Review Article
Cardiopulmonary resuscitation—From the past into the future
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Abstract

Since the first cardiopulmonary resuscitation (CPR) guidelines were published in 1966, periodic updates of the guidelines have been made by individual organizations all over the world. However, several important components of CPR have been determined with a lack of scientific basis. Proper hand placement on the sternum for chest compression, compression depth, and compression rate to produce optimal hemodynamic effect have yet to be investigated. Clinical trials have failed to demonstrate a survival benefit of the vasoactive drugs administered for resuscitation. Therefore, additional investigations to determine the most effective CPR method are necessary to overcome current CPR controversies. Moreover, global concern and the implementation of a plan for improving survival in communities with low survival rates as well as the introduction of internet or ubiquitous technology to resuscitation medicine can be effective strategies for improving the survival rate of cardiac arrest.

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1. Introduction

Sudden cardiac death is an important public health problem around the world. Cardiopulmonary resuscitation (CPR) began with struggles to reverse clinical death. The goal of modern CPR is to provide emergency ventilation and perfusion to the cardiac arrest victim, and this technique was established in the late 1950s and early 1960s.2,3 Despite every effort to resuscitate cardiac arrest victims, the overall survival rate of victims of out-of-hospital cardiac arrest ranges from 0.8% to 31% worldwide.3,4

Since the first CPR guidelines were published by the American Academy of Science in 1966,5 the scope and field of CPR have expanded to include various areas along with the advancement of resuscitation medicine and related technologies (Fig. 1). The introduction of automated external defibrillators made prehospital defibrillation possible. Newer CPR methods using various devices or extracorporeal circulatory support have been developed and introduced in clinical practice. The latest update of CPR guidelines in 2010 recommended comprehensive care to victims with cardiac arrest from the scene of the arrest to the hospital, which includes the immediate recognition of sudden cardiac death and activation of the emergency response system, early performance of high-quality CPR, rapid defibrillation, effective advanced life support, and integrated postcardiac arrest care.5 Despite recent advances in resuscitation science, some controversial issues regarding CPR must be reviewed in order to make further progress in the future.

2. Lessons learned from past and unsolved issues

2.1. A long-stalled process in changing the guidelines

During the past five decades, only a few minor changes have been made in the CPR technique to provide artificial ventilation and circulation (Table 1).5,7–12 It took more than 40 years to change the compression depth from 4–5 cm to at least 5 cm and the compression rate from 60 compressions/
min to 100 compressions/min. The 2010 International Liaison Committee on Resuscitation guidelines introduced the change in the CPR sequence from ABC to CAB, which is a new significant development that took almost 50 years to be implemented.

2.2. Chest compression and ventilation: a need for reappraisal

Although chest compression has been used as a method of artificial circulation for the past five decades, it is not an effective method to produce blood flow in a state of cardiac arrest. Blood flow generated by chest compression during CPR is about only one-third of the normal cardiac output, which is insufficient for maintaining tissue perfusion. Many of the important determinants of CPR have not been determined by clear evidence. The important determinants for artificial circulation including optimal positioning, depth, and rate for chest compression were not determined by studies on human beings. The compression–ventilation (CV) ratio of 30:2 was decided by expert consensus, not based on scientific evidence.

2.2.1. Optimal hand position for chest compression

Interestingly, the optimal hand position for chest compression during CPR is unknown. Chest computed tomography analysis showed that the intrathoracic structure just underneath the internipple line is the ascending aorta, the root of aorta, or the left ventricular outflow tract in 80% of the patients rather than the left ventricle itself. Only a small portion of the ventricle is subjected to chest compression when CPR is performed according to the current guidelines. Transesophageal observation of the heart during CPR revealed that the outflow of the left ventricle is compressed during standard CPR, resulting in varying degrees of narrowing in the left ventricular outflow tract or the aortic root. In a small clinical study, compressing the lower end of the sternum as an alternate method generated higher arterial pressure than standard CPR procedures in 15 of 17 cardiac arrest patients, with an average increase of peak arterial pressure of 20 mmHg. For more efficient and effective chest compression during CPR, compressing the sternum more caudally than the internipple line should be considered.

