The Society of Thoracic Surgeons Expert Consensus for the Resuscitation of Patients Who Arrest After Cardiac Surgery

The Society of Thoracic Surgeons Task Force on Resuscitation After Cardiac Surgery*

Executive Summary

The Society of Thoracic Surgeons Task Force on Resuscitation After Cardiac Surgery provides this professional society perspective on resuscitation in patients who arrest after cardiac surgery. This document was created using a multimodal methodology for evidence generation and includes information from existing guidelines, from the International Liaison Committee on Resuscitation, from our own structured literature reviews on issues particular to cardiac surgery, and from an international survey on resuscitation hosted by CTSNet.

In gathering evidence for this consensus paper, searches were conducted using the MEDLINE keywords "cardiac surgery," "resuscitation," "guideline," "thoracic surgery," "cardiac arrest," and "cardiac massage." Weight was given to clinical studies in humans, although some case studies, mannequin simulations of potential protocols, and animal models were also considered.

Consensus was reached using a modified Delphi method consisting of two rounds of voting until 75% agreement on appropriate wording and strength of the opinions was reached. The Society of Thoracic Surgeons Workforce on Critical Care was enlisted in this process to provide a wider variety of experiences and backgrounds in an effort to reinforce the opinions provided.

We start with the premise that external massage is ineffective for an arrest due to tamponade or hypovolemia (bleeding), and therefore these subsets of patients will receive inadequate cerebral perfusion during cardiac arrest in the absence of resternotomy. Because these two situations are common causes for an arrest after cardiac surgery, the inability to provide effective external cardiopulmonary resuscitation highlights the importance of early emergency resternotomy within 5 minutes. In addition, because internal massage is more effective than external massage, it should be used preferentially if other quickly reversible causes are not found.

We present a protocol for the cardiac arrest situation that includes the following recommendations: (1) successful treatment of a patient who arrests after cardiac surgery is a multidisciplinary activity with at least six key roles that should be allocated and rehearsed as a team on a regular basis; (2) patients who arrest with ventricular fibrillation should immediately receive three sequential attempts at defibrillation before external cardiac massage, and if this fails, emergency resternotomy should be performed; (3) patients with asystole or extreme bradycardia should undergo an attempt to pace if wires are available before external cardiac massage, then optionally external pacing followed by emergency resternotomy; and (4) pulseless electrical activity should receive prompt resternotomy after quickly reversible causes are excluded. Finally, we recommend that full doses of epinephrine should not be routinely given owing to the danger of extreme hypertension if a reversible cause is rapidly resolved.

Protocols are given for excluding reversible airway and breathing complications, for left ventricular assist device emergencies, for the nonsternotomy patient, and for safe emergency resternotomy. We believe that all cardiac units should have accredited policies and protocols in place to specifically address the resuscitation of patients who arrest after cardiac surgery.

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The American Heart Association (AHA) issued its latest edition of guidelines for resuscitation in October 2015 [1]. These guidelines do not provide specialist guidance for patients who arrest after cardiac surgery. The European Resuscitation Council (ERC) guidelines were published simultaneously and, in contrast, included a detailed section on the resuscitation of patients who arrest after cardiac surgery [2]. The ERC guidelines recommend resternotomy within 5 minutes of a cardiac arrest, allowing any trained practitioner to

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The STS Executive Committee approved this document.

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Abbreviations and Acronyms

AHA = American Heart Association
ECG = electrocardiogram
ECM = external cardiac massage
ECMO = extracorporeal membrane oxygenation
ERC = European Resuscitation Council
IABP = intraaortic balloon pump
ICU = intensive care unit
VF = ventricular fibrillation
VT = ventricular tachycardia

perform this task. They warn against full-dose epinephrine and allow external cardiac massage to be deferred while three-stacked shocks are given or pacing is begun. The ERC guidelines fully support the guidelines published by the European Association of Cardiothoracic Surgery in 2009 [3]. These documents have stimulated many clinicians managing cardiac surgical patients to evaluate more carefully how cardiac arrests are managed in their own units. There is now recognition that patients having a cardiac arrest after cardiac surgery are sufficiently different from patients in general to warrant their own treatment algorithm to optimize their survival after arrest.

Every year, more than 400,000 patients undergo cardiac surgery in the United States at one of approximately 1,200 medical centers [4–6]. The incidence of cardiac arrest after cardiac surgery is 0.7% to 8% [7–16]. The most remarkable statistic regarding these patients is their relatively good outcome. Approximately half survive to hospital discharge, a far higher proportion than is reported when cardiac arrest occurs in other settings. Reasons for this superior survival include the high incidence of reversible causes of the cardiac arrest. Ventricular fibrillation (VF) is the cause of cardiac arrest in 25% to 50% of cases. In the intensive care unit (ICU) setting, that can be immediately identified and treated. Cardiac tamponade and major bleeding account for another large percentage of the additional arrests. Both conditions can be quickly relieved by prompt resuscitation and emergency resternotomy to relieve tamponade and control bleeding.

Prompt recognition and treatment by ICU staff trained in the recognition and management of these arrests improves survival. Practicing protocol-based arrest management has been shown to reduce by 50% the time to chest reopening and reduce complications resulting from the resternotomy after cardiac surgery [16–21].

The protocol presented here addresses many issues particular to the cardiac surgical patient, including timing of emergency resternotomy, number of attempts at defibrillation before resternotomy, administration of epinephrine, ventilator management, infusion and pacemaker settings, emergency resternotomy instrumentation sets, use of the intraaortic balloon pump (IABP), and cardiac arrests in the non-ICU setting and under special circumstances. This protocol applies to all patients in the ICU, including pediatric, minimal access, left ventricular assist device, and transplant patients. It does not include patients undergoing pulmonary surgery. Issues regarding the treatment of patients in mixed specialty areas are discussed.

In the generation of The Society of Thoracic Surgeons (STS) expert consensus statement, we support and follow the American College of Cardiology Foundation/AHA clinical practice guidelines methodology [22], including the grading of recommendations.

Protocol for Cardiac Surgical Patients in the Intensive Care Unit

The recommended modification of the AHA algorithm to be applied in cases of cardiac arrest after cardiac surgery is presented in Figure 1. We recommend that this protocol be used in the ICU in preference to the Adult Advanced Cardiovascular Life Support algorithm that is currently advocated [1]. Major differences between the protocols are addressed below. Furthermore, we recommend that emergency resternotomy be a standard part of the resuscitation protocol until 10 days after surgery. For patients beyond day 10, the protocol should still be followed but a senior clinician should decide whether resternotomy is indicated. For these later postsurgical patients, the perceived benefit of resternotomy must be balanced against the increased difficulty of open resuscitation owing to the development of pericardial adhesions.

Defibrillation/Pacing Before External Cardiac Massage

One major change is the speed and priority with which defibrillation for ventricular fibrillation (VF) or pacing for asystole is performed. Before this guideline, a patient in VF after cardiac surgery was to receive external cardiac massage (ECM), then a single attempt at defibrillation followed again by ECM for 2 minutes [23]. Thereafter, the rhythm is reassessed and ECM ceased if evidence of spontaneous circulation is present. The AHA makes no recommendations for the use of temporary pacing wires in asystolic cardiac arrest.

