Original Article

Defibrillation and Resuscitation in a Piglet Model of Pediatric Ventricular Fibrillation following AHA 2005 Guidelines

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ABSTRACT

Objective. To evaluate the efficacy and safety of defibrillation on children according to AHA 2005 recommendations

Methods. Pig resembles human in the chest configuration, anatomy and physiology of the cardiovascular and pulmonary systems. Piglets weighing 7.0 Kg ± 1.4kg, 14.0kg ± 2.8kg, 25.0kg ± 5.0kg respectively, which represented children 1 to 8 yr old were induced ventricular fibrillation (VF). An adult biphasic AED was used in conjunction with pediatric attenuating electrodes which could deliver 50-J shock for 2 min and two min of cardiopulmonary resuscitation (CPR) immediately followed it. If VF did not reverse, 70-J shock combined with CPR was used, and the protocol was repeated five times. If an organized cardiac rhythm with mean aortic pressure more than 60 mmHg persisted for an interval of 5 minutes, the animal was regarded as successfully resuscitated. If the AED recognized a "non-shockable" rhythm, CPR was also performed immediately for 2 min. The same resuscitation program was exercised on piglets of manual defibrillator group. Neurologic alertness score, hemodynamic and myocardial functions were evaluated, autopsy was routinely performed to document possible injuries.

Results. In the AED group, 14 out of 15 animals, were successfully resuscitated, among them 11 piglets were resuscitated by 50-J defibrillation combined with cardiopulmonary resuscitation, and other three recovered to normal by 1 or 2 times of 70-J shocks and CPR. All animals in manual defibrillator group were successfully resuscitated by 50-J shocks and CPR. Left ventricular ejection fraction and fractional area change were reduced significantly during 3-4 hr post-resuscitation ($P<0.05$) and returned to baseline ranges at the end of 72 hr. There was no evidence of myocardial and pulmonary damage during autopsy, and neurologic recovery was also normal. Data of blood gas analysis, blood electrolytes and myocardial enzymes does not show any statistically significant difference ($P> 0.05$) in the groups. 50 J biphasic dose defibrillation combined with effective CPR, successfully terminated VF without adverse effects on myocardial function and survival in a piglet defibrillation model for young children 1 to 8 yr of age.

Conclusions. The new guidelines recommendation that one shock immediately followed by CPR is reasonable. Adults AED combined with pediatric electrodes is feasible to the diagnosis and treatment of pediatric VF model. But the user should not rely too much on AED's "automatic" function, but should accumulate and integrate his experience with AED technology. **[Indian J Pediatr 2010; 77 (8) : 893-897]** *E-mail: zacharyzhou@sohu.com*

Key words: *Cardiopulmonary resuscitation; AED; Defibrillator*

Cardiac arrest and ventricular fibrillation in children are not as uncommon as previously reported. Out-of-hospital cardiac arrests occur in 8-20 children about 100,000/year, and in-hospital arrests occur in 2-6% children admitted to a pediatric intensive care unit. Most pediatric arrests are precipitated by asphyxia or circulatory shock, but approximately 10% are precipitated by ventricular tachycardia or fibrillation.[1,2] The use of automated external defibrillators (AED) has been advocated as one part of the chain of survival to improve outcomes for adult cardiac arrest victim. However, till date the optimal biphasic defibrillation dose for children, especially for those younger than 8 yr is still unknown.[3,4,5] In 2005, International Liaison Committee on Resuscitation (ILCOR) and American Heart Association (AHA) instituted the latest and most authoritative guidelines for cardiopulmonary resuscitation and emergency cardiovascular care science, which is regarded as "scientific consensus".[6] Considering the paucity of clinical and experimental data on pediatric defibrillation,

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and pig resembles human in the chest configuration, anatomy and physiology of the cardiovascular and pulmonary systems, the piglet model is used to evaluate the efficacy and safety of defibrillation according to AHA 2005 recommendations.

MATERIAL AND METHODS

The protocol for this study was approved by the Administration Committee of Laboratory Animal, and the experimental procedure was in line with the Principles of Laboratory Animal Care.

Animals

A total of 30 male piglets were prepared and randomly divided into AED and manual defibrillator groups. Each group included five piglets weighing 7.0 Kg ± 1.4kg, 14.0kg ± 2.8kg, 25.0kg ± 5.0kg respectively, which represented children 1 to 8 yr old. All animals were fasted 12 hours before experiment, and were provided free access to water four hours before experiment.