2.2.2. Optimal compression rate

The optimal compression rate during CPR must be investigated. In an earlier study using animals, arterial pressure and coronary perfusion pressure were dependent on the compression rate. A compression rate of 120/minute resulted in higher systolic, diastolic, and coronary perfusion pressures compared to 60/minute. In a retrospective analysis of 3098 patients with out-of-hospital cardiac arrest, restoration of spontaneous circulation (ROSC) rates peaked at a compression rate of about 125/minute and then declined even though the chest compression rate was not significantly associated with survival to hospital discharge. Current guidelines recommend a compression rate of at least 100/minute. However, hard evidence for the recommendation regarding the compression rate is insufficient. A prospective randomized controlled study is necessary to investigate the optimal compression rate for survival.

2.2.3. Optimal CV ratio

The optimal CV ratio remains unknown. The CV ratio of 30:2 was determined in 2005 on the basis of expert consensus

Table 1

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Compression position</td>
<td>Lower half of the sternum</td>
<td>Lower half of the sternum</td>
<td>Lower half of the sternum</td>
<td>Lower half of the sternum</td>
<td>Center of the chest</td>
</tr>
<tr>
<td>Compression depth (cm)</td>
<td>4–5</td>
<td>4–5</td>
<td>4–5</td>
<td>4–5</td>
<td>≥5</td>
</tr>
<tr>
<td>Compression rate (1/min)</td>
<td>60</td>
<td>80–100</td>
<td>~100</td>
<td>~100</td>
<td>≥100</td>
</tr>
<tr>
<td>Compression/ventilation ratio</td>
<td>15:2 for one rescuer</td>
<td>15:2 for one rescuer</td>
<td>15:2 for one rescuer or two rescuers</td>
<td>30:2 for one or two rescuers</td>
<td>30:2 for one or two rescuers</td>
</tr>
<tr>
<td>Ventilatory volume (mL)</td>
<td>About twice the amount the patient normally breathes</td>
<td>800–1200</td>
<td>700–1000</td>
<td>500–600</td>
<td>~600</td>
</tr>
<tr>
<td>Ventilation rate (breaths/min)</td>
<td>Approximately 12</td>
<td>10–12</td>
<td>10–12</td>
<td>8–10</td>
<td>8–10</td>
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and a simulation study, not on the basis of scientific evidence. Animal studies for testing various CV ratios demonstrated no consistent findings for the optimal CV ratio. To date, there has been no randomized controlled study to investigate an optimal CV ratio. An analysis of changes in out-of-hospital cardiac arrest survival prior to and after the release of the 2005 guidelines for CPR and emergency cardiac care showed an increasing trend of survival after the implementation of the CV ratio of 30:2 that was recommended in the 2005 guidelines compared to the previously recommended CV ratio of 15:2. However, most studies analyzed the impact of the new guidelines on survival, and not specifically the CV ratio. Therefore, the optimal CV ratio still remains to be determined.

2.3. Epinephrine use during CPR

The effectiveness of epinephrine use during CPR remains controversial. Epinephrine has been used during CPR with unsubstantiated evidence for the dosage and mode of administration. Although epinephrine increases the rate of ROSC, it is associated with worse survival or neurologic outcomes in cardiac arrest patients. The alpha-adrenergic effect of epinephrine raises coronary perfusion pressure by decreasing the blood flow to other organs, which leads to an increase in the rate of ROSC. The impairment of cerebral microvascular blood flow that occurs when epinephrine is used during CPR may account for the worse neurological outcome. Clinical evidence demonstrates the paradoxical effect of epinephrine on the effect of resuscitation outcome and raises questions about the use of epinephrine during CPR. Hagihara et al analyzed the data of 417,188 out-of-hospital cardiac arrest patients from 2005 through to 2008 in Japan. They found that the rate of ROSC prior to hospital arrival was higher in patients who received prehospital epinephrine than in those who did not receive it (18.3% vs. 10.5%), but that epinephrine decreased the chance of survival (5.1% vs. 7.0%) and good functional outcomes 1 month after the event (1.3% vs. 3.1%). A recent randomized double-blind placebo-controlled trial of epinephrine in 601 out-of-hospital cardiac arrest patients showed that patients receiving epinephrine had no significant improvement in the rate of hospital discharge (1.9% vs. 4.0%) even though the rate of ROSC was higher than that in the placebo group (8.4% vs. 23.5%). Therefore, the routine administration of epinephrine may cause a harmful effect on the resuscitation outcome. A rigorous investigation on the effectiveness of vasopressor drugs including epinephrine during CPR should be performed.

