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Cardiopulmonary Resuscitation: Recent Advances

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Abstract

Cardiac arrest is the most significant reason for mortality and morbidities worldwide. With a better understanding of the pathophysiology of cardiac arrest, simple adaptations in basic life support to upcoming modifications in post-resuscitation care have been proposed by various resuscitation councils throughout the globe. Role of point of care cardiac ultrasound during cardiopulmonary resuscitation (CPR) has been explored and its contribution for identifying reversible causes and its real time management has been explored. A higher blood and tissue oxygenation levels contributed to an increased rate of return of spontaneous circulation (ROSC) which has to lead us to explore more options to increase the oxygenation. Starting from the CPR training, the use of sensors for spirometric feedback in ventilation maneuvers can help improve the quality of CPR. High flow nasal oxygenation during CPR has shown promising results. Extracorporeal CPR is another entity that has shown survival benefits in a selected group of patients. The aim of the newer advances has always been to decrease the morbidity and improve survival outcomes in terms of neurological deficit as well. These guidelines are reviewed and updated regularly to improve knowledge and training based on the current evidence. This chapter shall focus on recent advances in cardiopulmonary resuscitation.

Keywords: airway management, arrhythmias, cardiac arrest, cardiopulmonary resuscitation, epinephrine, extracorporeal circulation, post-resuscitation care, recent advances

1. Introduction

The recent era of cardiopulmonary resuscitation (CPR) began in 1960 by Kouwenhoven et al. [1], when the first time closed-chest compressions were brought into the clinical scenario. It was found that rhythmic chest compression can help in restoring spontaneous circulation of defibrillating heart after cardiac arrest. It was found that this technique was able to give the success rate of as high as 70% in anesthesia-induced arrest in operation theater [1]. This non-invasive technique replaced the conventional open-chest compression technique.

Since the introduction of closed-chest compression technique, various research has been continuously conducted to find techniques and interventions for overall improvement of cardiac arrested patients after CPR. Various communities are working on innovative techniques to improve the outcome of CPR. Resuscitation councils have a common basic goal of improving circulation and improving the outcome of the victim. The common feature was the willingness to bundle different

tried and tested ideas together, applying them for treatment for cardiac arrest. This chapter focuses on ideas and the innovative techniques, analyze their efficacy, and bring forward the latest updates to improve the CPR outcome.

2. Basic life support

2.1 Bystander CPR

During an event of cardiac arrest, sooner the temporary circulation is reestablished via chest compression, better are the chances of survival with good neurological function [2]. Clinical studies have shown an increase in survival if the victim receives early resuscitation including defibrillation. The analysis showed a four times increase in chance of survival in victims who received an early bystander CPR [3], which can be achieved if the bystander starts CPR by the time the professional rescuer team arrives at the site. Hence, it is encouraged to promote this critical aspect in our basic cardiopulmonary life support management to cardiac arrest victims through public awareness campaigns. Surveys among medical and public groups have shown the declining rates of bystander CPR. The primary reason was the apprehension of contracting the contagious disease and causing harm during the process [4, 5].

Since 1990, a simpler version of “chest compression-only” CPR is being explored for bystanders. A new concept came into the picture: cardiocerebral resuscitation. It emphasizes that circulation is more important than ventilation during the early efforts of resuscitation. One survey showed that it is more acceptable among the common public [6]. It has been reported that “chest compression-only” CPR or compression-only life support (COLS) is a viable option for providing immediate resuscitation by bystanders with an improved overall outcome as compared to no CPR [7].

2.2 CPR (dispatcher-assisted)

Emergency medical dispatcher services are crucial links in emergency health services [8, 9]. They are the first responders of an emergency call. Their role involves identifying the emergency, guiding the bystander and simultaneously dispatching an emergency medical service (EMS). Internationally, various strategies have been explored to increase the rate of bystander CPR. One of such strategies is to enhance the role of the emergency medical dispatchers and comprises services like giving CPR instructions to assist bystanders: dispatcher-assisted CPR (DA-CPR). For this system to work effectively, there is a need for optimal training of the dispatchers for providing instructions to bystanders to deliver CPR. EMS system needs to be configured to support DA-CPR. This strategy can have a positive impact on point of care instructions. It increases the feasibility of bystander CPR and improves the outcome of cardiac arrest outside the hospital.

If we combine the above-mentioned strategies of early bystander CPR and DA-CPR, the results can be promising. This will result in the early restoration of circulation and better neurological outcomes. It will be more acceptable by the bystanders to provide only chest compression as mouth to mouth breathing is either not acceptable or not performed appropriately delaying chest compression. A recent meta-analysis has demonstrated the beneficial survival outcome DA-CPR [10]. The recent international consensus strongly recommends that emergency medical dispatch service centers have a proper system to support DA-CPR services [11].

