

Application of a self-designed inspiratory impedance threshold device in cardiopulmonary resuscitation in three porcine models of cardiac arrest

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Abstract

Background: To evaluate and compare the efficiency of a self-designed inspiratory impedance threshold device in cardiopulmonary resuscitation (CPR) in the porcine models of cardiac arrest established by three approaches. **Methods:** Twenty healthy pigs were randomly assigned into the control group (n=5), model 1 (n=5), model 2 (n=5) and model 3 (n=5) groups. Following anesthesia induction, endotracheal tube was inserted and connected to the anesthesia machine. In the three model groups, pigs received intravenous injection of ketamine (model 1), MgSO₄ (model 2) and KCl (model 3), and subsequently pig models of cardiac arrest were established. Manual closed-chest CPR was performed at 80 bpm with the self-designed inspiratory impedance threshold device in the model groups and without this device in the control group. After 2-, 6- and 10-min CPR, the heart rate and hemodynamic parameters including arterial blood pressure, blood oxygen saturation, end-diastolic volume and cardiac output were quantitatively measured. The Esophageal echocardiography and blood-gas analyses were performed. **Results:** After CPR, the mean arterial blood pressure, end-diastolic volume and cardiac output in three model groups were significantly higher compared with those in the control group (all $P < 0.05$). In model 2 group, the stroke volume, cardiac output, end-diastolic volume, SPO₂ and PCO₂ levels and blood-gas parameters were the highest among three model groups (all $P < 0.05$). **Conclusions:** The self-invented inspiratory impedance threshold device yields the highest efficiency in the porcine model of cardiac arrest established by intravenous infusion of MgSO₄ by increasing the cardiac output during CPR compared with the remaining two pig models.

Background

Conventional manual cardiopulmonary resuscitation (CPR) can offer the blood supply to vital organs. Although CPR acts as the primary care for critically ill patients for years, the rescue rate of patients receiving conventional CRP is not satisfactory with a survival rate of lower than 7%. CPR can exert the effect upon letting the blood flow from the heart to the periphery, which can be accomplished by sufficient venous blood flow to the chest following each cycle of manual compression. To enhance the survival and rescue rates of critically ill patients after CPR, novel mechanical instruments and devices have been explored and applied(1).

Among these techniques, active compression-decompression CPR is a technique which can transforms the thorax to a more efficient bellows. During the stage of decompression of CPR, the chest is highly pulled upward using a manual negative-pressure suction device, which is able to impose heavy negative pressure within the thoracic cavity and effectively promote the blood flow into the heart during the stage of decompression(2). During the conventional CPR, the blood flow from the peripheral veins to the heart significantly relies upon the status of natural chest wall recoil.

Previous investigations have demonstrated that complete airway occlusion during the stage of decompression can lead to high negative pressure within the thoracic cavity, accelerate the blood flow from the peripheral veins to the heart and considerably enhance the efficiency of conventional CPR(3). In

previous researches(4), a newly-designed inspiratory impedance device was established to prevent the occurrence of inspiratory gas exchange throughout the stage decompression during CPR of the pressure within the thoracic cavity is lower compared with the atmospheric pressure.

In the present experiment, pig models were used as pigs carry similar size of hearts as human and are frequently used in previous CPR research. Healthy pigs were randomly assigned into the control group and three different models groups to establish cardiac arrest pig models via intravenous injection of ketamine, MgSO₄ and KCl, respectively. Subsequently, a self-designed inspiratory impedance threshold device (Patent registration No. CN 101697937 B) was developed and applied during CPR in the three animal models to evaluate the efficiency and safety, aiming to identify the self-designed device yields the highest efficiency in which pig model.

Methods

All animal experiments were performed with the approval of Animal Ethics Committee of Kunming Medical University. Animals were managed in accordance with Chinese Association for Laboratory Animal Sciences guidelines and current legal requirements. Our animal facilities meet the standards of Laboratory Animal-Requirements of Environment and Housing Facilities (GB 14925-2010). Twenty healthy pigs were randomly assigned into the control group (n=5), model 1 (n=5), model 2 (n=5) and model 3 (n=5) groups. Following anesthesia induction, endotracheal tube was inserted and connected to the anesthesia machine. In the three model groups, pigs received intravenous injection of ketamine (model 1), MgSO₄ (model 2) and KCl (model 3), and subsequently pig models of cardiac arrest were established. Manual closed-chest CPR was performed at 80 bpm with the self-designed inspiratory impedance threshold device in the model groups and without this device in the control group. After 2-, 6- and 10-min CPR, the heart rate and hemodynamic parameters including arterial blood pressure, blood oxygen saturation, end-diastolic volume and cardiac output were quantitatively measured. The Esophageal echocardiography and blood-gas analyses were performed.

Self-designed inspiratory impedance threshold device

As illustrated in Figure 1, the self-designed cardiopulmonary resuscitation auxiliary device was equipped with an oxygen supply end (10) connected with an oxygen supply pipe on the bottom (5) with a cavity (4). It had an air supply exhalation end (9) connected with a patient's mask or a throat catheter and an evacuation end (6) connected with the atmosphere. A single control valve (2) and the first one-way valve (3) were set on the oxygen supply end (10). The second one-way valve (7) was designed on the evacuation end. One end of the column body (5) was fixed with the bent pipe (1). The vertical port (10) of the bent pipe (1) was downward to form an oxygen supply end connected with the oxygen supply pipe. The other end of the column body (5) was fixed with a straight pipe (8) with a vertical upper port (6) and a vertical lower port (9), which was an air supply exhalation end to be connected with a mask or a laryngeal airway of a patient. The vertical upper port (6) of the straight pipe was an evacuation end, and the second

one-way valve (7) was designed on the evacuation end to allow for exhalation, whereas prevent inhalation.