Cardiac surgical patients are sufficiently different from noncardiac surgical patients to recommend an important departure from the AHA guideline. In recommending three sequential shocks for VF or the initiation of temporary pacing for asystole before ECM, we have considered several factors, as follows.

Is ECM Required Before Defibrillation?

We sought evidence to support whether an initial period of ECM before immediate defibrillation or pacing might benefit the patient or cause unnecessary harm. A search for the evidence on immediate versus delayed ECM is fully documented together with a summary of 22 identified papers [24]. Our evidence review agrees with the International Liaison Committee on Resuscitation that states there is no benefit from a period of external cardiac massage before immediate defibrillation for inhospital patients [25, 26].

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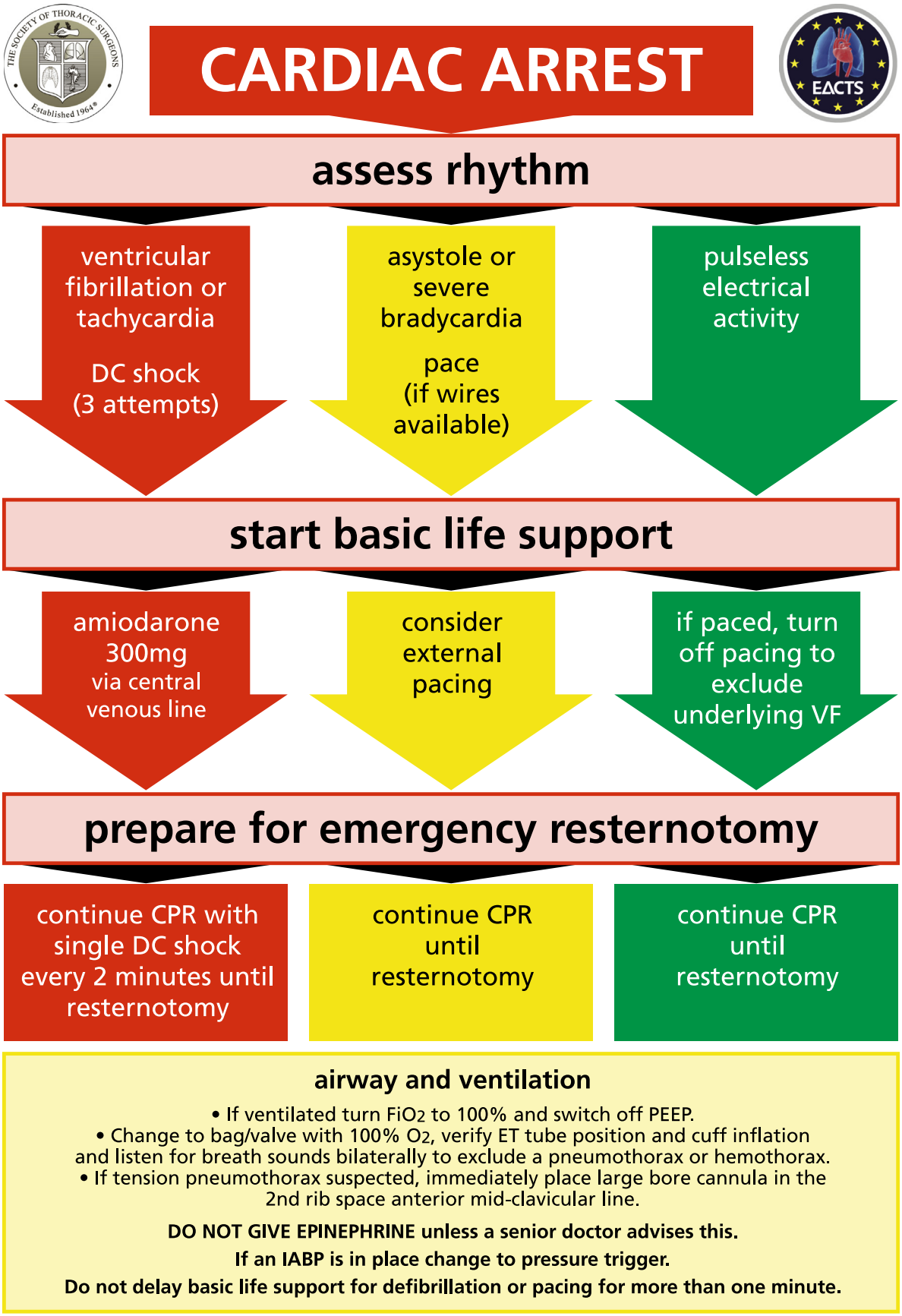
CARDIAC ARREST
assess rhythm
ventricular fibrillation or tachycardia
DC shock (3 attempts)
asystole or severe bradycardia
pace (if wires available)
pulseless electrical activity
start basic life support
amiodarone 300mg via central venous line
consider external pacing
if paced, turn off pacing to exclude underlying VF
prepare for emergency resternotomy
continue CPR with single DC shock every 2 minutes until resternotomy
continue CPR until resternotomy
continue CPR until resternotomy
airway and ventilation
• If ventilated turn FiO2 to 100% and switch off PEEP.
• Change to bag/valve with 100% O2, verify ET tube position and cuff inflation and listen for breath sounds bilaterally to exclude a pneumothorax or hemothorax.
• If tension pneumothorax suspected, immediately place large bore cannula in the 2nd rib space anterior mid-clavicular line.
DO NOT GIVE EPINEPHRINE unless a senior doctor advises this.
If an IABP is in place change to pressure trigger.
Do not delay basic life support for defibrillation or pacing for more than one minute.

Potential Trauma Induced by ECM

We identified 4 patients in the cardiothoracic literature who had massive hemorrhage after external cardiac massage [27, 28]. However, several cohort studies of patients receiving ECM after cardiac surgery documented that no injuries were seen due to that in their series [10, 29].

In the noncardiac surgical literature, a meta-analysis of 23 studies demonstrated that the incidence of pericardial injury after ECM was 8.9%, the sternal fracture rate was 15%, and the postresuscitation rib fracture rate was 32% [30]. They also document numerous case reports of myocardial lacerations, cardiac chamber ruptures, prosthetic valve dehiscence, major vascular dissection and rupture, papillary muscle rupture, and a 10% incidence of conduction system injuries.

We found no studies reporting cohorts of patients resuscitated primarily by external pacing or temporary wire pacing. As this intervention is no more invasive than defibrillation, guidance on its timing in relation to ECM in asystole will parallel the timing recommendation for defibrillation in VF. In both cases, delay in obtaining the equipment is an indication for immediate ECM.

In summary, most evidence supporting immediate cardiopulmonary resuscitation before defibrillation or pacing is from out-of-hospital cardiac arrests. Survival after inhospital arrest is optimized with early defibrillation when appropriate. After cardiac surgery, ECM is associated with potentially fatal complications, and may not be necessary in situations where the cardiac arrest can be immediately reversed by defibrillation or pacing. We therefore recommend that if defibrillation or pacing (as appropriate) can be performed within 1 minute, then it is preferable to defer ECM until they have been attempted.