2.3 Cardiocerebral resuscitation (CCR)

The concept of cardiocerebral resuscitation was first developed by the University of Arizona Saver Heart Center Resuscitation Group [3, 12–15]. The original idea had three components which include continuous chest compression by bystanders, EMS advanced cardiac life support, and aggressive post-resuscitation care. The notion of CCR involves chest compressions only and avoiding mouth to mouth ventilation in cases of witnessed cardiac arrest. The basis of this model was a three-phase time-sensitive model of cardiac arrest for ventricular fibrillation by Weisfeldt and Becker [16]. The first phase is the electric phase that lasts less than 4 min and the appropriate intervention is defibrillation followed by ventilation. The second phase is the circulatory phase (4–15 min) when the fibrillating heart has consumed all of the energy stores. During this phase, it is preferable to start with chest compression followed by defibrillation to perfuse the myocardium and reduce metabolic acidosis which in turn increases the success of defibrillation. There is a high possibility of developing asystole or pulseless electrical activity if defibrillation is done before chest compression in such cases [17].

Considering the above discussion, the main question arises if the rescue breaths are a misnomer? Recent data has shown a decrease in survival among patients with bystander initiated rescue effort with assisted-ventilation, especially in a subset of patients who are at a greater chance of survival like witnessed cardiac arrest and shockable rhythm [18, 19]. There are many drawbacks of mouth to mouth resuscitation like the decreased willingness of bystander, inability to deliver optimal rescue breaths by lay-person along with long interruptions to chest compressions during cardiac arrest [20]. Even if interruptions are minimal, positive pressure ventilation increases the intrathoracic pressure, decreasing the venous return, eventually worsening the perfusion of vital organs [21].

There are two subsets of cardiac arrest: primary cardiac arrest with arterial blood-rich in oxygen and other being secondary to respiratory arrest with deoxygenated arterial blood [3]. Above approach may not be very useful in the later.

3. Ventricular fibrillation (VF) and pulseless ventricular tachycardia (pVT): defibrillation

3.1 Early vs. late rhythm analysis

Rhythm analysis is an important component of the CPR algorithm. It helps us to determine further course of action based upon the type of rhythm: shockable or non-shockable. No specific time frame is given to check the rhythm by the currently available literature. A randomized control trial was conducted to compare the impact of brief interval 30–60 s versus long interval of 120 s of chest compression before rhythm analysis in OHCA [22]. It was concluded that the duration for rhythm analysis is to be decided by the EMS team based on local circumstances. It is usually preferable to have an early rhythm analysis in cases where bystander CPR was given before EMS arrival. The authors also emphasized on delivering high-quality chest compressions before defibrillation.

3.2 Analysis during compressions with fast reconfirmation

There is a need for rhythm analysis intermittently while performing CPR. Chest compressions can create artifacts that make it difficult to analyze the rhythm. [23]. Thus, interruptions of chest compressions (CCs) are mandatory during

CPR. Ineffective and interrupted chest compressions can lead to poor outcomes post-CPR [24, 25]. While using an AED, the duration of interruption includes time for rhythm analysis, charging, and a warning to stand clear of the patient before a shock is delivered.

The analysis during compressions with fast reconfirmation (ADC-FR) is a new technology that can significantly reduce the CC interruptions. It comprises of special accelerometers embedded in the defibrillator pads that can sense the CCs. During the CCs, high pass digital filters are applied to analyze the ECG. This filtered rhythm is then compared with the previously validated data to determine whether the rhythm is shockable or not. This rhythm is further cross-checked with the compression-free ECG picked up during the interruption of CCs. In case of shockable rhythm, the defibrillator gets charged just 4 s before 2 min CPR interval. This ensures minimal interruption during CPR.

In a retrospective study, the sensitivity and specificity were found to be >95% and 99%, respectively, for identifying shockable/non-shockable rhythm which exceeds the AHA recommendations for standard artifact-free ECG analysis. Recent studies have demonstrated higher CC fractions have a higher likelihood of ROSC and survival after OHCA [25–32]. We can conclude that ADC-FR is a new alternative that can accurately differentiate shockable from non-shockable rhythm [33]. More clinical studies need to be conducted to provide supportive evidence for ADC-FR.

3.3 Defibrillation strategy

Defibrillation is one of the most important strategies that can improve post-cardiac arrest patients' outcome. Over the last two decades, various studies have demonstrated the relevance of early defibrillation in shockable rhythms [34]. With every minute of delay in defibrillation, there is a decrease in survival by 7–10%. Combined crucial basic life support strategy of early CPR and early defibrillation can improve the overall survival of the patient [35]. The development of an automated external defibrillator (AEDs) was an important breakthrough. Efforts are being made to encourage targeted lay-person early defibrillation. These devices can record the rhythm, analyze it, and deliver a shock. A recent study has demonstrated better neurological outcomes with the application of public access AED to patients of OHCA regardless of the first documented rhythm [36].

