (SD) of 35 mmHg between the S-CPR and A-CPR group, it was calculated at least 10 subjects would be needed in both groups to provide a statistical power of 80% with a two-sided alpha value of 0.05 [15]. Twenty animals were chosen, considering that 10% of animals would be excluded in the analysis due to unpredictable experimental failure.

Hemodynamic data were analyzed using the average of each parameter measured during the data-sampling period. The values of each parameter were the averages of the values measured for 30 seconds at 6, 8, 10, 12, 14, 16, 18, and 20 minutes after the induction of VF. Continuous variables were presented as mean \pm SD. A student's *t*-test was used to compare the continuous variables between the S-CPR and A-CPR group. The nominal variables were reported as counts and percentages, and were compared with a chi-square or Fisher's exact test, as appropriate. A linear mixed model analysis was used to compare hemodynamic parameters. A value of $p < 0.05$ was considered significant. Analyses were carried out using SPSS statistics 20.0 for Windows (IBM Corp., Chicago, IL, USA). Any differences were regarded as significant if the *p*-values were less than 0.05.

3. Results

3.1 Baseline measurements

Of the twenty pigs used in the study, 10 animals were included in S-CPR group and 10 in the A-CPR group. Among the S-CPR group, one case with dislodged catheter and one case with arterial bleeding were excluded from the analysis. There was no difference in the baseline characteristics and hemodynamic parameters between the two groups (Table 1).

3.2 Comparisons of the hemodynamic effects between S-CPR and A-CPR

SBP was significantly higher in the A-CPR group than the S-CPR group ($p = 0.046$ by group-time interaction analyses). The

TABLE 1. Baseline measurements.

Variables	S-CPR (N = 8)	A-CPR (N = 10)	<i>p</i>
Body weight (kg)	39.5 ± 5.6	37.6 ± 2.2	0.386
Chest circumference (cm)	72.6 ± 5.4	70.4 ± 1.7	0.337
SBP (mmHg)	114.6 ± 27.8	119.7 ± 17.2	0.639
DBP (mmHg)	85.5 ± 19.4	89.9 ± 10.7	0.548
RADP (mmHg)	-1.5 ± 6.6	-2.6 ± 6.2	0.876
CPP (mmHg)	88.1 ± 19.1	91.0 ± 10.9	0.725
ETCO ₂ (mmHg)	43.3 ± 3.1	41.8 ± 3.3	0.361

Data are expressed as mean ± standard deviation.

SBP, systolic blood pressure; DBP, diastolic blood pressure; RADP, right atrial diastolic pressure; CPP, coronary perfusion pressure; ETCO₂, end-tidal carbon dioxide; S-CPR, standard cardiopulmonary resuscitation; A-CPR, automatic simultaneous sterno-thoracic cardiopulmonary resuscitation.