Baseline data

Twelve healthy miniature pigs (~16 weeks old, indicating sexual maturity), both male and female, weighing (28±5) kg on average, were provided by the animal laboratory of Kunming Medical University and selected for subsequent experiment. The pigs used in the experiment were accustomed and fed in the laboratory for more than one day until all physiological parameters tended to be stable and be prepared for the subsequent experiment. The experimental animals were subject to dietary fasting but had free access to water on the night before surgery. The auxiliary device was designed based on the principle of negative pressure suction under this background. After completing the tracheal intubation, the self-designed device was connected. When the self-designed device was closed after each cycle of CPR was completed when the chest wall was pressed to the lowest point to occlude the flow of gas into the lungs. The effect of increasing the blood flow to the heart was achieved by using the principle of negative pressure suction generated by increasing the elastic retraction of chest wall.

2.3. Establishment of pig models

Anesthesia was used in all surgical interventions, all unnecessary suffering was avoided, and research was terminated if unnecessary pain or fear resulted in our pigs.

All pigs were subject to basic anesthesia via intramuscular administration of ketamine at a dose of 15 mg/kg, atropine 0.02 mg/kg, and rimwest 0.2 mg/kg, respectively. After the pig stood unstably, the animals were transferred and fixed on the operating table. Electrocardiogram was performed to measure the blood oxygen saturation (SPO₂). The auricular vein was cut open and supplemented with the balance salt solution at a dose of 20 ml/kg. Intravenous injection of propofol 3 mg/kg and fentanyl 2 µg/kg were administered. Spontaneous breathing was retained and ID6.5-7.5 endotracheal tube with bursa was inserted with a depth of 16-18 cm. After successful intubation, the breathing machine was connected to perform intermittent positive pressure mechanical ventilation (IPPV). The breathing parameters were adjusted with a breathing frequency of 15-20 times/min, a tidal volume of 8-10 ml/kg, and an inspiratory-to-expiratory ratio of 1:2. The end-expiratory carbon dioxide partial pressure (ETPCO₂) was kept at 35-40 mmHg, which was connected to the Datex. Ohmeda monitoring machine. The femoral artery puncture was performed and was connected to the transducer on the monitoring machine to measure the dynamic blood pressure. Throughout the entire experiment, the esophageal TEE probe was inserted into the esophagus by approximately 30 cm to measure the cardiac output and returned blood volume of the experimental animals.

After the baseline data were recorded, intravenous injections were processed differently until the electrocardiogram hinted the signs of cardiac arrest. Ventricular fibrillation occurred prior to cardiac arrest. By observing the ventricular fibrillation waveform of electrocardiogram, ventricular fibrillation was defined when the arterial blood pressure was lower than 40 mmHg. The mechanical ventilation was

terminated upon the incidence of ventricular fibrillation. CPR was initiated at the presence of cardiac arrest.

2.4. CPR

Under the same experimental conditions, the animals were randomly divided into the device group (group I, n=6) and non-device group (group II, n=6). The depth of chest was 25% (approximately 5 cm) of the anterior and posterior diameter of the chest. The compression frequency was 100 times/min to ensure the chest to fully rebound. The proportion of compression relaxation period was 50%:50% to minimize the interruption as possible. CPR was terminated after chest compression endured for 4 min. Cardiac arrest of all pigs in this experiment was induced by 5% KCl solution, and no of them was successfully rescued after experiments. Carcass of pigs were handed over to the Animal Laboratory of Kunming Medical University for unified handling.

2.5. Data collection

Measurement of hemodynamic parameters: after the carbon dioxide was maintained within 35-40 mmHg and hemodynamics remained stable, the heart rate (HR), mean arterial blood pressure (MAP), pulse blood oxygen saturation (SPO₂), end diastolic volume (EDV), cardiac output (CO) and alternative parameters were recorded as the baseline values. After the chest compression was started, the values of these parameters were recorded at 2 min, 4 min and 10 min, respectively.

2.6. Statistical analysis

SPSS 19.0 software was utilized for statistical analysis (SPSS Inc., Chicago, IL). Measurement data were expressed as mean \pm standard deviation ($\bar{x}\pm s$). Hemodynamics and blood gases during CPR were analyzed with single factor ANOVA. A *P* value of less than 0.05 was considered as statistical significance.

Results

Comparison of hemodynamic parameters

Prior to the induction of ventricular fibrillation, HR, systolic blood pressure (SP), diastolic blood pressure (DP) and mean arterial pressure (MAP) did not significantly differ among four groups (all *P*>0.05). Throughout the experiment, the SP was persistently elevated in the model 2 group (*P*<0.05). At 2-, 6- and 10-min after CPR, the SP in the control group was significantly higher compared with those in the three model groups (all *P*<0.05), as illustrated in Figure 2A. During the entire experiment, the DP in the control and model 3 groups was continuously increased (*P*<0.05), whereas no significant changes were noted in the model 1 and 2 groups (both *P*>0.05). At each time point following CPR, the DP in the control group was significantly higher than those in the three model groups (all *P*<0.05), as demonstrated in Figure 2B. During the entire experiment, the MAP in the model 2 and 3 groups tended to elevate, whereas that in the model 1 group tended to decline. At 2-, 6- and 10-min after CPR, the MAP in the control group was

significantly higher than those in the three model groups (all $P<0.05$), as revealed in Figure 2C. Regarding the HR, no statistical significance was observed at each time point after CPR between the control and three model groups (all $P>0.05$).