Experimental procedures: Each piglet was pre-anesthetized with 20 mg/kg ketamine intramuscular injection, followed by sodium pentobarbital 20 mg/kg intravenously. Additional 5mg/kg pentobarbital was administered intravenously through ear vein to maintain anesthesia. After tracheal intubation, animals were mechanically ventilated with a volume-controlled ventilator (SCH-300, Shanghai Medical Instruments Corporation). A fluid-filled catheter was advanced from the left femoral artery to the descending aorta, to continuously monitor aortic pressure during the procedure. To measure the right atria pressure, a catheter was advanced through the right jugular vein. In order to induce VF, a 3-Fr pacing catheter was advanced from the right jugular vein into the right ventricle until a specific electrocardiogram was recorded. An AC current, continuing 1-2 sec, was progressively increased from 5 to 20 mA until EF was confirmed by ECG and aortic mean pressure to less than 10 mmHg. The ventilator was discontinued during the end exhalation period after VF was confirmed, and the respiratory, frequency was adjusted into 24 times per min, which was in line with CPR.

The pediatric electrodes (9730 Cardiac Science Corporation, USA) incorporated circuitry, to attenuate the defibrillation energy, were used in AED group. Right electrode was put in right infraclavicular region and the left was in cardiac apex. After 2 min of untreated VF, AED (9200, Cardiac Science Corporation, USA) was used in conjunction with pediatric attenuating electrodes which could deliver a nominal energy level of 50-J shock, followed immediately by two min of cardiopulmonary resuscitation (CPR). If VF did not reverse, 70-J shock combined with CPR was used and repeated five times. If an organized cardiac rhythm with mean aortic pressure more than 60 mmHg persisted for an interval of 5 minutes, the animal was regarded as successfully resuscitated. If the AED recognized a "non-shockable" rhythm, CPR was also performed immediately for 2 min. The precardia compression force was adjusted to decrease one-third or half of the anteroposterior diameter of the chest, at the same time the electrocardiogram and the pressure wave of main artery were observed. The frequency of precardial compression was 100 times per min mechanically ventilations were provided twice with 30 compressions each and were repeated 5 times. The protocol for manual defibrillator group was identical to AED group except for two modifications, namely the electrodes and the defibrillator (TEC-7731C, Nihon Kohden Corporation Japan). Pediatric self-adhesive electrodes (H316 Nihon Kohden Corporation, Japan) and defibrillator (TEC-7731C, Nihon Kohden Corporation Japan) were used in the experiments.

Measurements

At the beginning of the experiment and 5 min, 1hr, 2hr, 3hr, 4hr, 72hr after the successful resuscitation, echocardiography (SONOS5500, Philips) were performed to evaluate myocardial function. Two- or four-chamber windows were used for echocardiographic measurements. The heart rate (HR), left ventricular end-systolic area (LVE SA), left ventricular end-diastolic area (LVEDA), left ventricular end-systolic volume (LVESV), end-diastolic volume (LVEDV) ejection fraction (EF), and left ventricular fractional area of change (LVFAC) were computed according to Simpson2 s formula (EF= (LVEDV-LVESV)/ LVEDV, FAC=(LVEDA-LVESA)/ LVEDA); all data was the average of three cardiac cycles.

Within 4 hr after successful resuscitation, arterial blood were collected for blood gas analysis (pH, PaO_2, $PaCO_2$, HCO_3, BE), and venous blood for electrolytes (K^+, Na^+, CL^-). Myocardial enzymes Lactate dehydrogenase (LDH), Aspartate aminotransferase (AST) were determined at hourly interval. Vital signs were continuously monitored for a period of 72 hrs. A quantitative neurologic score was used to evaluate neurologic recovery every 24 hrs. Appearance was scored from 0 (normal) to 400 (neurologic defect), based on objective grading of level of consciousness, posture, respiration, food and water intake and excretion. Mercy killing of the piglets was done at 72 hrs after resuscitation by intravenous injection of 150 mg/kg pentobarbital. Anatomy was then performed to document possible injuries to the thorax, heart and lung.

Statistical analysis : Statistical analysis was performed by means of version11.5 of the SPSS software statistical program. Results are presented as the mean ± standard deviation. t test was used to compare quantitative variables between independent groups. $P < 0.05$ was considered to be statistically significant.

RESULTS

The electrocardiogram of all piglets were normal before the experiment, and all of them were successfully induced ventricular fibrillation. After defibrillation, ST segment of some piglets had variation (depression or elevation), but recovered within a few min (Figs. 1-5).

Fig. 1. Normal ECG (lead II) of piglets.