Suggestions

- If the electrocardiogram (ECG) shows VF/pulseless ventricular tachycardia (VT), you may delay external cardiac massage for up to one minute to administer shocks. (Class IIA, Level B)
- If the ECG shows asystole, you may delay external massage for as long as a minute to maximize the temporary pacemaker output. (Class IIA, Level C)

Number of Attempts at Defibrillation Before Resternotomy

Evidence was sought for the optimal number of attempts at external defibrillation for VF before proceeding to emergency resternotomy. This search is fully documented [31], together with a summary of 15 identified papers.

When data from all 15 papers are combined, the average success rate of sequential shocks declines from 78% for the first shock to 35% for the second shock and to 14% for the third. Therefore, the likelihood of successful cardioversion declines dramatically from the first to the second shock, and declines further from the second to the third shock. We conclude that proceeding to resternotomy after the third shock is preferable owing to the minimal likelihood of fourth shock success.

Suggestions

- For patients with VF or pulseless VT, three sequential shocks should be given without intervening ECM. (Class I, Level B)
- For VF or pulseless VT, emergency resternotomy should be performed after three failed attempts at defibrillation, with ECM started as a bridge to internal massage. (Class I, Level B)

Basic Life Support in the ICU

Patients who arrest in the ICU are highly monitored and often intubated and ventilated. A potential cardiac arrest will most likely be signalled by monitoring alarms. The first person alerted to the possibility of a cardiac arrest should immediately assess all monitored waveforms. During a cardiac arrest, not only will the arterial line show no pulsatility, but also the central venous pressure, pulse oximetry, and pulmonary artery pressure waveforms will flatten, and in a ventilated patient, a rapid decrease in end-tidal carbon dioxide will also occur. The ECG may show VF or asystole, which are clearly not compatible with cardiac output (in the absence of a ventricular assist device or other mechanical support).

An ECG demonstrating QRS complexes without pulsatile waveforms or end-tidal carbon dioxide should be diagnosed as a pulseless electrical activity cardiac arrest. Pulseless VT may also be diagnosed on a similar basis. Feeling for a central pulse may be unreliable, and when several monitoring waveforms are compatible with a cardiac arrest, palpation of pulses may be omitted.

On recognition of a cardiac arrest, there is no need to assess for 10 seconds or check that all monitoring equipment is working properly. The first responder should immediately initiate the cardiac arrest protocol and loudly and clearly call for help.

In some cases, there is an organized ECG and the arterial waveform gradually diminishes as the blood pressure falls. Assuming that the arterial line is functioning well (ie, central venous pressure, pulmonary artery, and oximetry trace amplitudes also diminish), then immediate expert assistance should be sought, but cardiac arrest should not be called and the protocol not instituted until the arterial impulse is absent and all pressure waves become flat.

Fig 1. The Society of Thoracic Surgeons protocol poster for the resuscitation of patients who arrest after cardiac surgery. (CPR = cardiopulmonary resuscitation; DC = direct current; ET = endotracheal tube; Fio_2 = fraction of inspired oxygen; IABP = intraaortic balloon pump; PEEP = positive end-expiratory pressure; VF = ventricular fibrillation.)

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Suggestions

- If the ECG shows VF or asystole, call cardiac arrest immediately. (Class I, Level C)
- If the ECG is compatible with a cardiac output, look at the pressure traces. If arterial and other pressure waveforms, including end-tidal carbon dioxide, are pulseless, then call cardiac arrest immediately. (Class I, Level C)
- Feeling for a central pulse should only be used if there is significant doubt about the diagnosis. (Class I, Level C)

Basic Life Support—External Cardiac Massage

If a rhythm change to VF/pulseless VT is witnessed, ECM may be delayed until three shocks have been given, if a defibrillator is rapidly available (within 1 minute).

If asystole is witnessed, ECM may be delayed while the temporary pacemaker's output is maximized (or the emergency button pressed on the pacemaker if available). Otherwise, ECM should be immediately initiated in standard fashion at a chest compression rate of 100 to 120 beats per minute [23].

In the ICU setting, the effectiveness of compressions can be confirmed by looking at the arterial pressure trace on the monitor. A systolic impulse more than 60 mm Hg should be aimed for, and the rate or depth of compressions can be increased to achieve this. The goal is to prevent cardiac distension and provide coronary artery and vital organ perfusion (brain, myocardium, and kidney).

However, the inability to achieve an acceptable compression-generated blood pressure indicates the need for immediate emergency resternotomy (ie, likely etiology of severe bleeding or tamponade), and chest reopening should be performed within 5 minutes. Notify the whole team immediately if you are unable to achieve a systolic impulse in excess of 60 mm Hg.

Suggestions

- Inability to obtain a systolic pressure greater than 60 mm Hg on the arterial trace with external cardiac massage indicates that tamponade or extreme hypovolemia is likely, and emergency resternotomy should be performed (Class I, Level C)

Basic Life Support—Airway

In the ICU, airway issues may contribute to arrest and must be quickly remedied; therefore, the second rescuer should address airway and breathing. If the patient is not intubated, the second rescuer should administer 100% oxygen using a bag-valve-mask device at a ratio of two breaths for every 30 compressions. However, most patients will be intubated and ventilated on arrest, and the priority for the second rescuer is to immediately increase the ventilator oxygen concentration to 100%. After this, removing positive end-expiratory pressure is also recommended to decrease intrathoracic pressure and thereby augment venous return.

Although an acute airway or ventilator problem is an uncommon cause for cardiac arrest in the ICU, the possibility of a tension pneumothorax or misplaced endotracheal tube must be considered as a cause for the cardiac arrest. The following steps are important to ensure satisfactory airway and ventilation:

- Check the position of the endotracheal tube.
- Listen for any air excursion around the tube, and that the cuff is inflated.
- See if there is fog formation on the endotracheal tube on exhalation, which would support the presence of a patent airway.
- Palpate the trachea; is it central or deviated?
- Inspect the chest for bilateral expansion.
- Auscultate with a stethoscope (both axillae and epigastrium) for bilateral air entry.
- Confirm that capnography demonstrates end-tidal carbon dioxide, remembering that levels may be minimal in a cardiac arrest.
- We recommend that the ventilator be disconnected and that breaths are temporarily administered with a bag-valve connected to 100% oxygen. That allows a manual assessment of airway pressure and facilitates easier auscultation of breath sounds with a stethoscope. Once good air entry to both lungs has been confirmed, then the patient may safely be returned to the ventilator.
- If the examination indicates that a tension pneumothorax is a possibility, a large-bore cannula should immediately be placed into the second intercostal space (located below the second rib), anterior midclavicular line. The second rib can be quickly identified as it inserts into the sternomanubrial junction (angle of Louis). If this diagnosis is correct, the cardiac arrest may resolve. It is unlikely that this will cause a pneumothorax, but if the pleura is closed on that side, or if in doubt, a chest tube may be indicated unless proceeding to resternotomy.
- If inflating the lungs with the bag-valve device is not possible, and a suction catheter will not pass down the endotracheal tube, then tube occlusion or malpositioning should be suspected. The endotracheal tube should be immediately removed and a bag-valve-mask with airway adjuncts used.