Comparison of esophageal ultrasound parameters

During the whole experiment, the stroke volume (SV) in the control and model 2 groups were significantly increased (both $P<0.05$), whereas no statistical significance was noted in the model 1 group ($P>0.05$). The SV tended to decline in the model 1 and 3 groups, as illustrated in Figure 3A. At each time point, the cardiac output (CO) was significantly increased in the control and model 2 groups (both $P<0.05$), whereas no statistical significance was observed in the model 1 and 3 groups ($P>0.05$). The CO in the model 1 and 3 groups tended to decline (Figure 3B). The ejection fraction in the control and model 1 groups tended to significantly increase (both $P<0.05$). The ejection fraction in the model 3 group tended to decline, and that was declined and then elevated in the model 2 group (Figure 3C).

Comparison of blood-gas parameters

In the model 1 and 3 groups, the SpO_2 tended to decline, whereas that was increased in the model 2 group. The SpO_2 was restored to the normal value at 10 min after CPR in the model 2 and 3 groups (Figure 4A). In three model groups, the pH values were significantly increased at each time point. At 10 min following CPR, the pH value was almost restored to normal in the model 2 group, whereas the pH at 10 min-CPR was significantly higher than the normal value in the model 3 group ($P<0.05$, Figure 4B). In three model groups, the PCO_2 values were significantly declined at each time point after CPR. At 10 min after CPR, the PCO_2 was restored to normal in model 2 group, significantly higher than the normal value ($P<0.05$) in the model 1 group, and considerably lower compared with the normal level in the model 3 group ($P<0.05$), as demonstrated in Figure 4C. In the model 1 group, the HCO_3^- level was increased and subsequently decreased at each time point. In the model 2 group, the HCO_3^- level was persistently increased, whereas that was continuously declined in the model 3 group. At 10 min after CPR, the HCO_3^- levels were almost restored to normal in the model 1 and 2 groups (Figure 4D). At 10 min after CPR, the TCO_3 was almost restored to normal in the model 2 group. The changes of TCO_3 were similar to those of HCO_3^- . Identical variations were noted in terms of Baeef in three model groups (Figure 5).

In the model 1 group, the blood urea nitrogen (BUN) level was enhanced and then decreased at each time point. In the model 2 group, the BUN level tended to decline and subsequently elevate, whereas that was continuously declined in the model 3 group. At 10 min after CPR, the BUN levels were almost restored to normal in the model 1 and 3 groups (Figure 6A). At each time point, the white blood cell (WBC) count was increased in the model 1 group, the WBC did not significantly change in the model 2 group ($P>0.05$), and that tended to decline in the model 3 group. At 10 min-CPR, the WBC was considerably lower than the normal value in the model 3 group ($P<0.05$) (Figure 6B). In the model 1 group, the red blood cell (RBC) count was increased and then decreased, that was decreased and subsequently increased in the model 2 group and that tended to decline in the model 3 group. In the model 3 group, the RBC was significantly

lower than the normal at 10 min after CPR ($P<0.05$) (Figure 6C). Similar outcomes were obtained for the hemoglobin (HGB) levels in three model groups. In the model 1 and 3 groups, the hematocrit (Hct) tended to decline and that was elevated in the model 2 group. At 10 min after CPR, the Hct was significantly lower than the normal value in the model 3 group ($P<0.05$, Figure 6D). In the model 1 group, the Na level was initially declined and then increased at each time point, that was elevated and then decreased in the model 2 group, and that was increased in the model 3 group. The Na values were restored to normal at each time point after CPR in three model groups (Figure 7A). In the model 1 group, the Na value was restored to normal at 10 min after CPR, that was evidently higher in the model 2 group and significantly lower than the normal values in the model 3 group (both $P<0.05$). In the model 1 group, the K level was initially increased and then decreased at each time point, and that was declined in the model 2 and 3 groups (Figure 7B). In the model 1 group, the Cl level was initially decreased and then increased at each time point and that was decreased in the model 2 group, whereas persistently increased in the model 3 group. At each time point after CPR, the Cl levels were significantly higher compared with the normal levels in three model groups (all $P<0.05$, Figure 7C). In the model 1 and 2 groups, the Glu values tended to elevate and that was declined in the model 3 group. At 10 min after CPR, the Glu values were significantly higher than the normal levels in the model 1 and 2 groups, and that was evidently lower compared with the normal level in the model 3 group (all $P<0.05$, Figure 7D).

Discussion

In this experimental protocol, three animal models of cardiac arrest were established by intravenous injection of ketamine (model 1), $MgSO_4$ (model 2) and KCl (model 3), respectively. After the establishment of three animal models, routine blood test parameters were quantitatively measured and statistically compared among three models. The detection outcomes demonstrated that the model 3, which was established by intravenous administration of KCl was the optimal pig model for subsequent CPR experiment.