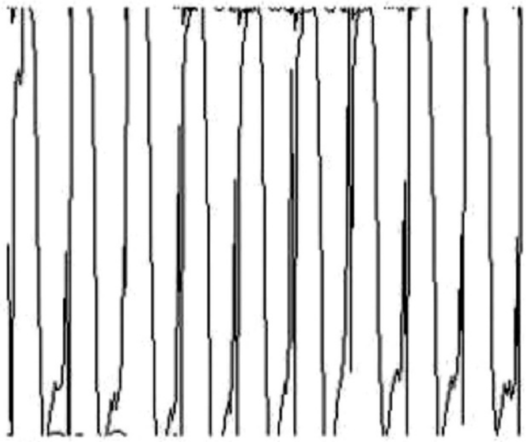

Fig. 2. ECG of the electrode at the right ventricle (precordial lead).

14 of 15 animals in AED group were successfully resuscitated. Among them 11 piglets were resuscitated by 50-J defibrillation combined with cardiopulmonary resuscitation, and rest three recovered to normal by 1 or 2 times of 70-J shocks and CPR (Table 1). All animal in manual defibrillator group were successfully resuscitated by 50-J shocks and CPR (Table 2). Among 14 resuscitation piglets of AED group, two piglets died of asphyxiation at 6 hr after defibrillation and one piglet died of pulmonary hemorrhage at 2 hr and the rest 11 piglets could survive for 72 hrs. All animals of manual defibrillator group were successfully resuscitated and survived for 72 hrs. There was no evidence of myocardial and pulmonary damage during autopsy, and neurologic recovery was normal.

There were no significant difference of the heart rate, cardiac output, stroke volume before ventricular fibrillation and after successful resuscitation, in both AED

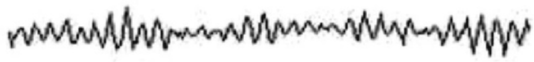

Fig. 3. ECG of ventricular fibrillation (lelad II).

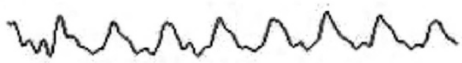

Fig. 4. Normal arterial pressure waveform.

Fig. 5. Arterial pressure of ventricular fibrillation.

Table 1. Outcome of Resuscitation in AED Group

	No. of successful resuscitated piglets		
Dose and frequency of defibrillation	7.0 kg±1.4 kg	14.0kg ± 2.8 kg	25.0 kg ± 5.0 kg
50J-CPR	5	5	1
50 J-CPR-70J-CPR			
Once			2
Twice			1
Successful resuscitation	5	5	4
Survival at 72 h after resuscitation	5	2	4

Table 2. Outcome of Resuscitation in Manual Defibrillator Group

	No. of successful resuscitated piglets		
Dose and frequency of defibrillation	7.0 kg ± 1.4 kg	14.0kg ± 2.8 kg	25.0 kg ± 5.0 kg
50J-CPR	5	5	5
50 J-CPR-70J-CPR			
Once			
Twice			
Successful resuscitation	5	5	5
Survival at 72 h after resuscitation	5	5	5

and manual defibrillator group. Left ventricular ejection fraction and fractional area change were reduced significantly during 3-4 hrs post-resuscitation ($P < 0.05$) and returned to normal range at the end of 72 hrs (Fig. 6-9). All the data of blood gases analysis, blood electrolytes and myocardial enzymes show that there is no statistically significant difference ($P > 0.05$) in both groups.

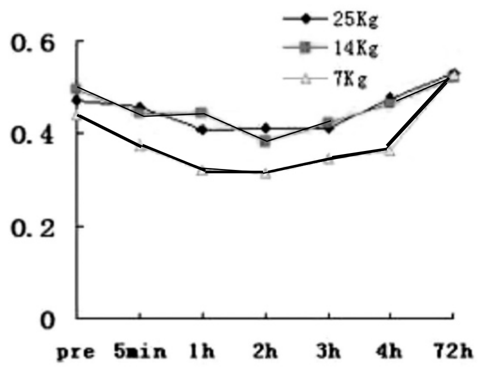

Fig. 6. Left ventricular fractional area of change of manual defibrillation group.

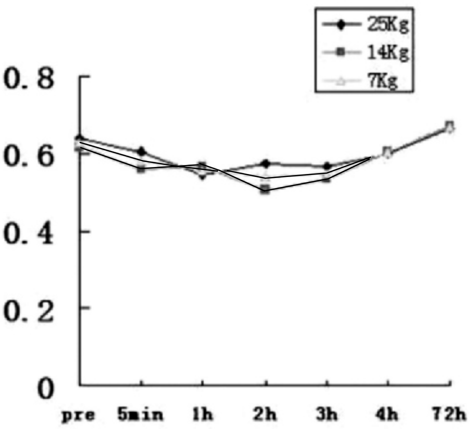

Fig. 7. Ejection fraction of manual defibrillation group.