There is an evidence of high first shock success rate with biphasic waveform with less incidence of post-shock myocardial dysfunction for both atrial and ventricular arrhythmias, as compared to monophasic waveform [37, 38]. It is recommended to start with the biphasic shock energy of 150 or 360 J in case of the monophasic waveform. There is a strong recommendation to follow defibrillators' manufacturer's instructions for initial and subsequent shocks [23]. Single shock is always preferred over stacked shocks to minimize interruptions in chest compressions [37, 38]. Secondly, it is seen that if a biphasic waveform is unable to defibrillate, then chest compressions are the next best step. It is recommended to escalate the defibrillation energy with subsequent biphasic shocks. This escalation may be useful in preventing the risk of fibrillation [39].

3.4 Hands-on defibrillation

“All clear” is a routine warning given before the delivery of defibrillation. Due to potential side effects, it is important not to be in touch with the patient while delivering a shock. There have been some case reports in the literature of rescuer

being thrown away [40, 41] to as severe as death [42]. In all these cases, the rescuers were barehanded. The main aim of defibrillation is to deliver the appropriate dose (100–360 J) of energy to defibrillate the patient without causing any harm to the rescuer [43]. The energy used is same for cardiac arrest with ventricular fibrillation and pulseless ventricular tachycardia. Lloyd et al. first demonstrated the safety of gloves while defibrillation [44]. This triggered the idea of “hands-on defibrillation” minimizing the CC interruptions during shock delivery. In previous studies, the relationship between the success rate of defibrillation and the time delay between chest compression and shock delivery has already demonstrated [45, 46]. Subsequently, studies have been conducted to determine the efficacy of different types of gloves. One study concluded nitrile glove, neoprene gloves, and fire-fighter gloves can prevent the detection of defibrillation in 99% of cadaver cases [47]. A polythene sheet as thin as 0.002 inches can reduce the current delivered [48]. With the use of these new safety measures, hands-on defibrillation can be made safer.

4. Airway, oxygenation, and ventilation

Oxygen supplementation during CPR has been an acceptable practice. But the concentration of oxygen delivery during CPR can benefit or harm the overall survival depending on the clinical situations. Similarly, various devices have been used in various clinical settings for securing the airway. Ventilation strategies during CPR have been also proposed by various guidelines but the optimal ventilation protocol remains uncertain.

4.1 Oxygen dose during CPR

The optimum tissue and blood oxygenation during CPR are unknown and no study has been done to define the oxygenation goals during CPR. The common practice of giving 100% oxygen during CPR has been challenged in some clinical situations. Most of the current guidelines suggest the use of maximal possible oxygen concentration during CPR. There are numerous limitations to these recommendations. Lack of current clinical evidence to suggest optimal tissue/ blood oxygenation during CPR and unavailability of techniques measuring tissue oxygenation during CPR are important limitations in deciding optimum dosing of oxygen.

4.2 Airway management during CPR

Airway management during CPR includes basic airway management by the bag and mask ventilation with or without oropharyngeal airways and advanced airway management like supraglottic airway devices (SAD) and endotracheal intubation. The optimal management of airway during CPR is an unclear and traditional belief of superiority of advanced airway over basic airway management has been challenged by some of the recent observational studies. Most of the studies comparing various advanced airway devices like an endotracheal tube, combitube, supraglottic airway devices and bag and mask device during CPR were observational studies and were done in OHCA patients. The data were extrapolated for IHCA settings. Most of the newer guidelines in developing and low resource countries also recommend the use of any advanced airway or bag and mask to secure airway to achieve adequate ventilation. Type of airway device in use depends on the skills of rescuer [49]. Tracheal intubation mandates training of health care provider and may be

unsuccessful in emergencies with high chances of unrecognized-esophageal intubation. Comparatively, insertion of supraglottic devices is easier. A stepwise approach to airway management including bag and mask, supraglottic devices, and the endotracheal tube is commonly followed during CPR. This stepwise approach has never been validated in any human studies or RCT.

One of the serious complication in airway management during CPR is unrecognized esophageal intubation. There are few methods of confirming the correct placement of endotracheal tube which have been applied and tested in various settings. Waveform capnography is the most reliable method used to ensure the correct placement of an advanced airway device. This non-invasive monitoring has high sensitivity and specificity with very low false-positive rates [50]. Waveform capnography is an indicator of pulmonary blood flow and guides the quality of CPR. The use of esophageal detection devices and airway ultrasound during CPR is limited due to the lack of RCT and have considered inferior to waveform capnography.

5. Circulation support

5.1 Inspiratory impedance threshold device (ITD)

The efficacy of CPR chiefly depends upon the negative intrathoracic pressure which drives the venous return and cardiac output. Inspiratory impedance threshold device was put forward for the first time in the mid-1990s by Lurie. With the help of a pressure-sensitive unidirectional valve between the patient and the ventilation tool, it augments the negative intrathoracic pressure created during chest recoil which in turn increases venous return and hence improves cardiac output. As per 2010 guidelines by American Heart Association guidelines for CPR, it was put under class 2b recommendation [51]. Two randomized studies have been conducted until now. In the first study, non-blinded randomized control study active compression and decompression device was used along with the ITD, the results showed a statistically significant survival benefit of 3% with this intervention [52]. In the second blinded study, ITD was used along with CPR; however, it was discontinued due to the futility of the intervention [53]. Due to these discrepancies in the outcome, ITD, when used with CPR, may offer no advantage but it may offer some survival benefit when used with a compression-decompression device. To date, no studies have been conducted on the use of ITD during in-hospital cardiac arrest.