The variations of passive chest wall recoil and subsequent intra-thoracic pressure decide the blood return to the lungs and heart in standard CPR. Closed chest standard CPR without vasopressors cannot maintain minimal levels of vital organ blood flow required for life sustain(5–8). The results from this study demonstrate that intermittent airway occlusion with self-designed inspiratory impedance threshold device during the decompression phase in CPR enhanced the blood return to the heart and lungs and significantly enhance the blood return to vital organs. The application of the self-designed inspiratory impedance threshold device enhanced the efficiency of standard CPR, increased the cerebral blood flow and elevated the myocardial perfusion.

In this investigation, the hemodynamic parameters significantly differed among different groups, suggesting that application of the self-designed device can improve the efficiency of conventional CPR in pig models. By preventing the inspiratory gas exchange in standard CPR, an increased negative intrathoracic pressure was induced throughout the decompression phase of conventional CPR.

Both hemodynamic parameters and blood flow data have validated the fundamental significance of increasing the blood return into the chest in conventional CPR. Although increasing cardiac arrest times can enhance the resistance to sufficient reflow to the vital organs(9), the use of the self-designed impedance valve can maintain relatively high SBP, DBP and MAP during the standard CPR in pig models, whereas the HR did not significantly differ between the control and model groups even with the application of the self-designed impedance valve, which is consistent with previous studies which compared the efficiency of conventional CPR with and without an impedance valve(10–13). With active decompression and use of the self-designed impedance valve, the left ventricular and brain blood flow can be approximately 55% and 125% of baseline levels(14). Previous clinical trials have demonstrated that for patients undergoing CPR, the mean blood pressure was 110/56 when CPR was performed with the impedance valve, which is significantly higher compared with 90/35 in patients receiving CPR without the application of the impedance valve(15).

The hemodynamic effect of the self-designed impedance valve during standard CPR is probably correlated with the arrest time, fluid status, endogenous hormone level, ventricular wall compliance and CPR duration, *etc.* Throughout conventional CPR, the compliance of the chest wall and the respiratory system significantly declines(16). The effect of the impedance valve is determined by multiple influencing factors during standard CPR, which could possibly explain why the impedance valve exerted a more significant effect when the cardiac arrest time was prolonged from 2 to 10 min. A previous study has proven that the effect of the impedance valve was significant with a shorter arrest time, but the effect was less than those with longer arrest time(17). Earlier reports have identified that use of the self-designed impedance valve in the respiratory system prevented the ventilation by occluding the airflow during chest compression, leading to higher-than-normal arterial carbon dioxide values in the model groups(18). Besides, the blood gas parameters also supported the efficiency of the self-designed impedance valve in the model 3 group. At 10-min CPR, the SPO₂, PCO₂, HCO₃ and BUN levels, as well as Beecf value were almost restored within normal range in the model 3 group. In addition, the WBC, HGB, Hct and Glu levels were significantly lower than the normal values.

Conclusions

In this experiment, the pig models of cardiac arrest were established by three techniques and the comparative results demonstrated that the pig model established by intravenous injection of KCl was the optimal and ideal model for subsequent research. Besides, the supplementary use of the self-made impedance valve could significantly improve the blood return to the heart and lungs and evidently increase the cardiac output in the porcine models.

Abbreviations

CPR: cardiopulmonary resuscitation

IPPV: intermittent positive pressure mechanical ventilation

ETPCO₂: end-expiratory carbon dioxide partial pressure

TEE: Trans-Esophageal Echocardiogram

HR: heart rate

MAP: mean arterial blood pressure

SpO₂: pulse blood oxygen saturation

EDV: end diastolic volume

CO: cardiac output

SP: systolic blood pressure

DP: diastolic blood pressure

SV: stroke volume

BUN: blood urea nitrogen

WBC: white blood cell

RBC: red blood cell

HGB: hemoglobin

Hct: hematocrit

Declarations

Ethics approval and consent to participate

This study involved the use of animals and was approved by the Ethics Committee of Kunming Children's Hospital.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

CL constructed the self-designed inspiratory impedance threshold device and animal models, and are main contributor in writing the manuscript; HFG, XLH and YZ participated in the animal experiments, JQM, LH and MZ contributed in the data collection and results analysis; LMC, JLW and WKD contributed to results analysis and figure plotting; LL provided ideas and suggestions to the study. All authors read and approved the final.

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Not applicable.