2.4. Therapeutic hypothermia

Therapeutic hypothermia has become one of the major treatment modalities of postcardiac arrest syndrome. Because therapeutic hypothermia demonstrates long-term survival benefits and has an influence on neurologic recovery, it is recommended for the treatment of unresponsive patients resuscitated from cardiac arrest based on the 2005 guidelines. However, there is no consensus about the optimal timing, duration, and temperature for therapeutic hypothermia.

2.4.1. Optimal temperature and duration of hypothermia

In early landmark studies, the protocol for hypothermia was applied differently. The Bernard group induced hypothermia with the core body temperature reduced to 33 °C within 2 hours after the return of spontaneous circulation and maintained at that temperature for 12 hours. The HACA group (Hypothermia after Cardiac Arrest Study) induced hypothermia within 3 hours after ROSC while maintaining the temperature between 32 °C and 34 °C for 24 hours from the beginning of cooling. The therapeutic effect of hypothermia using various temperatures and durations remains under investigation.

2.4.2. Timing of cooling

Early cooling has been suggested as the optimal timing of cooling. An animal study using cardiac arrest mice demonstrated that early cooling during the intra-arrest period is associated with a better survival rate than delayed post-ROSC cooling. However, two randomized controlled trials testing the beneficial effect of prehospital cooling after ROSC revealed no survival benefit over hospital cooling irrespective of the presenting rhythm during cardiac arrest. A recent investigation adds clinical evidence that the timing of initiation of therapeutic hypothermia has become obscure. The Italian Cooling Experience Study Group conducted an observational prospective clinical study that included cardiac arrest patients who had ROSC to evaluate the effect of timing of hypothermia initiation on resuscitation outcome. In their study, an early-initiation group received therapeutic hypothermia less than 2 hours after cardiac arrest and the late-initiation group received it after more than 2 hours. The mortality rate in the ICU at 1 month and 6 months were higher in the early-initiation group than in the late-initiation group. Considering the results from the clinical studies, the timing of therapeutic hypothermia should be determined.

3. Emerging modalities to enhance resuscitation outcome

Conventional CPR is approaching the limits that it can reach. To increase the survival rate of cardiac arrest, the introduction of new emerging modalities is necessary. The modification of the resuscitation protocol, combination of multiple therapeutic modalities, CPR assistance by extracorporeal support, and the creation of new CPR devices can be promising modalities to enhance resuscitation outcomes.

3.1. Modification of the protocol

Cardiocerebral resuscitation (CCR) is a typical model of protocol modification. CCR protocol includes 200 continuous chest compressions following rhythm analysis and shock, delaying of the advanced airway in the early resuscitation phase, and aggressive comprehensive postresuscitation care
including hypothermia and percutaneous coronary intervention. The application of CCR has resulted in good resuscitation outcomes. A Wisconsin study for comparing findings prior to and after the new protocol implementation showed an increase of VF survival, from 15% to 40%. A randomized controlled study in Arizona also showed that the survival rate was almost four times higher with CCR than with the conventional protocol. The Arizona trial is the best model of demonstrating that the modification of the protocol in the community can improve resuscitation outcomes.

3.2. Extracorporeal CPR

CPR assisted by extracorporeal bypass support is one promising modality for artificial circulation. Chen et al reported a 3-year prospective observational study on the use of extracorporeal life support for patients with witnessed in-hospital cardiac arrests undergoing extracorporeal CPR for more than 10 minutes compared with patients receiving conventional CPR. They concluded that extracorporeal CPR had short-term and long-term survival benefits over conventional CPR in patients with in-hospital cardiac arrests of cardiac origin irrespective of CPR duration. A meta-analysis of Japanese literature reported that the survival rate at discharge of out-of-hospital cardiac arrest patients who received extracorporeal CPR was 26.7%. Extracorporeal CPR is expected to contribute to the improvement of survival of out-of-hospital as well as in-hospital cardiac arrests along with technological advances in the extracorporeal bypass method.