5.2 Mechanical CPR devices

There is a constant emphasis on the term “high quality” used along with CPR. For a resuscitation to be successful with good neurological outcome, chest compressions need to be adequate. Clinical studies have demonstrated that the CCs quality is often poor and variable [54, 55]. These limitations lead to the invention of mechanical CPR devices, that can provide automated, high-quality CCs without any risk of fatigue. Two trials, CIRC and LINC trials, have failed to demonstrate any added advantage of using this device [56, 57].

Various studies have been conducted to compare the mechanical device to the manual CC so far, none of them demonstrated any significant difference between the two methods. It is suggested to use mechanical CPR devices in situations where sustained high-quality CC are not possible like where safety is at risk, conditions where fatigue may impair the delivery of high-quality CPR (Hypothermic arrest) or in certain procedures (coronary angiography, preparation for ECPR).

5.3 Extracorporeal CPR (ECPR)

Extracorporeal membrane oxygenation is also known as extracorporeal life support. It provides mechanical support to circulation as well as an extracorporeal gas exchange when the conventional resuscitation techniques fail [58]. Since its introduction in 1972, its role has been explored in various fields including cardiac arrest [59, 60]. ECMO can be a ray of hope for the patients who fail to respond to conventional CPR and helps extend the recovery period for treatable causes of cardiac arrest. It is necessary to familiarize oneself with the hemometabolic effects and limitations of ECMO to extract maximum benefit for a selected group of patients. It is expected to be more successful in IHCA and OHCA where early and effective CPR was started on time. The major challenge is gaining vascular access which can be difficult in an emergency scenario as well as time-consuming. Time is very crucial in cardiac resuscitation, ECPR time may be divided into two parts: time taken to start ECMO and time to achieve temperature management. The ideal time suggested by previous studies is between 30 and 60 min [61–63]. Successful ECPR demands coronary angiography/PCI along with temperature management. The CHEER trial covered 26 patients (11 OHCA and 15 IHCA) with refractory cardiac arrest who were given ECPR. The results were dramatic with a successful resuscitation of 92% and survival to hospital discharge was achieved in 54% cases [64].

Although evidence is limited, ECPR is recommended in cases of refractory CPR. The major limitation of this technique is a lack of resources and training to deliver ECPR.

6. Pharmacological advances

Various drugs have been used during cardiopulmonary resuscitations in OHCA and IHCA with different efficacy in terms of patients' survival, survival to discharge, and survival to neurological outcomes. Task forces have given their recommendations based on available literature with preferences given to RCTs and systemic reviews than observational studies. The pharmacological drugs used have been different in different cardiac arrest clinical situations depending on the patient profile, presence of intravenous access, and institutional protocols.

6.1 Epinephrine

International Consensus on CPR in 2015 suggested the use of epinephrine with weak recommendations considering short term benefits like ROSCs and uncertainty in long term benefits like improvement in neurological outcomes. The standard dose considered is 1 mg epinephrine. There is a weak recommendation of using high dose epinephrine (0.2 mg/kg) compared to standard-dose epinephrine (1 mg bolus). ACLS also recommend the use of intravenous epinephrine as the first choice of the drug during cardiac resuscitation. Epinephrine increases the perfusion to brain and heart by its alpha-1 mediated vasoconstriction and increases heart rate and myocardial contractility by its beta-1 mediated properties. Early administration of epinephrine is suggested in non-shockable rhythm compared to shockable VF/pulseless VT rhythm. The appropriate timing of administration has not been suggested by international resuscitation guidelines.

6.2 Vasopressin

Use of vasopressin in place of standard-dose epinephrine has not been suggested by any task forces or resuscitation guidelines due to lack of any evidence suggesting

no improvement in short term benefits like ROSC and admission to discharge criteria or any long term benefits in quality of life/neurological outcomes. The combination of epinephrine and vasopressin has also been non-superior to epinephrine alone in improving clinical outcomes in patients [65–67].

6.3 Antiarrhythmic drugs

Antiarrhythmic drugs are used in refractory ventricular dysrhythmias during cardiac arrest. Refractory ventricular arrhythmias are defined as the “persistent or recurrent VT/pulseless VT after 1 shock.”