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Figures

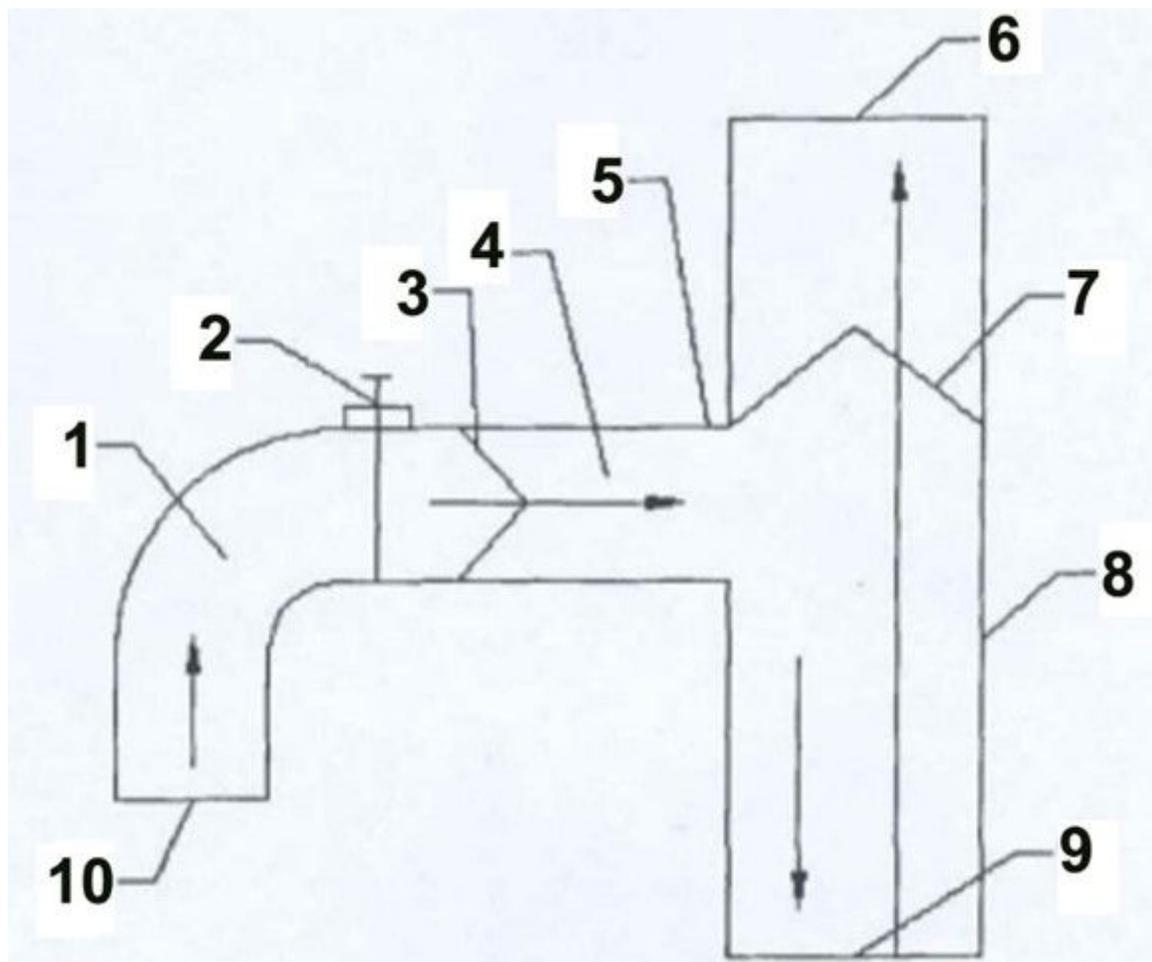


Figure 1

Structure of the self-designed inspiratory impedance threshold device. 1. Bent pipe; 2. Control valve; 3. First one-way valve; 4. Cavity; 5. Oxygen supply pipe; 6. Evacuation end; 7. Second one-way valve; 8. Straight pipe; 9. Vertical lower port; 10. Vertical port.

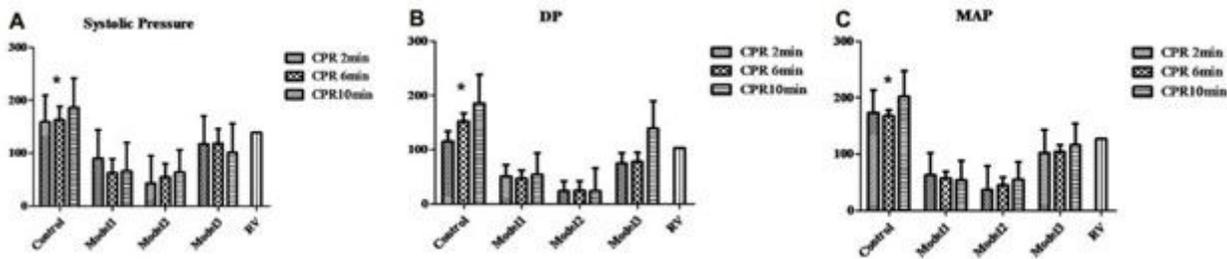


Figure 2

Comparison of hemodynamic parameters. A. SP was persistently elevated in the model 2 group ($P < 0.05$). At 2-, 6- and 10-min after CPR, the SP in the control group was significantly higher compared with those in the three model groups (all $P < 0.05$); B. DP in the control and model 3 groups was continuously increased ($P < 0.05$), whereas no significant changes were noted in the model 1 and 2 groups (both $P > 0.05$). DP in the control group was significantly higher than those in the three model groups (all $P < 0.05$) at each time point following CPR; C. MAP in the model 2 and 3 groups tended to elevate, whereas that in the model 1 group tended to decline. At 2-, 6- and 10-min after CPR, the MAP in the control group was significantly higher than those in the three model groups (all $P < 0.05$).