Suggestions: Airway and Breathing

- Immediately increase the inspired oxygen to 100%. (Class I, Level C)
- For ventilated patients, the ventilator should be disconnected and a bag-valve used. Look and listen for breath sounds on both sides with equal chest movement, specifically examining for a pneumothorax or a hemothorax. Confirm the presence of end-tidal carbon dioxide. (Class I, Level C)
- If you suspect a tension pneumothorax, place a large-bore needle into the second intercostal space, anterior midclavicular line, followed either by a chest drain or opening of the pleura at resternotomy. (Class I, Level C)
- Once adequate airway and breathing are confirmed, the patient may be reconnected to the ventilator

(positive end-expiratory pressure should be removed). (Class IIA, Level C)

Administration of Epinephrine or Vasopressin

We sought evidence whether routine epinephrine or vasopressin administration is either beneficial or potentially harmful for patients who have a cardiac arrest after cardiac surgery [3, 32, 33].

Seventeen studies were reviewed in detail in addition to current AHA guidelines. The AHA 2015 guidelines state that "to date no placebo-controlled trials have shown that administration of any vasopressor agent at any stage during management of VF, pulseless VT, PEA, or asystole increases the rate of neurologically intact survival to hospital discharge" [1].

Its continued recommendation is based on some studies that indicate an increased return of spontaneous circulation to neurologically intact hospital discharge but not survival. Studies supporting this recommendation included an 851-patient randomized clinical trial in 2009 [34], a 534 patient randomized clinical trial in 2011 [35], and two 2014 metaanalyses of all published trials of vasopressors [33, 36].

Studies reporting the outcome of cardiac arrests after cardiac surgery fail to consistently or completely report use of epinephrine, providing no conclusive evidence that this was either a beneficial or harmful intervention. The risk of administering epinephrine to patients after cardiac surgery is the development of severe hypertension and bleeding in patients who regain spontaneous circulation [37].

We acknowledge that epinephrine may be beneficial in the impending arrest or periarrest situation and may also be safely used in smaller doses (eg, 50 to 300 μg boluses). However, once cardiac arrest has occurred, we recommend that epinephrine should only be administered by clinicians with experience in its use in cardiac surgery, and it should not be included in the routine arrest protocol.

Suggestions

- We recommend that neither epinephrine nor vasopressin be given during the cardiac arrest unless directed by a clinician experienced in their use. (Class III [harm], Level C)

Infusions

We are aware of some unpublished cases of cardiac arrest after cardiac surgery due to drug administration. Inadvertent flushing of a vasodilator or residual drug in the lumen of a central line is another conceivable cause of cardiac arrest.

Conversely, during cardiac arrest, it is unlikely that a drug running by infusion before arrest would assist the conduct of the cardiac arrest by its continued administration. Many sedatives and anesthetic medications such as propofol are vasodilators. Their cessation for a few minutes in the context of very low cerebral perfusion is unlikely to cause awareness. Once stability has been achieved and adequate cerebral perfusion restored, recommencing the infusion may be indicated.

We would recommend that once all immediate attempts at resuscitation have failed such as defibrillation or pacing, and once external compressions have been established, that pre–cardiac arrest infusions should be stopped until an experienced clinician arrives to review each medication.

Suggestions

- In an established cardiac arrest, all infusions before arrest should be stopped. (Class IIA, Level C)
- If there is concern about awareness, it is acceptable to continue the sedative infusions. Other infusions can be restarted as indicated by the clinical situation by an experienced clinician. (Class IIA, Level C)

Cardiac Arrest in Patients With Intraaortic Balloon Pump

Patients with an IABP present special considerations. Whereas VF or asystolic arrests are readily identified on the ECG, pulseless electrical activity or an asystole arrest with an active pacemaker may continue to trigger the IABP. The resulting arterial waveform falsely suggests cardiac ejection and cardiac output. Cardiac arrest is confirmed by the loss of the cardiac component of the IABP pressure trace or by the loss of pulsatility in other pressure waveforms such as the central venous pressure, pulmonary artery, end-tidal carbon dioxide, or pulse oximetry tracings. Pausing the IABP may help to confirm that the patient is in cardiac arrest.

After a cardiac arrest, ECG recordings are either absent or highly variable and subject to artefact from chest compressions, making the ECG unreliable as a trigger for the IABP. Pressure trigger mode, however, will coordinate diastolic balloon inflation with cardiac massage and may help improve mean blood pressure as well as coronary artery perfusion pressure. Once cardiac arrest is established, therefore, the IABP should be set to pressure trigger mode with 1:1 counterpulsation at maximal augmentation. That will allow augmentation of cardiac massage and improved cardiopulmonary resuscitation, without interference from the ECG trace. If there is a period with no cardiac output and no cardiac massage, the IABP may be set to internal trigger at 100 beats per minute.

Suggestions

- In cardiac arrest with an IABP in place, the IABP should be set to pressure trigger mode. (Class IIA, Level C)
- If there is a significant period without massage, triggering should be changed to an internal mode at a rate of 100 beats per minute until massage is recommenced. (Class IIA, Level C)

Management of the Cardiac Arrest

We have identified six key roles for clinical staff in the cardiac arrest situation after cardiac surgery and

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evaluated them in manikin simulation [17]. Group simulation training should be given in the conduct of these six key functions. When the cardiac arrest occurs, each role should be taken by appropriately trained persons (Fig 2).

1. External Cardiac Massage: Once the cardiac arrest has been established, one person is allocated to ECM. That should begin at a rate of 100 to 120 beats per minute while looking at the arterial trace to assess effectiveness. The only exception to this is when immediate defibrillation or pacing is appropriate before ECM.
2. Airway and Breathing: The second rescuer increases the inspired oxygen to 100%, removes positive end-expiratory pressure, and assesses airway and breathing per protocol specifically to exclude pneumothorax, hemothorax, or an endotracheal tube problem.
3. Defibrillation: This person connects the defibrillator and administers shocks, if indicated. He or she is also assigned to manage pacing, and if emergency resternotomy is performed, this person must ensure that the internal defibrillator is available on the sterile field and properly connected.
4. Team Leader: This senior person should conduct overall management of the cardiac arrest, ensuring that the protocol is followed and a person is allocated to each role. In addition, the senior person ensures that a team quickly prepares for resternotomy.
5. Drug Administration: This person stops all infusions after initial resuscitative efforts have failed, administers amiodarone, and manages other drugs or infusions as appropriate.
6. Intensive Care Unit Coordinator: The role of this person, typically a charge nurse or senior nursing unit leader, is to coordinate activity peripheral to the bedside. That includes preparing for potential resternotomy as soon as a cardiac arrest is called, directing available personnel, and calling for expert assistance if not immediately available while continually reporting progress to the team leader.