6.3.1 Amiodarone

Amiodarone is a mainly a class III antiarrhythmic drug but also shows class I, II, and IV antiarrhythmic properties which showed benefits in ROSC. Although, no long term benefits were observed in survival to discharge benefits by the drug administration compared to placebo [68]. Amiodarone should only be used in the case when cardioversion/defibrillation and epinephrine administration have failed to revert the fatal arrhythmias to sinus rhythm. The dosing regimen during CPR is 300 mg intravenous/intraosseous bolus followed by the second dose of 150 mg failing the initial bolus dose to convert the rhythm. After successful cardioversion, amiodarone infusion should be continued for 6 h at the rate of 1 mg/min followed by 0.5 mg/min for the next 18 h.

6.3.2 Lidocaine

Lidocaine is a local anesthetic which has been used as a substitute of amiodarone during a cardiac arrest for refractory VF/pulseless VT in cases of unavailability of the later. The initial dose is 1–1.5 mg/kg by the intravenous or intraosseous route. The evidence for the use of lidocaine during cardiac arrest is lacking and no survival benefits have been shown with its use [69].

6.3.3 Magnesium sulfate

Magnesium sulfates have been used in torsade's de points caused by low serum magnesium levels. There is no survival benefit with the routine use of magnesium sulfate during cardiac arrest and routine use of magnesium sulfate during cardiac arrest is discouraged [70].

7. Recent advances in post-resuscitation care

There has been considerable literature available in post-resuscitation care from 2010 in various domains of resuscitation. All the post-resuscitation care interventions are aimed to increase the survival to discharge ratio and decrease the neurological morbidities and mortalities.

7.1 Oxygen supplementation after ROSC

Hypoxia during a cardiac arrest has been the cause of neurological injury and post-cardiac arrest morbidity. The optimum level of blood oxygenation for improving the neurological outcome has been studied but no RCTs and systemic reviews are available to support or refute normoxia or hyperoxia. Hypoxia has been well known

to cause irreversible brain damage and hyperoxia has been implicated in neurological injury due to increased free radicals. With the availability of current literature, emphasis should be given to prevent further hypoxia after cardiac arrest [71].

7.2 Post-resuscitation ventilation

Cardiac arrest has been associated with brain injury as well as injury to other organs including lungs. The optimal PCO₂ to prevent further injury to the brain is critically important and need to optimize our ventilator strategy. Normocarbica is preferred in post-cardiac arrest to maintain the physiological homeostasis and acid-base balance. Ventilatory strategies should be individualized to patients. Hypercapnia and hypocapnia should be avoided.

7.3 Hemodynamic support

Hemodynamic support is necessary to maintain organ perfusions. Vital organs like brain, kidneys, and heart are most vulnerable to get affected by low perfusion states. A state of post-cardiac arrest shock is mostly due to cardiogenic shock and needs inotropic support. Vasopressors are also supplemented to achieve hemodynamic goals like maintaining the mean arterial pressure (MAP). The cutoff value for mean arterial pressure has not been suggested by any large RCTs or systemic reviews but most of the observational studies and data from other critical patients suggest maintaining a MAP > 65 mm Hg. Other goals like urine output have also been targeted. Hemodynamic goals should be individualized based on comorbidities and complexities of individual physiology [72, 73].

7.4 Temperature management

Targeted temperature management (TTM) has been the keystone of post-cardiac arrest care to prevent neurological injury and improving the outcome of the patients. The current evidence suggests maintenance of optimum core body temperature of 32–36°C for 24 h after cardiac arrest in initial shockable rhythm in which patients remained unresponsive after ROSC. TTM has also been suggested in OHCA for non-shockable rhythm. There is no role of inducing hypothermia by cold intravenous infusion in OHCA cardiac arrest [74].

7.5 Post-cardiac arrest seizures prophylaxis and treatment

Post-cardiac arrest seizures and status epilepticus have been linked with poor neurological outcomes. Post-cardiac arrest seizures can be due to brain damage during cardiac arrest. Seizures can further exacerbate the neurological injury. There is no sufficient literature to comment on the routine use of seizures prophylaxis after cardiac arrest. Based on the available current literature, the task force suggests against the routine use of seizures prophylaxis in IHCA and OHCA situations. There is a strong recommendation to treat post-cardiac arrest seizures. Various antiepileptic drugs have been used solely or in combinations in different dosing regimens to treat seizures to prevent further neurological injury and improve survival [75].

8. Physiological monitoring during CPR

Current CPR guidelines suggest a common approach to all the patients irrespective of the varied underlying physiological differences among patients and clinical

situations. This mandates the development of newer strategies to target physiological parameters to guide resuscitation. Recent literature has reviewed the applications of various basic and advance physiological monitoring to improve precision during CPR and improve survival of the patients. Various strategies of monitoring include ETCO₂ monitoring, coronary perfusion pressure monitoring, cardiac ultrasound and regional cerebral oxygen monitoring.