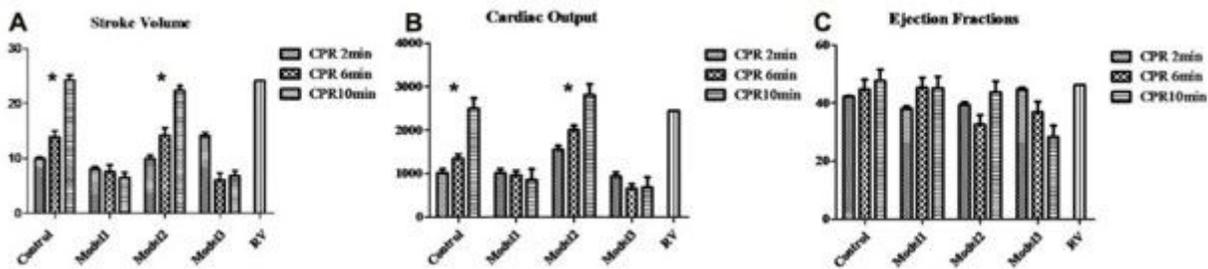


Figure 3

Comparison of esophageal ultrasound parameters. A. SV in the control and model 2 groups were significantly increased (both $P < 0.05$), whereas no statistical significance was noted in the model 1 group ($P > 0.05$). SV tended to decline in the model 1 and 3 groups; B. At each time point, CO was significantly increased in the control and model 2 groups (both $P < 0.05$), whereas no statistical significance was observed in the model 1 and 3 groups ($P > 0.05$). CO in the model 1 and 3 groups tended to decline; C. Ejection fraction in the control and model 1 groups tended to significantly increase (both $P < 0.05$). The ejection fraction in the model 3 group tended to decline, and that was declined and then elevated in the model 2 group.

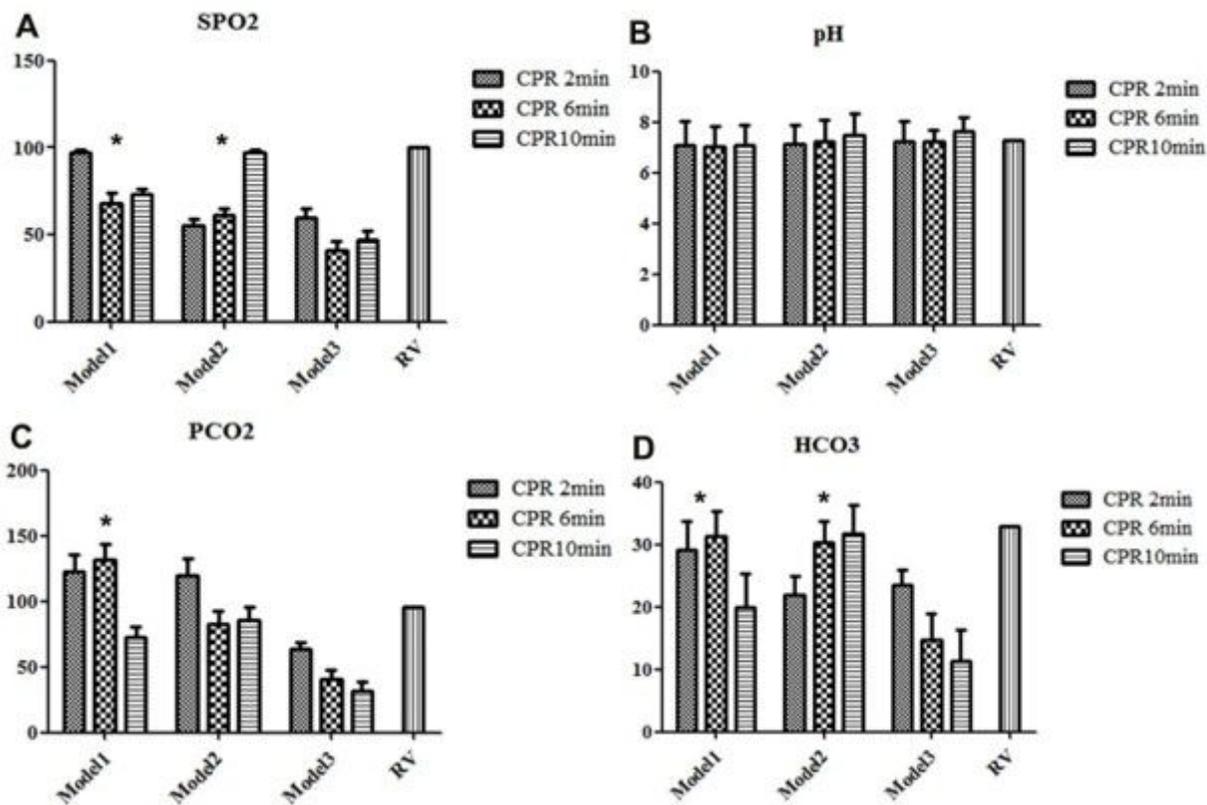


Figure 4

Comparison of SPO₂, pH, PCO₂ and HCO₃ among different groups. A. In the model 1 and 3 groups, SPO₂ tended to decline, whereas that was increased in the model 2 group. SPO₂ was restored to the normal value at 10 min after CPR in the model 2 and 3 groups; B. In three model groups, the pH values were significantly increased at each time point. At 10 min following CPR, the pH value was almost restored to normal in the model 2 group, whereas the pH at 10 min-CPR was significantly higher than the normal value in the model 3 group; C. In three model groups, the PCO₂ values were significantly declined at each time point after CPR. At 10 min after CPR, the PCO₂ was restored to normal in model 2 group, significantly higher than the normal value ($P < 0.05$) in the model 1 group, and considerably lower compared with the normal level in the model 3 group ($P < 0.05$); D. In the model 1 group, the HCO₃ level was increased and subsequently decreased at each time point. In the model 2 group, the HCO₃ level was persistently increased, whereas that was continuously declined in the model 3 group. At 10 min after CPR, the HCO₃ levels were almost restored to normal in the model 1 and 2 groups.