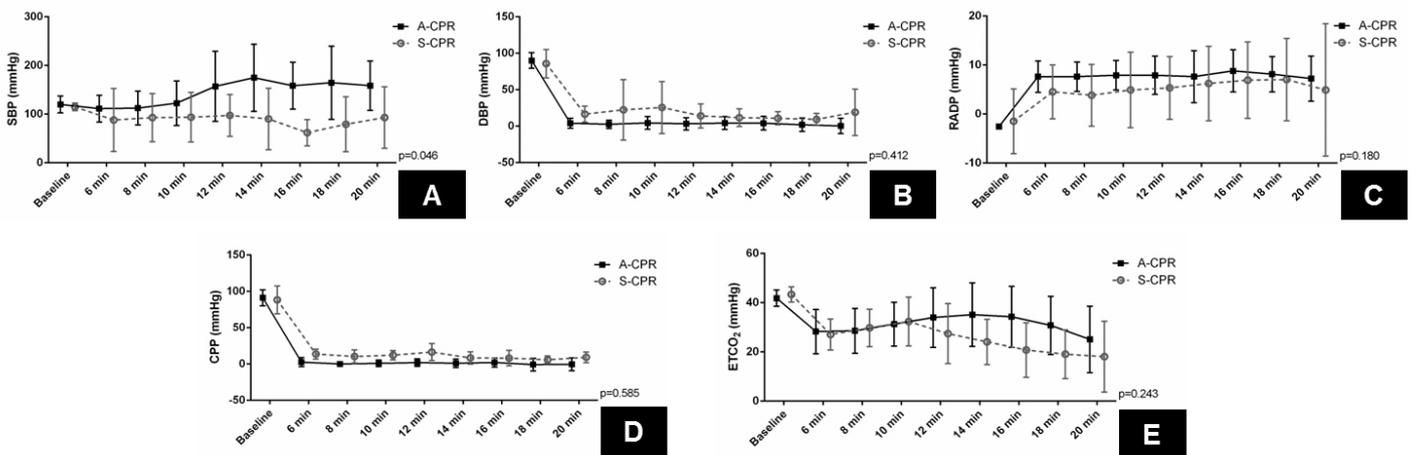


FIGURE 2. Comparisons of the hemodynamic effects between S-CPR and A-CPR. SBP, systolic blood pressure; DBP, diastolic blood pressure; RADP, right atrial diastolic pressure; CPP, coronary perfusion pressure; ETCO₂, end-tidal carbon dioxide.

hemodynamic parameters including DBP, right atrial diastolic pressure, CPP and ETCO₂ did not differ statistically between two groups (Table 2) (Fig. 2).

3.3 Energy requirement and resuscitation outcome

The total defibrillation energy doses were 775 ± 161 J in the S-CPR group and 901 ± 278 J in the A-CPR group. ROSC was observed in three pigs (38%) in the S-CPR group and one (10%) in the A-CPR group. Two pigs (25%) in the S-CPR group and none in the A-CPR group achieved 2-hour survival (Table 3).

3.4 Complications

Complications, including rib fractures, lung contusion, hemothorax, or hemopericardium, were found on autopsy (Table 4). Rib fracture was noticed more frequently in S-CPR group (*p* = 0.043) than in A-CPR group. A minimal amount of hemopericardium was seen in a case of both groups.

4. Discussion

This study demonstrated that a motor-driven automatic SST-CPR device produces higher SBP compared to standard manual CPR, CPP, ETCO₂ and resuscitation outcomes including the rate of defibrillation success, ROSC, and 2-hour survival were not different between the two groups.

Since the blood flow by standard CPR is insufficient to maintain tissue perfusion, efforts have been made to develop new CPR techniques to increase blood flow [5, 20]. Mechanical CPR devices using various mechanisms and techniques have been developed and are being used in clinical practice. Most of them are designed to apply direct mechanical power to compress a patient's sternum, as a manner of manual chest compression [9]. The active compression-decompression (ACD) CPR device is composed of a central piston that is attached via a suction cup, which enhances vascular filling by active decompression after chest compression [10]. The Lund University Cardiopulmonary Assist System (LUCAS™, Physio-Control Inc., Lund, Sweden) is an automatic device that applies ACD-CPR [21]. The load-distributing band CPR (AutoPulse™ Resuscitation

TABLE 2. Comparisons of hemodynamic parameters during cardiopulmonary resuscitation.