3.3. CPR devices

Currently, there are several devices that perform or assist in CPR available in clinical practice or experimental settings. CPR devices can provide consistent CPR regardless of the rescuer’s ability to perform CPR as well as produce a higher hemodynamic effect than with conventional CPR. Load-distributing bands, automatic active compression-decompression devices, and impedance threshold valves have been tested on cardiac arrest patients. Although CPR devices have several limitations when used in clinical practice, they are strong candidates as replacements for conventional CPR, and more practical and efficient devices are being developed for use in the near future.

4. CPR in the future, strategies to improve survival

How can we make progress in resuscitating cardiac arrest victims in the future? The comprehensive approach to overcome the current dismal resuscitation outcomes and to improve the survival of cardiac arrest patients can be suggested as follows: (1) incessant investigation for solving the controversial issues and seeking out the most effective CPR method; (2) development of a community strategy that will most likely enhance survival from cardiac arrest including strengthening the Chain of Survival; (3) global concern and implementation of a plan for improving survival in communities with a low survival rate of cardiac arrest; and (4) the early application of advanced technologies from biotechnology, internet technology, and ubiquitous technology to resuscitation medicine (Fig. 2).

4.1. Investigation for solving controversial issues

Chest compression is not a perfect method of artificial circulation during CPR and must be revised as mentioned earlier. The most effective method of chest compression should be sought as early as possible because chest compression is currently being used widely for resuscitation. Rigorous investigation should be performed to solve current controversial issues and to develop an alternative method of CPR including the use of a mechanical device to enhance blood flow.

4.2. Community strategy

Survival rates vary from community to community even in a country. Each community must set and implement its own plan to improve the survival of cardiac arrest patients. Community concern and preparedness will facilitate establishing a plan for cardiac arrest survival. Community campaigns, public

Fig. 2. A comprehensive approach to improve the survival of cardiac arrest patients (see text). CPR = cardiopulmonary resuscitation; EMS = emergency medical system.
education, the application of an effective emergency medical system protocol, and the optimal utilization of resources are important components for a community plan. A good community plan such as the Save Hearts in the Arizona Registry and Education program improved the rates of survival to hospital discharge from 3.7% to 9.8% in 5 years.48

4.3. Global concern for countries with low survival rates

Most underdeveloped or developing countries have no CPR guidelines. The regional variation of parameters associated with resuscitation outcome is remarkably high. For example, bystander CPR rates range from 1.5% to 36% among Asian countries.3 Knowledge exchange and communication between countries and a global concern for the communities with low resuscitation outcomes will improve the resuscitation outcome around the world. Special concern should be paid to underdeveloped or developing countries that have low public awareness about sudden death.

4.4. Technological advances, prevention of cardiac arrest, and CPR

Prevention and early detection of cardiac arrest is possible through the detection of genes associated with sudden cardiac arrest and application of a surveillance system to detect pro-drome or terminal events of cardiac arrest. Predisposing factors including genetic mutations can be identified and used to prevent sudden cardiac arrest.49,50 Internet and ubiquitous sensor technologies can be used to monitor patients with high risk factors for sudden cardiac arrest at any time and any place, including at home. The all-in-one device that automatically performs CPR and defibrillation can also perform the diagnosis of cardiac arrest, automatically activate the emergency medical system, perform chest compressions, and execute automated defibrillation or emergency pacing. This type of device may replace the bystander’s role in the future (Fig. 3).

5. Concluding remarks

Once cardiac arrest develops, the chance for survival is very low even with the exertion of every effort including well-implemented prehospital and hospital management. Therefore, we need to focus on primary prevention for reducing death from sudden cardiac arrest. An improvement in risk stratification and investigations in genetic abnormalities responsible for the development of sudden cardiac arrest will make primary prevention possible in the future. We should continue performing investigations in order to resolve current controversies and to search for the most effective CPR method. The early application of advanced technologies from internet or ubiquitous technology will help make progress in resuscitation medicine. Finally, we must develop a community strategy that will most likely enhance survival from cardiac arrest and build a strategy to overcome regional variations in survival rates in the community and around the world.

References

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