Beef

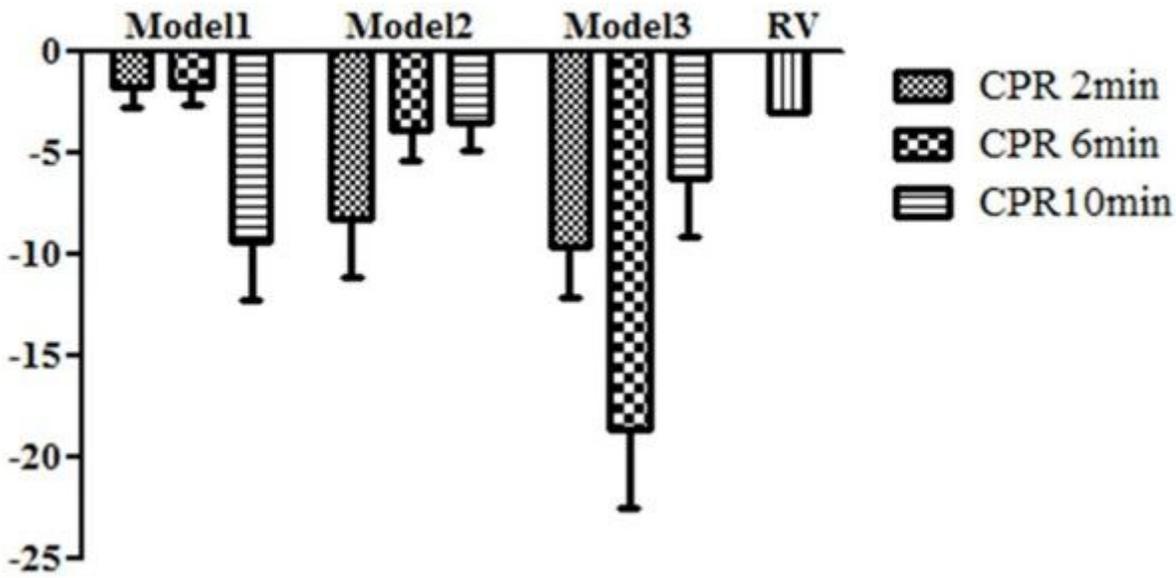


Figure 5

Comparison of Beef values among different groups. Identical variations were noted in terms of Beef in three model groups.