8.1 End-tidal carbon dioxide monitoring

ETCO₂ is an indirect measure of the cardiac output and pulmonary blood flow. The right side of the heart receives CO₂ containing venous blood which is pumped to lungs for exhalation. Over 35 clinical studies have been conducted to explore the association and prognostication of end-tidal carbon dioxide with ROSC and survival of the patients [76, 77]. Low values of ETCO₂ reflect low cardiac output state during chest compressions. Clinical significance of end-tidal carbon dioxide during CPR is varied with wide applications. It is well known that a low ETCO₂ values (<10 mm Hg) have been associated with very high mortality [78]. It has been observed that a higher ETCO₂ value during CPR has been associated with higher chances of ROSC. The American Heart Association also recommends ETCO₂ level of greater than 20 mm Hg as an indicator of good chest compressions. There are some limitations of ETCO₂ monitoring during CPR. There can be a significantly higher level of ETCO₂ in asphyxia related cardiac arrest during the initial few minutes of CPR [79]. Similarly, epinephrine administration can reduce ETCO₂ levels due to pulmonary vasoconstriction. Despite these limitations, ETCO₂ remains one of the most important physiological parameters guiding resuscitation due to its availability, simplicity, and non-invasive technique.

8.2 Cerebral oximetry

Neurological injuries are common during cardiac arrest. Maintaining cerebral perfusion during CPR is crucial for survival and good neurological outcome. Cerebral oximetry is a newer technique to measure regional cerebral oxygenation using near-infrared spectroscopy (NIRS) devices. The device emits continuous near-infrared light from a source probe and received by a detector probe on the forehead. The light penetrates the cranial cavity (few centimeters) depending on the water and lipid content [80]. Change in light intensities due to differential absorption by oxygenated and deoxygenated blood in the cranial cavity detects rSO₂. There is no RCT comparing the use of commercially available NIRS devices during CPR. A multicenter observational prospective study with cerebral oximetry during cardiac arrest in an adult cohort population showed a lower percentage of IHCA patients with ROSC who had lower values of rSO₂ [81]. There are certain limitations to this technological advancement of the non-invasive method of measuring regional cerebral oxygenation. There are no defined values of rSO₂ derived from RCTs and meta-analysis during CPR. There is a logistics issue in placing of NIRS monitors during CPR with commercially available monitors. Prospective studies are required to validate these devices and define values of rSO₂ for target approach during CPR.

8.3 Focused cardiac ultrasound

Use of point of care cardiac ultrasound during a cardiac arrest has been implemented to find the cause of cardiac arrest (5Hs and 5Ts) rather than guiding the resuscitations. However, some imaging studies have revealed the intrathoracic

structures beneath the described rescuer's hand position (lower half of sternum) during chest compression may be aorta or left ventricle outflow tract (LVOT) which would obstruct the blood outflow [82, 83]. A prospective study by Hwang et al. using transesophageal cardiac ultrasound identified compressions of aorta and LVOT in all the cases of chest compressions during CPR with variable degrees. The authors suggested that LV stroke volume increased by improving the precisions of compressions proximal to left ventricle guided by cardiac ultrasound [84]. However, no RCT has been done to explore the use of cardiac ultrasound during CPR. Moreover, there may be a risk of the potential harm of distracting the rescuers from high-quality CPR while focusing on cardiac ultrasound [85]. Simulation-based programs can be used to mitigate this problem.

9. Cardiac arrest in special circumstances

9.1 Traumatic cardiac arrest

The traumatic arrest is one of the etiologies of cardiac arrest with a very poor outcome [86–92]. To improve its outcome, there is a need to draw our attention to the possible reversible causes of traumatic cardiac arrest [93].

Recent data has clarified that traumatic cardiac arrest patients have no worse outcome than that of the medical causes of cardiac arrest [94]. Some of the reversible causes of cardiac arrest in traumatic patients are hypovolemia, tension pneumothorax, and cardiac tamponade.

9.1.1 Hypovolemia and rapid fluid resuscitation

In-depth analysis of traumatic cardiac arrest patients has demonstrated that the majority of the survivable traumatic cardiac arrest patients have pulseless electrical activity (PEA) [95]. This implies that the heart is beating, but the peripheral pulse is not palpable. It is often seen that this is a low output state rather than a true cardiac arrest. This is supported by the fact that such patients often have multiple wounds and suffer significant blood loss. Chest compressions are more effective in euvoletic patients as compared to suspected hypovolemic patients of traumatic cardiac arrest, rather they can worsen coronary perfusion [96]. Considering the etiology, the treatment algorithm must also be modified in these cases. Treatment must involve external compression to stop further loss, gaining access to wide-bore cannula, and initiate rapid transfusion of blood and blood products along with the attempts of CPR. In contrast to the traditional teaching, blood and blood products are preferred over the crystalloid transfusion [97, 98]. Although supportive evidence has demonstrated improved survival in patients receiving more fluid resuscitation (crystalloids) [99].