Parameter	Baseline	6 min	8 min	10 min	12 min	14 min	16 min	18 min	20 min	<i>p</i> trend
SBP (mmHg)										0.046
S-CPR	114.6 ± 27.8	87.7 ± 64.7	92.6 ± 49.6	93.3 ± 51.0	97.0 ± 42.8	89.9 ± 63.3	61.6 ± 27.1	78.9 ± 56.4	92.6 ± 63.2	
A-CPR	119.7 ± 17.2	111.0 ± 27.7	112.1 ± 34.8	122.4 ± 45.7	156.8 ± 72.0	174.6 ± 69.0	158.2 ± 48.2	164.3 ± 75.1	158.3 ± 50.8	
DBP (mmHg)										0.412
S-CPR	85.5 ± 19.4	16.2 ± 11.0	22.2 ± 41.5	25.4 ± 35.6	13.9 ± 16.5	11.4 ± 12.2	10.6 ± 9.0	9.1 ± 8.3	18.9 ± 31.8	
A-CPR	89.9 ± 10.7	3.9 ± 6.8	2.4 ± 5.7	4.2 ± 8.7	3.0 ± 8.4	4.1 ± 8.8	3.9 ± 9.3	1.8 ± 9.2	1.1 ± 10.4	
RADP (mmHg)										0.180
S-CPR	-1.5 ± 6.6	4.5 ± 5.5	3.8 ± 6.3	4.9 ± 7.7	5.3 ± 6.4	6.2 ± 7.6	6.9 ± 7.8	7.0 ± 8.4	4.9 ± 13.5	
A-CPR	-2.6 ± 6.2	7.6 ± 3.2	7.6 ± 3.0	7.9 ± 3.0	7.9 ± 3.9	7.6 ± 5.3	8.8 ± 4.3	8.1 ± 3.6	7.2 ± 4.6	
CPP (mmHg)										0.585
S-CPR	88.1 ± 19.1	13.6 ± 6.8	10.2 ± 9.0	12.0 ± 6.4	16.2 ± 11.7	8.2 ± 8.4	7.9 ± 10.7	5.8 ± 5.1	9.0 ± 7.2	
A-CPR	91.0 ± 10.9	2.4 ± 6.1	-0.1 ± 3.2	0.7 ± 4.5	1.7 ± 5.2	0.9 ± 5.8	1.9 ± 6.2	-1.0 ± 8.8	-0.6 ± 8.9	
ETCO₂ (mmHg)										0.243
S-CPR	43.3 ± 3.1	27.0 ± 6.3	29.7 ± 7.6	32.3 ± 9.9	27.4 ± 12.2	24.0 ± 9.2	20.7 ± 11.1	19.0 ± 9.9	18.0 ± 14.4	
A-CPR	41.8 ± 3.3	28.2 ± 9.0	28.5 ± 9.1	31.2 ± 8.9	33.9 ± 12.1	35.1 ± 12.9	34.2 ± 12.4	30.7 ± 11.8	25.0 ± 13.5	

Data are expressed as mean ± standard deviation.

S-CPR, standard cardiopulmonary resuscitation; A-CPR, automatic simultaneous sternothoracic cardiopulmonary resuscitation; SBP, systolic blood pressure; DBP, diastolic blood pressure; RADP, right atrial diastolic pressure; CPP, coronary perfusion pressure; ETCO₂, end-tidal carbon dioxide.

TABLE 3. Comparisons of resuscitation outcomes.

Variables	S-CPR (N = 8)	A-CPR (N = 10)	<i>p</i>
Defibrillation energy (J)	775 ± 161	901 ± 278	0.055
Number of defibrillations	5 ± 1	5 ± 2	0.186
Total epinephrine dose (mg)	4 ± 0	4 ± 1	0.965
ROSC (%)	38	10	0.275
2-hour survival (%)	25	0	0.183

Data are expressed as mean ± standard deviation.

ROSC, return of spontaneous circulation; S-CPR, standard cardiopulmonary resuscitation;

A-CPR, automatic simultaneous sterno-thoracic cardiopulmonary resuscitation.

TABLE 4. CPR complications confirmed by autopsy.

Variables	S-CPR (N = 8)	A-CPR (N = 10)	<i>p</i>
Number of cases of complications	6	7	1.000
Rib fracture	5	1	0.043
Lung contusion	4	6	1.000
Hemothorax	1	2	1.000
Hemopericardium	1	1	1.000

S-CPR, standard cardiopulmonary resuscitation; A-CPR, automatic cardiopulmonary resuscitation.

System, ZOLL, Sunnyvale, CA, USA) uses a band that is placed around the victim’s chest wall, and the inflation-deflation technique is performed in turns so that chest wall constriction can occur [11]. This device generates blood flow by producing fluctuations of the intrathoracic pressure, instead of directly compressing the cardiac structure. The SST-CPR device is designed to compress the victim’s sternum, directly, using a piston, and simultaneously constrict the victim’s chest wall using a thoracic strap [14]. Additional constriction of the thorax is presumed to contribute to a further increase in the pressure of the intrathoracic compartment by preventing configurative changes of the thorax during chest compression. SST-CPR is expected to produce a higher hemodynamic effect than standard CPR or the use of a chest compressing device because it follows the methodology of standard CPR and adds simultaneous thoracic constriction. The efficacy of prototype SST-CPR has been proved by an animal study which demonstrated significantly higher arterial pressures and improved resuscitation outcomes, relative to standard CPR [15]. In this study, the systolic blood pressure was found to be increased with an automatic SST-CPR device, but it was not demonstrated that hemodynamic efficacy is associated with resuscitation outcome.