Resternotomy Team

In addition to the six key roles above, a resternotomy team should be identified and immediately gown and glove in preparation for emergency resternotomy. That should occur **immediately upon identifying a cardiac arrest**, rather than waiting until other conservative attempts at resuscitation have failed. Because arrest due to tamponade is always a possibility, this team must be sufficiently trained to always be able to perform a resternotomy within 5 minutes of arrest in the ICU.

Amiodarone

Evidence was sought as to whether amiodarone or lidocaine may be useful for VF/pulseless VT, not responding to defibrillation. This search is fully documented [38], together with a summary of eight identified papers, including four large randomized trials [39–42].

Amiodarone should be given as a bolus injection of 300 mg. A further dose of 150 mg may be given for recurrent or refractory VF/VT, followed by an infusion of 900 mg over 24 hours. Lidocaine 1 mg/kg may be used as an alternative and may have a similar efficacy [42].

Suggestions

- After three failed attempts at defibrillation for VF/pulseless VT, a bolus of 300 mg intravenous amiodarone should be given through the central line. (Class IIA, Level A)

Automated External Defibrillators

For noncardiac surgical patients, automated external defibrillators have been recommended in certain circumstances to facilitate defibrillation, despite varied results in animals and manikins that often showed a delay in defibrillation. Only one case report of automated external defibrillator use in cardiac surgery was found, and the patient was on cardiopulmonary bypass [43]. In cardiac surgical patients, the importance of rapid defibrillation or immediate resternotomy cannot be overemphasized. Automated external defibrillators will not deliver three shocks as rapidly as trained clinicians and may delay the decision to perform resternotomy; therefore, we do not recommend automated external defibrillators for use with cardiac surgical patients in the ICU when manual defibrillators are available.

Suggestions

- Automated external defibrillators should not be used in cardiac surgical patients in the ICU when a manual defibrillator is available. (Class III [harm], Level C)

Automatic External Compression Devices

These devices are available in some hospitals but have not yet been tested on patients after a sternotomy. They should not be used in cardiac surgical patients until their safety in this context can be demonstrated.

Suggestions

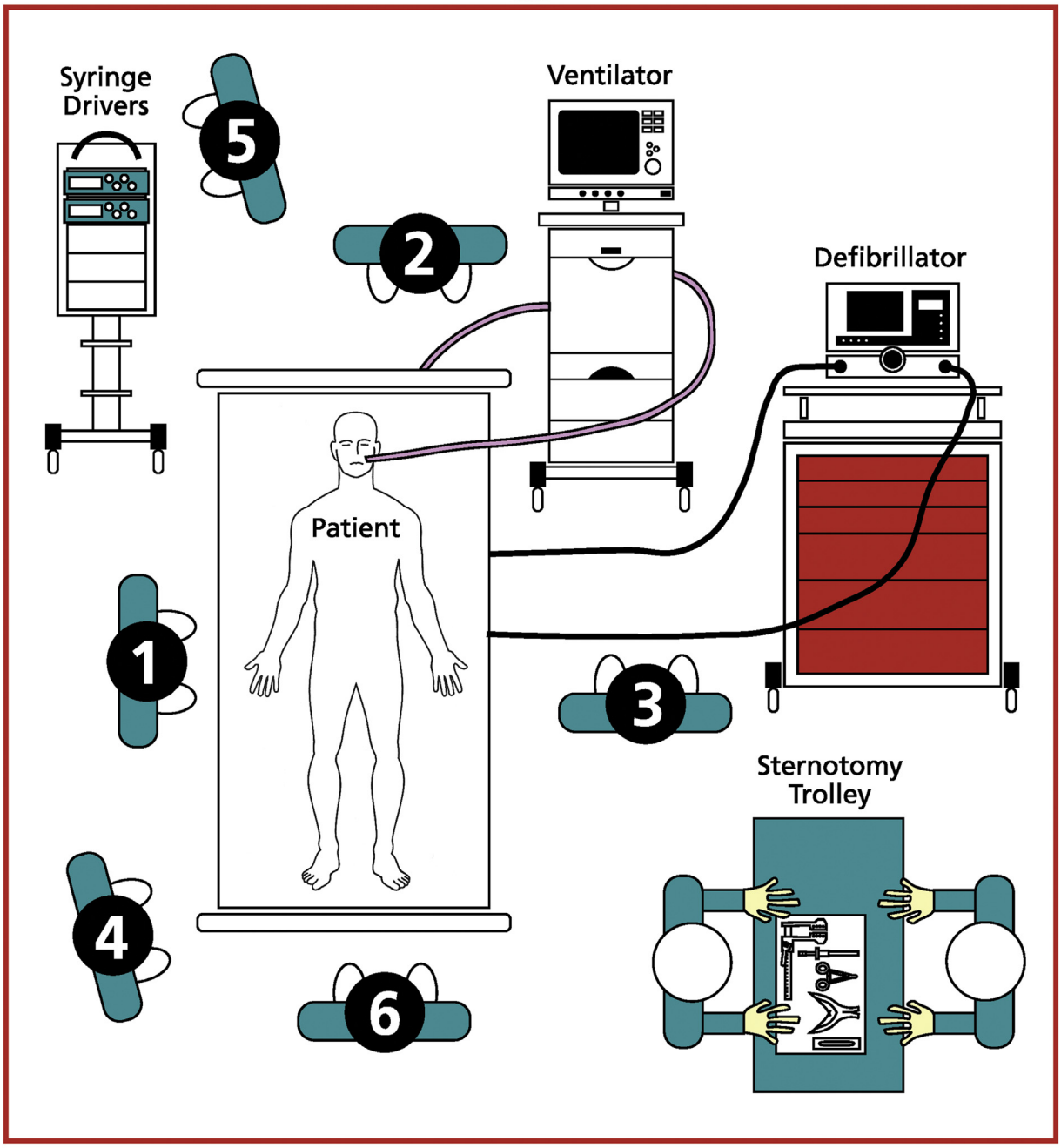
- Automated external compression devices should not be used on cardiac surgical patients. (Class III [harm], Level C)

Pacing

Rhythms amendable to defibrillation are present in 30% to 50% of patients having a cardiac arrest. The remainder have other rhythms, which cannot be treated by defibrillation. Of these, predominant rhythms that may be amenable to pacing are severe bradycardia or asystole (Fig 1).

If epicardial pacing wires are in place, they should be immediately connected to a pacemaker. This device

Six key roles in the cardiac arrest



Six key roles in the cardiac arrest:

1. External cardiac massage
2. Airway and breathing
3. Defibrillation
4. Team leader
5. Drugs and syringe drivers
6. ICU co-ordinator

should be set to dual chamber pacing at a rate of 80 to 100 beats per minute using maximal atrial and ventricular outputs. If that fails to restore cardiac output or if there is a delay in obtaining pacing equipment beyond 1 minute, ECM must be commenced.

Many pacing generators have emergency settings using a single button that delivers maximal outputs with asynchronous pacing. They are acceptable, and providers should be trained in their use.

In the absence of epicardial pacing wires, pacing can be achieved using external (transcutaneous) pacing if it seems likely that the cardiac arrest is due to an extreme bradyarrhythmia. We have prioritized this intervention after ECM has commenced, owing to the additional complexity in setting up external pacing and our repeated observations that clinicians are often unfamiliar with this intervention even after training.