9.1.2 Tension pneumothorax

Tension pneumothorax may be suspected when there is decreased air entry even after checking the position of the endotracheal tube. It is one of the reversible causes of cardiac arrest, it is stated that chest compression should not delay the treatment of the reversible cause. It can either be achieved by immediate needle decompression or thoracotomy. In the case of positive pressure ventilation, thoracostomy is a preferred technique as it is more effective than needle decompression and less time-consuming than chest tube insertion [86]. Whereas, in the case of needle decompression, there can be technical difficulties like kinking, dislodgment,

insufficient length of needle leading to insufficient decompression [100]. Decompression demonstrated the return of ROSC in these patients [101]. On the scene, decompression is recommended for all patients of traumatic cardiac arrest with tension pneumothorax [102].

9.1.3 Cardiac tamponade

Low energy penetrating wounds can cause myocardial injury leading to an accumulation of blood in pericardial space. Cardiac tamponade can be a cause of arrest in 10% of cardiac arrests in trauma. Cardiac tamponade needs to be evacuated immediately to achieve successful resuscitation post-CPR. Retrospective data collected from a military hospital has demonstrated survival as high as 21.5% in post-traumatic cardiac arrest patients post thoracotomy [95].

Ultrasound can help in timely diagnosis PEA, cardiac tamponade, tension pneumothorax, and even hypovolemia by IVC diameter [103].

9.2 Cardiac arrest after cardiac surgery

Cardiac arrests after cardiac surgeries are unique entities that need to be addressed uniquely. It usually takes place within the hospital facility which thereby increases the chances of early diagnosis. Timely resuscitation is possible in the presence of expertise with easy access to defibrillator or pacing facility, early CPR, and rapid sternotomy. About 8% of the cardiac surgery patients suffer from perioperative cardiac arrest, with a shockable rhythm in 30–50% and mechanical causes like cardiac tamponade or graft failure in 28% of the cases [104]. The incidence of different arrhythmias varies in different studies. A recent study reported the incidence of VF and pVT in 70%, asystole in 17%, and PEA in 13% of cardiac arrests [105].

During the cardiac arrest, various monitoring waveforms like arterial pressure, central venous pressure, and pulmonary artery pressure are non-pulsatile. If the ECG tracing reveals VF/ pVT, three stacked shocks must be delivered if available within 1 min. Brief CPR in patients shortly after cardiac surgery can induce lacerations and hemorrhage due to serrated sternal edges and projecting steel wires and hence not preferred [106, 107]. Numerous studies have demonstrated improved outcomes with early defibrillation for witnessed arrest [108, 109]. In the scenario of OHCA, single shock protocol is preferred but the same may not be applicable for witnessed IHCA and procedural settings. Subsequent shocks given within 1 min showed statistically significant survival benefits over the deferred second shock in VF/pVT [110]. Thus, considering the risks and benefits it is recommended to give three sequential shocks without intervening external cardiac massage in patients of VF/pVT if available within 1 min. A bolus of 300 mg intravenous amiodarone should be given via central line after failed defibrillation and CPR should be initiated [111]. Studies have demonstrated the advantage of internal cardiac massage as compared to external in establishing adequate cerebral and coronary perfusion (CPP) [112, 113]. Maximal CPP is a direct indicator of ROSC [114]. It is recommended to perform cardiac massage at the rate of 100–120 per minute with a target systolic pressure of at least 60 mm of Hg.

If the CPR is performed correctly, and still the target pressure is not achieved, it suggests a surgical problem like cardiac tamponade. PEA is commonly seen in cardiac tamponade or hemorrhage. Rapid sternotomy is the treatment of choice and once compression is released; internal massaging can be continued allowing initial stabilization while the patient is shifted back to the operating room. Direct visualization allows the diagnosis of the mechanical cause of the arrest and early intervention. Pottle and colleagues have demonstrated survival benefit when the

sternotomy was done within 5 min of arrest supporting internal cardiac massage over external [115].

In asystole, epicardial pacing (DOO mode, maximal atrial, and ventricular output, 80–100/min) should be initiated within 1 min if available before CPR and resternotomy otherwise transcutaneous pacing may be used. Transcutaneous pacing involves delivery of electrical impulses through the patient chest by applying pads on thoracic wall stimulating the heart. It is mainly indicated during hemodynamic instability due to refractory bradycardia, sick sinus syndrome, and asystolic cardiac arrest. Transcutaneous pacing during cardiac arrest is more successful in witnessed cardiac arrest.

In cases of PEA, the pacemaker should be temporarily turned off to check the rhythm as it can mask the VF. Atropine is not recommended as a part of the resuscitation protocol for cardiac surgery patients [111].

Epinephrine is not routinely recommended as a part of the resuscitation protocol in post-cardiac surgery patients. Studies have demonstrated it can cause more harm than help. Although successful in restoring the circulation, it can raise the blood pressure to such high levels that can damage the anastomosis sutures leading to hemorrhage. Many research trials have shown the success of epinephrine in starting the initial rhythm but poor overall survival rates and increase brain damage [116]. If required, it can be used in impending arrest at a lower dose (50–300 mcg) only if ordered by an experienced clinician.