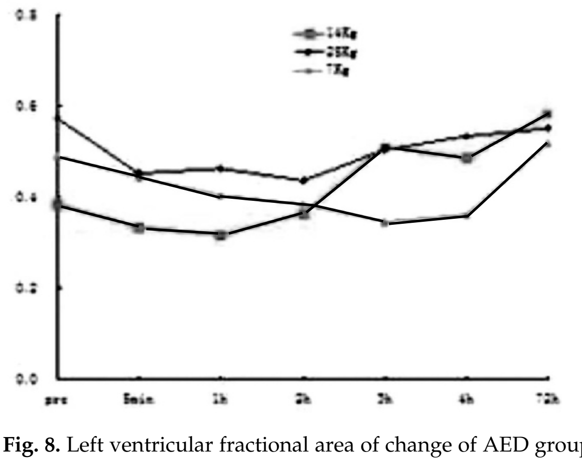

Fig. 8. Left ventricular fractional area of change of AED group.

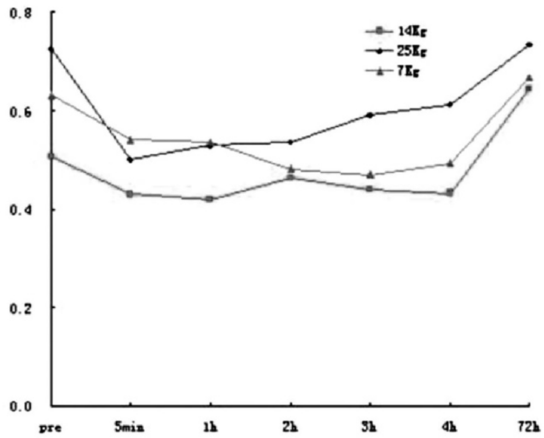

Fig. 9. Ejection fraction of AED group.

DISCUSSION

The interval time between the onset of VF and the first defibrillation play a important role to decide whether a VF victim can be successfully resuscitated or not. Early defibrillation has been shown to be the most effective treatment. It was estimated that the survival rate will decrease by approximately 7-10 percent with each min of delay of defibrillation.[4] The use of AED by emergency medical system (EMS) personnel and nonmedical lay people represents a significant breakthrough to decrease the time to defibrillation.[7] Laboratory animals were divided into the AED and manual defibrillator groups with uniform experimental conditions. The experiments show that the defibrillation effect of manual defibrillator group were better than AED's. In AED group, one piglet failed to resuscitate because the AED constantly recognized a "non-shockable" rhythm after performing CPR 5 times. One piglet died of pulmonary hemorrhage because AED could not accurately determine when to release a shock. The study suggested that the user should not rely too much on AED's "automatic" function, but should accumulate and integrate his experience with AED technology. Some scholars had the same opinion and emphasized that better understanding about AED and its context of use may challenge established practice.[8]

The energy delivered by defibrillator should convert the correct rhythm to perfusing rhythm without causing myocardial damage. The ideal energy dose for safe and effective defibrillation for children is unknown. Current pediatric protocols and AHA 2005 guidelines recommend energy doses of 2 to 4 J/kg for defibrillation of children.[6] A variable dose manual defibrillator or an AED which is able to recognize pediatric shockable rhythms and equipped with dose attenuation, are preferred. The new guidelines emphasized the importance of early defibrillation combined with CPR.[6] CPR would convey certain amount of blood and nutrition for the brain and heart, thus increasing the survival of VF victims significantly. The protocol for this study was made in accordence with AHA 2005 guidelines. Piglets weighing 7 to 25 kg represented children aged 1 to 8 yr and 50 J or 70 J biphasic dose were delivered through a pediatric pad/ cable system immediately followed with CPR. The experiments demonstrated that all piglets of manual group were successfully resuscitated with one shock of 50 J energy combined with CPR. It means the new guidelines recommendation that one shock followed immediately by CPR was reasonable. Despite the difference in body weight, the 50 J shock resulted in no detectable difference in post-resuscitation cardiovascular function, indicating that weight-based dosing may be of limited value in pediatric defibrillation.[9,10]

Thus, effective methods to treat VF should be used as early as possible to improve the survival for younger children and the use of AED in children had received more and more attentions.[11, 12] There is a need to develop strategies to provide early defibrillation for them. The present study suggested that adult AED combined with pediatric electrodes is feasible to the diagnosis and treatment of pediatric VF model.

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