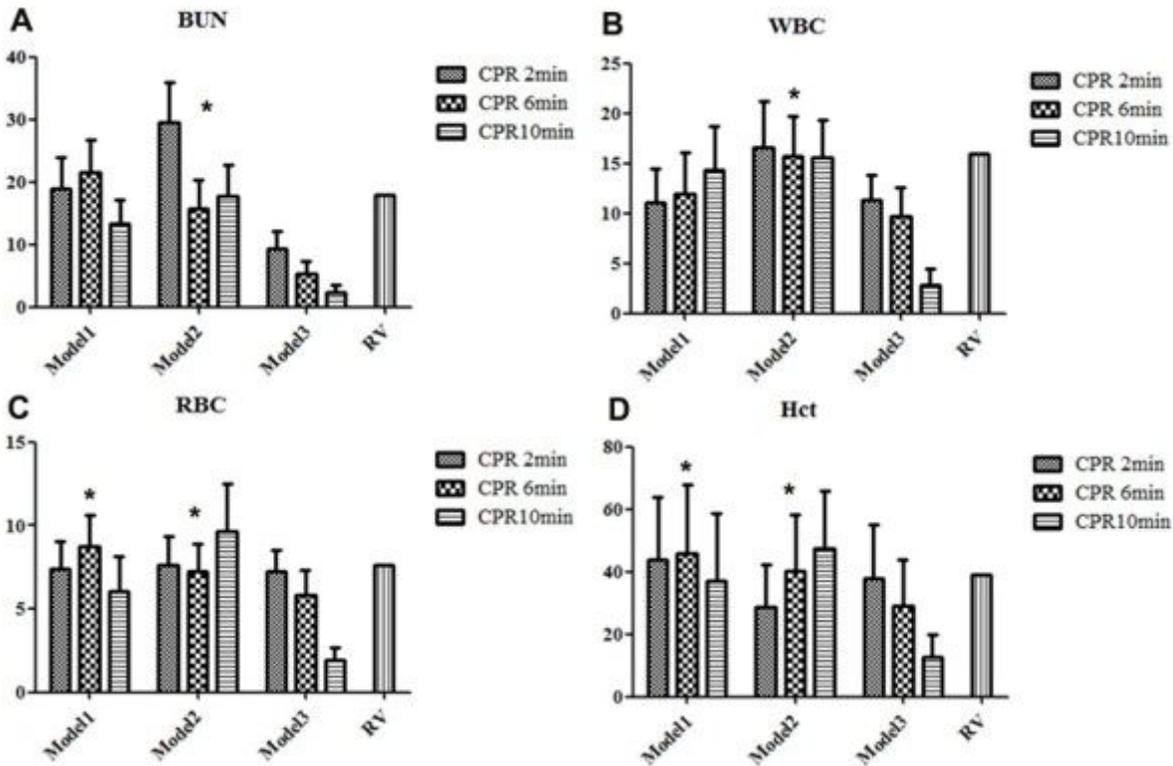


Figure 6

Comparison of BUN, WBC, RBC and Hct among different groups. A. In the model 1 group, BUN level was enhanced and then decreased at each time point. In the model 2 group, the BUN level tended to decline and subsequently elevate, whereas that was continuously declined in the model 3 group. At 10 min after CPR, the BUN levels were almost restored to normal in the model 1 and 3 groups; B. At each time point, WBC count was increased in the model 1 group, the WBC did not significantly change in the model 2 group ($P>0.05$), and that tended to decline in the model 3 group. At 10 min-CPR, the WBC was considerably lower than the normal value in the model 3 group ($P<0.05$); C. In the model 1 group, RBC count was increased and then decreased, that was decreased and subsequently increased in the model 2 group and that tended to decline in the model 3 group. In the model 3 group, the RBC was significantly lower than the normal at 10 min after CPR ($P<0.05$); D. In the model 1 and 3 groups, Hct tended to decline and that was elevated in the model 2 group. At 10 min after CPR, the Hct was significantly lower than the normal value in the model 3 group ($P<0.05$).

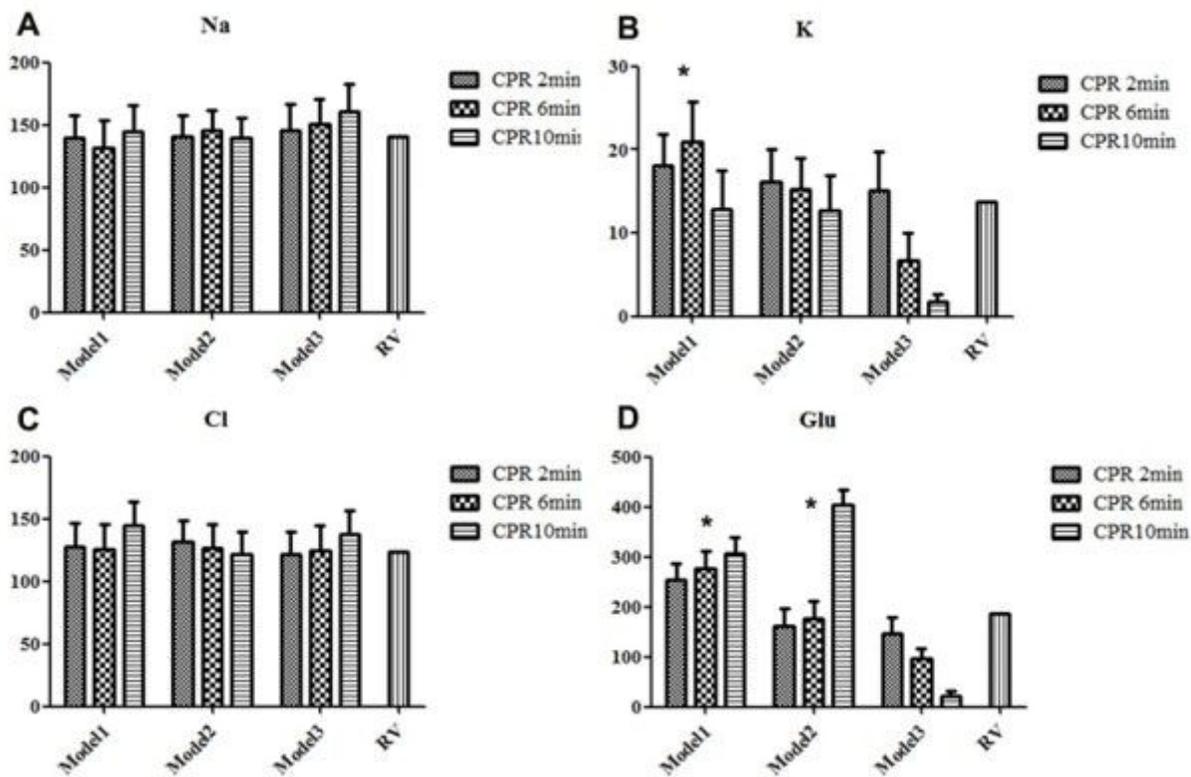


Figure 7

Comparison of Na, K, Cl and Glu among different groups. A. In the model 1 group, the Na level was initially declined and then increased at each time point, that was elevated and then decreased in the model 2 group, and that was increased in the model 3 group. The Na values were restored to normal at each time point after CPR in three model groups; B. In the model 1 group, the K level was initially increased and then decreased at each time point, and that was declined in the model 2 and 3 groups; C. In the model 1 group, the Cl level was initially decreased and then increased at each time point and that was decreased in the model 2 group, whereas persistently increased in the model 3 group. At each time point after CPR, the Cl levels were significantly higher compared with the normal levels in three model groups

(all $P < 0.05$); D. In the model 1 and 2 groups, the Glu values tended to elevate and that was declined in the model 3 group. At 10 min after CPR, the Glu values were significantly higher than the normal levels in the model 1 and 2 groups, and that was evidently lower compared with the normal level in the model 3 group (all $P < 0.05$).

Supplementary Files

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- [supplement1.pdf](#)