If the pacemaker is connected and functioning before the cardiac arrest, and the patient has arrested with an ECG showing pulseless electrical activity at a rate that looks like a paced rhythm, the pacemaker spikes on the monitor may disguise underlying VF. We recommend that, in this situation, the pacemaker should be paused and the rhythm evaluated to exclude underlying VF.

Suggestions

- For asystole or severe bradycardia, connect the epicardial pacing wires and set to DDD mode at 80 to 100 beats per minute at the maximum atrial and ventricular output voltages. If the pacing generator has an emergency pacing button, it may be used. (Class I, Level C)
- If the rhythm is pulseless electrical activity and a pacemaker is connected and functioning, then briefly turn off the pacemaker to exclude underlying ventricular fibrillation. (Class IIA, Level C)

Atropine

The benefit of atropine is not well established. Five prospective, nonrandomized, controlled trials involving noncardiac surgical patients failed to establish a survival benefit for inhospital or out-of-hospital cardiac arrest [44].

We were unable to find any further evidence in favor of atropine in the cardiac surgical literature. It is also not advocated in the universal algorithm, and our expert consensus group believed that a cardiac arrest due to bradycardia or asystole would ideally be treated with pacing and that atropine administration would only create delay. Therefore, we do not support atropine as a standard part of the cardiac arrest protocol.

Suggestions

- For patients with asystole or extreme bradycardia, atropine is not recommended as a routine part of the protocol. (Class III [no benefit], Level C)

Emergency Resternotomy After Non-VF/VT Arrest

In noncardiac surgical patients, non-VF/VT arrests are associated with poor outcomes. The AHA guidelines ask clinicians to consider the following as causes of the cardiac arrest: hypoxia, hypovolemia, hypokalemia or hyperkalemia, hypothermia, hydrogen ions, tension pneumothorax, thromboembolism, tamponade, and toxins—the so-called "H"s and "T"s.

In contrast, cardiac surgical patients who have a non-VF/VT arrest are likely to have tamponade, severe hypovolemia, or tension pneumothorax. Prompt treatment is associated with an excellent outcome, and the impact of delays to perform resternotomy should therefore not be minimized.

If each of the "H"s and "T"s are considered in turn, it is apparent that none of these should delay resternotomy. Reversible causes of hypoxia should have been addressed as part of the basic life support protocol already described. Hypovolemia as a cause of arrest will inevitably require a resternotomy to control the bleeding.

Hypokalemia, hyperkalemia, and hydrogen ions are unlikely causes of arrest after cardiac surgery as serum potassium and pH are carefully monitored. If that is the cause for arrest, a prolonged period of cardiopulmonary resuscitation may be needed, and is more effective when performed by internal massage or on bypass.

Hypothermia causing arrest is unlikely, but active rewarming on bypass is preferable to passive rewarming that would already have been used in the ICU before the cardiac arrest. Toxins are also unlikely, but cessation of infusions is the preferred approach unless clinical suspicions regarding a specific drug are raised.

Tension pneumothorax should be identified by the assessment of the airway and breathing during basic life support and treated by chest tube drainage. If undetected clinically, it will be promptly relieved by emergency resternotomy.

Tamponade requires immediate resternotomy; it is the commonest cause of non-VF/VT arrest after cardiac surgery and is the reason that a resternotomy team must always be available within 5 minutes.

Finally, thromboembolic or mechanical obstruction such as a pulmonary embolus, coronary thrombosis, or obstructed valve will be difficult to treat without cardiopulmonary bypass for stabilization.

Therefore, for a non-VF/VT cardiac arrest that does not resolve after exclusion of an airway or respiratory problem and by following the protocol presented here, prompt resternotomy should be performed. We recommend this within 5 minutes, and that is mandatory if the systolic pressure with external massage is less than 60 mm Hg. Rapid initiation of extracorporeal membrane oxygenation (ECMO) is an acceptable alternative within the same time frame in expert institutions who have the availability of rapid ECMO deployment. If a systolic blood pressure of

Fig 2. The Society of Thoracic Surgeons protocol for the organization of the six key roles in the cardiac arrest: (1) external cardiac massage; (2) airway and breathing; (3) defibrillation; (4) team leader; (5) drugs and syringe drivers; and (6) intensive care unit coordinator. (ICU = intensive care unit.)

60 mm Hg is consistently achieved with external massage, then it is acceptable to defer emergency resternotomy beyond 5 minutes, although this protocol will already have addressed all reversible causes, and therefore it is unlikely that intentional delay will result in superior outcomes compared with rapid resternotomy. If the resternotomy is delayed more than 5 minutes, the resternotomy team should remain available, gowned and gloved, by the bedside should the team leader then require them.

Suggestions

- In a non-VF/VT cardiac arrest that does not resolve after pacing and exclusion of readily reversible causes, emergency resternotomy should be performed within 5 minutes. (Class I, Level C)

Conduct of Emergency Resternotomy

Internal Versus External Cardiac Massage

Evidence was sought to compare the efficacy of internal to external cardiac massage. This search is fully documented together with a summary of 15 identified papers [45], and the International Liaison Committee on Resuscitation also provided a systematic review of the topic as part of the worksheet review process [46]. They report the benefits of internal cardiac massage that includes better coronary perfusion pressure, increased return of spontaneous circulation, superior organ blood flow, and better survival rates as compared with ECM. They recommend consideration of open-chest cardiopulmonary resuscitation for cardiac arrest in the early postoperative phase after cardiothoracic surgery or when the chest or abdomen is already open. There are risks associated with resternotomy and internal cardiac massage including cardiac and graft injury that could be reduced with appropriate technique. We recommend internal cardiac massage by appropriately trained personnel to improve the quality of resuscitative efforts or if cardiopulmonary resuscitation extends beyond 5 minutes.

Suggestions

- Internal cardiac massage is superior to external cardiac massage. In patients with a recent sternotomy in whom resuscitative efforts are likely to last more than 5 minutes, emergency resternotomy is indicated to perform internal cardiac massage. (Class IIA, Level C)

Abdominal Compression as Alternative to External Cardiac Massage

Evidence was sought to assess the efficacy of abdominal-only ECM compared with ECM. This search is fully documented with a summary of 10 papers [47]. We conclude that abdominal-only resuscitation theoretically has the potential to provide systemic perfusion while an emergency resternotomy is being performed, but further evidence is needed before it can be recommended for routine use.

Emergency Resternotomy Set

If a resternotomy is to be performed rapidly, ICU staff must be trained in this multipersonnel procedure. One reason for delay in emergency resternotomy is the preparation of a standard sternotomy instrument set [17], which may contain more than 30 items of equipment, although only five items are essential: a scalpel, a wire cutter, a heavy needle holder, a single piece sternal retractor, and a sucker (Fig 3). Surgical scissors and an all-in-one sterile thoracic drape may also be useful. Larger sets are unnecessary in the setting of an emergency resternotomy and may serve to confuse staff unaccustomed to assisting in surgery. In addition, when the operating team arrives, the full thoracic instrument set may be lost or contaminated when opened emergently by the ICU staff, and need replacement.