The first version of the automatic SST-CPR device was operated by a pneumatic actuator. Hence, rescuers were required to carry an oxygen tank, thereby limiting the use of the device outside the hospital or in places without pressurized oxygen supply. To overcome these disadvantages, we remodeled the device, and it is now operated by a motor-driven piston that is powered by an electrical battery; thus, rescuers do not have to carry an oxygen tank. This expect to enhance its utility, with

better portability and ease of use, in prehospital settings. The results of this experimental study showed that the new version of the SST-CPR device has a hemodynamic advantage in maintaining high systolic blood pressure compared to standard CPR. However, the diastolic pressure and coronary perfusion pressure were lower compared to the previous version of the SST-CPR device [14, 22]. Likewise, unlike previous reports, the automatic SST-CPR device failed to improve the resuscitation outcome, including ROSC rate and 2-hour survival rate, compared to S-CPR [15]. The previous version of the SST-CPR device driven by a pneumatic actuator places the actuator on the sternum without a supporting structure for the actuator. The current version of the SST-CPR device, which uses an electric motor, has a driving part installed on the supporting structure. As a result, compared to the previous version, the rib cage around the driving part does not come into close contact with the rib cage. Due to the incomplete adhesion between the thoracic strap and the rib cage observed in current version of the SST-CPR device, sufficient diastolic blood pressure and coronary perfusion pressure for ROSC were not maintained, possibly affecting the resuscitation outcome. For the use of the current CPR device in clinical practice, it is necessary to improve the current version of the automatic SST-CPR device for fully implementing the mechanism of SST-CPR, which compresses the sternum and constricts the chest simultaneously. Since this study was conducted using a prototype device, additional studies are needed to evaluate the hemodynamic effect and resuscitation outcome of the device after the device is improved.

This study has some limitations. Since the results of this study were obtained from animal experiments, there is a limit to applying the results of the study to the human body. In particular, the chest of a pig is quite different in configuration, and is smaller in size compared to the human chest. Since the device used in this study was designed for human use, the experimental results in animals may not be identically observed in the human body. Since the quality of chest compressions was not monitored in the S-CPR group, the quality of chest compressions and its hemodynamic effects are unknown. Although compressors were highly trained emergency physicians, alternating chest compressions every 2 minutes, it was not possible to determine whether the quality of chest compressions was maintained optimally. The small sample size may have limited our ability to determine differences in the resuscitation outcomes.

5. Conclusion

Compared with standard CPR, CPR with a prototype of a motor-driven automatic SST-CPR device maintains higher systolic blood pressure, but there is no difference in diastolic pressure, coronary perfusion pressure, ROSC rate and 2-hour survival rate. Further investigation is needed to prove the efficacy of this automatic CPR device.

AVAILABILITY OF DATA AND MATERIALS

The data are contained within this article.

AUTHOR CONTRIBUTIONS

SOH—the conception and design of the study; KCC, HIK, YSL—acquisition of data; KCC—drafting the article; HSK—statistical analysis; WJJ, YIR—revising draft critically for important intellectual contents; SOH—final approval of the version, all authors read and approved the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This animal experimental study was reviewed and approved by the Institutional Animal Care and Use Committee at Yonsei University Wonju College of Medicine (YWC-160324-1).

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CONFLICT OF INTEREST

Sung Oh Hwang is a patent-holder of this device (US patent: cardiopulmonary resuscitation apparatus, US 7214203 B2). The device used in this experiment is a battery-powered, motor-driven mechanical device performing SST-CPR, which is a product in development (X-CPR™) by CU medical systems, Inc., Wonju, Korea. Dr. Hwang is not an employee of the CU medical systems, Inc. and has no ownership of stocks or shares of the company. The authors declare no conflict of interest. Sung Oh Hwang is serving as one of the Editorial Board members of this journal. We declare that Sung Oh Hwang had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to OK.

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