Usually, the post-cardiac surgical patients are intubated, there is a risk of endobronchial intubation, pneumothorax, and hemothorax. Management of airway and ventilation involves increasing the FiO_2 to 100% and excluding the positive end expiration pressure, checking the position of the endotracheal tube and excluding tension pneumothorax or hemothorax [39]. In case of tension pneumothorax or hemothorax, a wide-bore needle should be inserted in second intercostal's space, the midclavicular line to decompress immediately.

Cardiac arrests in post-cardiac surgery patients is a unique entity that mandates necessary changes in conventional resuscitation protocols to improve their outcome [104, 117].

9.3 Cardiac arrest in pregnancy

Cardiac arrest in pregnant patients is dealt with as a separate entity. Recent data has shown most etiology due to reversible cause with a high survival rate of >50% [118]. This challenges the historical concept of poor survival and futility of resuscitation [119]. This special group of young people responds well to resuscitation efforts, encouraging us to streamline resuscitation guidelines [118].

First and foremost is the need to identify common causes of arrest in pregnant patients, which must be reversed while resuscitating the patients to improve the chances of ROSC. Anesthetic complications like inadvertent spinal injection and airway complications are the most common cause followed by hemorrhage (intrapartum or postpartum) [120]. Other causes can be attributed to cardiovascular causes like peripartum cardiomyopathy, heart failure owing to pre-existing valve disease, drugs errors, anaphylaxis, and thromboembolic complications.

Resuscitation in pregnant patients requires sequential coordinated simultaneous interventions. A multidisciplinary team of health care providers including an obstetrician, neonatologist, anesthesiologist, intensivist, a cardiologist, and cardiovascular surgeon should be involved during resuscitation. High-quality chest compressions of 5–6 cm depth at the rate of 100–120 per minute at the mid sternal position with adequate recoil will provide a good circulatory function. The gravid uterus can lead to aortocaval compression, impairing venous return. Tilting

the patient to a lateral position relieves the compression but does not allow chest compression. A study on mannequin demonstrated that a tilt of 27° was enough during chest compression to stop mannequin from falling but with the limitation of achieving 80% of force for CCs as compared to supine position [121]. A virtual gastroscopy demonstrated lateral displacement of the heart on lateral tilt offsetting the pumping action of chest compression [122]. A study utilized MRI to demonstrate compression of inferior vena cava and partial release on the lateral tilt of 30° in pregnant patients as compared to non-pregnant patients [123]. Considering this, manual displacement of the uterus can relieve the compression without affecting the vector force during chest compression, although delivery of the fetus is the ultimate and most comprehensive way of relieving the aortocaval compression. CPR is performed at a ratio of 30 compressions and 2 breaths. Oxygenation is the ultimate goal, the airway must be secured as soon as possible. It prevents aspiration and provides treatment for the respiratory cause of arrest. Considering the physiological changes of pregnancy and experienced laryngoscopist must perform intubation with an endotracheal tube of a smaller diameter. Recent studies have shown no advantage of the advanced airway during CPR in-hospital resuscitation, but this may not hold in pregnant patients keeping in view the physiological changes of pregnancy [124].

Rhythm analysis, defibrillation, and drugs used are similar to non-pregnant patients. Intravenous cannulation must be established above the diaphragm, to prevent the cut off of drugs due to gravid uterus causing aortocaval compression.

It is reasonable to perform perimortem caesarian delivery within 5 min of resuscitation maternal cardiac arrest. It maximizes the neonatal outcome as well as improves the maternal outcome [118].

10. Conclusion

Managing cardiac arrest can be very challenging considering its complexity and time sensitivity. However, over the last couple of years, lot of research has been done in this field and implementation of these research-proven interventions has led to improvement of the overall outcome. For example, we know that early identification of cardiac arrest, early implementation of bystander CPR, compression-only CPR, early activation of the EMS system, early defibrillation by AED, and aggressive post-arrest care that includes therapeutic hypothermia, early cardiac catheterization, seizure control, and goal-directed care improve outcomes.

Nomenclature

ADC-FR	analysis during compressions with fast reconfirmation
AED	automated electronic defibrillator
CA	cardiac arrest
CC	chest compression
CCP	cerebral and coronary perfusion
CCR	cardiocerebral resuscitation
CPR	cardiopulmonary resuscitation
DA-CPR	dispatcher assist CPR
ECMO	extracorporeal membrane oxygenation
ECPR	extracorporeal CPR
EMS	emergency medical service
IHCA	in-hospital cardiac arrest

ITD	inspiratory impedance threshold device
LVOT	left ventricle outflow tract
NIRS	near-infrared spectroscopy
OHCA	out of hospital cardiac arrest
PEA	pulseless electrical activity
pVT	pulseless ventricular tachycardia
ROSC	Return of spontaneous circulation
SAD	supraglottic airway devices
TTM	targeted temperature management
VF	ventricular fibrillation

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