We recommend that every cardiac surgical ICU be equipped with a small emergency resternotomy set (Fig 3). Once the chest has been opened, this set can be discarded and a full set opened in a more measured fashion. This concept is not new and dates back to 1985 [48].

Suggestions

- A small emergency resternotomy set should be available in every ICU, containing only the instruments necessary to perform the resternotomy. They should include a disposable scalpel attached to the outside of the set, a wire cutter, a heavy needle holder, a single piece sternal retractor, and a sucker. An all-in-one drape and scissors is also very useful.
- This small set should be in addition to a full cardiac surgery sternotomy set, which need not be opened until after the emergency resternotomy has been performed.
- These sets should be clearly marked and checked regularly. (Class I, Level C)

Preparation for Emergency Resternotomy

Emergency resternotomy is required for 20% to 50% of cardiac arrests after cardiac surgery [8, 14]; and it is a multipractitioner procedure that should ideally be

Fig 3. Recommended emergency resternotomy set.

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performed as rapidly as possible using full aseptic technique. Two or three staff members should gown and glove and prepare for an emergency resternotomy as soon as a cardiac arrest is called. Handwashing is time consuming in an emergency situation and incomplete drying of the hands will slow the donning of gloves. Therefore, handwashing is not necessary if an aseptic closed-sleeve technique in donning gown and gloves is used.

Suggestions

- Two to three staff members should put on gown and gloves as soon as a cardiac arrest is called, and prepare the emergency resternotomy set. (Class IIA, Level C)
- Handwashing is not necessary before closed-sleeve donning of gloves. (Class IIA, Level C)

Personnel Performing Emergency Resternotomy

Emergency resternotomy may be required for 0.8% to 2.7% of all patients undergoing cardiac surgery. Although an experienced surgeon is optimal, there may be situations in which the surgeon is either unavailable or unable to attend immediately. As resternotomy is often an integral part of successful resuscitation after cardiac surgery, it is beneficial for all personnel who participate in resuscitations in this setting to be aware of and practice the technique of emergency resternotomy. That ensures better assistance for the surgeon and, in the unlikely situation that resternotomy is required and a surgeon is not immediately available, resternotomy by another staff member may be life-saving.

If there are gaps in availability for 24-hour surgeon coverage, we recommend that nonsurgeons be trained and certified to perform emergency resternotomy. Physician assistants and advanced practice nurses, or senior intensive care nurses, may be the ideal clinicians to undergo this training and provide the necessary coverage on site, although it is up to local units to allocate these roles and ensure adequate training to ensure competency. The Association of Physician Assistants in Cardiovascular Surgery has set up a charitable organization to promote training of this protocol in the United States to assist with this task (available at: www.csu-als.com).

Emergency Resternotomy

- Two or three providers don a gown and gloves in a sterile fashion using the closed-glove technique. The ECM must continue until you are ready to apply the all-in-one sterile thoracic drape.
- When ready, ask the person performing ECM to stand aside after removing the sternal dressing.
- Apply preferably an all-in-one sterile drape (single, full-bed, sterile drape with an operative plastic window), or skin preparation followed by appropriate thoracic draping, ensuring the whole bed is covered by drapes.
- Recommence ECM (changeover from nonsterile ECM to sterile ECM should take no more than 10 seconds).
- When equipment is ready (Fig 3), cease ECM and use the scalpel or scissors to cut the sternotomy incision, including all sutures deeply down to the sternal wires.
- Cut all sternal wires with the wire cutters and pull them out with the heavy needle holder. The sternal edges will separate and a tamponade may be relieved at this point if present. This is significantly faster if one person cuts the wires with the wire cutter and a second assistant removes the wires with the heavy needle holder.
- Use sterile suction to clear excessive blood or clot.
- Place the retractor between the sternal edges and open the sternum. If cardiac output is restored, you have successfully treated the cardiac arrest and should wait for expert assistance.
- If there is no cardiac output, carefully identify the position of any grafts and then perform two-handed internal cardiac massage and internal defibrillation as appropriate.
- If the pericardium or mediastinal fat has been closed over the heart, the sutures used for this should be carefully and slowly cut to allow visualization of the heart.

Method of Internal Cardiac Massage

This procedure is potentially injurious to the patient, and any personnel who may be required to perform it must undergo prior training to carry this out safely. Risks to the patient include avulsion of a bypass graft, with the left internal mammary artery being at particular risk. Inexperienced providers should not rush to perform internal cardiac massage after opening the chest. It is essential to carefully remove any clot and identify structures at risk such as grafts before placing your hands around the heart. Single-hand massage techniques may disrupt the right ventricle, especially if it is thin or distended.

There are several acceptable methods of internal massage, and experienced providers may use the technique that is most suitable for the clinical situation. In our view, the two-handed technique is safest for people who do not routinely handle the heart.

Before attempting internal massage, inspect the heart to locate the internal mammary and other grafts, carefully removing blood clots. Pass the right hand over the apex of the heart (minimizing the likelihood of avulsing grafts, as these are rarely placed near the apex). The right hand is then further advanced round the apex to the back of the heart, palm up and hand flat. The left hand is then placed flat onto the anterior surface of the heart, and the two hands are squeezed together. Flat palms and straight fingers are important to avoid an unequal distribution of pressure onto the heart, thereby minimizing the chance of trauma.

If there is a mitral valve replacement or repair, care should be taken not to lift the apex by the right hand, as this can cause a posterior ventricular rupture. Squeeze both hands together at a rate of 100 to 120 beats per minute and look at the arterial trace to verify adequate

internal massage. You should try to obtain a systolic impulse of more than 60 mm Hg.

Cardiac Arrest Protocol and Emergency Resternotomy Outside ICU

Emergency resternotomy outside of the ICU is associated with poor survival although, occasionally, patients do survive [8, 11, 49]. Postoperative wards may not only care for patients after cardiac surgery, but may also have thoracic surgical or medical patients. It is important that members of a resuscitation team have clearly defined resuscitation protocols, and this guideline is appropriate only for patients who have recently undergone cardiac surgery.

While emergency resternotomy is less effective outside of an ICU and we cannot recommend it be performed routinely on the ward, our defibrillation, pacing strategies, and epinephrine recommendations remain appropriate and are preferred to the AHA guidelines if the patient has undergone cardiac surgery. In addition, arrangements should be made locally for experienced cardiac surgical personnel to be immediately available to attend a cardiac arrest on the ward.

Local guidelines as to the appropriate location and personnel for an emergency resternotomy should be defined that address circumstances for emergency resternotomy on the ward. It may be preferable to use trained ICU personnel with their emergency resternotomy equipment on the ward, or alternatively, to transport the patient immediately to the ICU or operating room [49].

Finally, if a ward is mixed specialty and there is the potential for confusion as to which protocol to use in an emergency, the AHA guidelines should be used. Local ward-based protocols should be created to ensure that there is no confusion.

Suggestions

- In mixed ward areas outside of the ICU, it may not be appropriate to follow this guideline. Immediate defibrillation or pacing, and epinephrine dosing, as described here, is preferred in lieu of the 2015 AHA guidelines.
- Local protocols for emergency resternotomy outside of the ICU should be drawn up and rehearsed.

How Long After Cardiac Surgery Is Emergency Resternotomy No Longer Indicated?

As the patient recovers from cardiac surgery, the chance of a cardiac arrest due to a cause that can be corrected by emergency resternotomy is reduced. The majority of tamponades, graft occlusions, or even arrhythmias will occur in the hours after cardiac surgery. However, delayed tamponade may still occur. That may be due to pacing wire removal or excessive anticoagulation therapy. For cardiac arrests occurring several days after cardiac surgery, the internal cardiac massage technique remains a superior method of resuscitation compared with ECM. Therefore, even if a reversible cause such as tamponade is not suspected, emergency resternotomy is indicated in preference to prolonged ECM. However, that must be balanced against the danger of resternotomy once adhesions have started to form.

It is the opinion of the task force that significant adhesions would be unlikely to be present until at least 10 days postoperatively. Therefore, emergency resternotomy should form a standard part of the cardiac arrest protocol until the 10th postoperative day. Thereafter, emergency resternotomy should be considered but a senior clinician should make the decision as to whether the resternotomy is performed, balancing the risks of damage to increasingly adherent mediastinal structures with the likely chances of a successful outcome to the cardiac arrest with emergency resternotomy.

Suggestions

- Emergency resternotomy should form an integral part of the cardiac arrest protocol until the 10th postoperative day. (Class IIA, Level C)
- Beyond the 10th postoperative day, a senior clinician should decide whether emergency resternotomy should still be performed. (Class IIA, Level C)

Cardiopulmonary Bypass After Emergency Resternotomy

If spontaneous cardiac output has not been established after emergency resternotomy and internal cardiac massage, a further option is the institution of cardiopulmonary bypass. We found no papers to guide the technical aspects of the safe passage onto bypass in this special situation, although Rousou and associates [50] documented a 56% survival among 16 patients with refractory VF despite open chest cardiopulmonary resuscitation who were then placed on bypass in the ICU.

We make the following best practice recommendations:

- There is a concern that the heparin may not circulate fully in a cardiac arrest. In addition to an immediate dose to the patient of 30,000 IU heparin as early as possible before commencement of cardiopulmonary bypass, we recommend that 10,000 IU heparin be added to the bypass machine reservoir. It is not necessary to check an activated clotting time before commencing cardiopulmonary bypass.
- Cannulas may be inserted into the aorta and right atrium without pursestring sutures and held by assistants until purse-strings are applied on bypass. Surgeons should be aware that the right atrial pressure will be substantially higher than in routine cannulation, and prior connection of the venous cannula to the circuit will reduce blood loss.
- In units expert in the use of peripheral ECMO, that may be instituted in preference to central cannulation, and local protocols should be constructed to manage this situation and rehearsed on a regular basis. (See www.elso.org for guidelines on this issue.)

Suggestions

- In addition to an immediate dose to the patient of 30,000 IU heparin as early as possible before

commencement of cardiopulmonary bypass, we recommend that 10,000 IU heparin be added to the bypass machine reservoir. (Class IIA, Level C)

Should Patients After Emergency Resternotomy Receive Additional Antibiotics?

Evidence was sought for whether additional antibiotics reduces the incidence of mediastinitis after emergency resternotomy. This search is fully documented, and nine papers are summarized [51]. For patients who require an emergency resternotomy in the ICU, the incidence of sternal wound infection or sepsis after this emergency treatment is approximately 5% of survivors in these papers. Of those, five studies reported routine additional intravenous antibiotics and an iodine washout.

We conclude that the incidence of subsequent infection is low in emergency resternotomy after cardiac arrest, and that full aseptic technique including gown and gloves is both indicated and feasible. It is common practice also to give additional antibiotics and an antiseptic washout, although we could identify no comparative studies to support of this.

Suggestions

- It is common practice to perform an antiseptic washout after emergency resternotomy and to give additional intravenous antibiotics. That is reasonable and is indicated if the resternotomy has not been performed using full aseptic techniques. (Class IIA, Level B)

Induced Hypothermia After Resuscitation From Prolonged Cardiac Arrest

Current AHA guidelines recommend that comatose (ie, lack of meaningful response to verbal commands) adult patients with return of spontaneous circulation after cardiac arrest have targeted temperature management. It is recommended to select and maintain a constant temperature between 32° and 36°C during targeted temperature management. Targeted temperature management should be maintained for at least 24 hours after achieving target temperature.

Vollroth and colleagues [52] described a protocol for cooling after cardiac surgery, and targeted temperature management should be considered if it is thought that there has been a significant period of poor cerebral perfusion during the resuscitation period.

Special Considerations

There are many special considerations within cardiac surgery related to the specific operative procedures. The cases below serve as examples, and all clinicians should consider whether the patient that they are returning to the ICU may present a particular challenge should cardiac arrest occur, and if so, that should be clearly documented and discussed with the ICU staff.

Transplant Patients

Patients undergoing heart, heart-lung, or double lung transplant through a sternotomy may be resuscitated using these guidelines. Patients having a transplant procedure through a clam-shell incision or bilateral thoracotomy incisions may have an emergency reopening of the clam-shell incision using the same indications in this guideline. Patients with bilateral thoracotomy may need a sternotomy in case of an arrest. Only a surgeon experienced in this particular approach should perform this procedure, and local guidelines should be drawn up to address these issues.

Pediatric Patients

The only reported series that we found sets the incidence of cardiac arrest at 4% after cardiac surgery in children [53]. The success of resuscitation is similar to that of adult patients and the causes are also similar, although 11% had a respiratory arrest in this series. This guideline should be read together with the AHA guidelines on pediatric cardiac arrest. Pediatric cardiac surgery ICUs may use this protocol, but it must be noted that none of the drug dosages are intended for use in children, and all dosages must be corrected for body weight or surface area, as is the usual practice for drug administration in pediatrics. Rehearsing for emergency situations in pediatric cardiac surgery has been shown to improve outcomes [54].

Open Chest Patients

Occasionally after a high-risk operation, a patient will be returned to the ICU with the sternum open. The heart may be surrounded by gauze packs, especially if bleeding has been difficult to control. Such patients are at high risk for cardiac arrest. The surgeon should hand over specific guidelines for their care should a cardiac arrest occur. However, we recommend that they be cared for using this guideline.

The ECM should be performed at the midpoint of the chest, over the packs, and the arterial pressure trace should be observed to assess the effectiveness of external massage. Less force may be required for open chest patients. If emergency internal cardiac massage is then indicated, full aseptic technique should be used, and that will be easier as sternal wires will not need to be removed. In particular, the packs may contribute to cardiac compression, inducing an element of tamponade, and should be carefully removed, making sure that no grafts are adherent to them.

Patients With Cardiac Assist Device

All clinicians caring for these patients should have full training in the procedures for equipment failure and the "cardiac arrest" situation. These are highly complicated situations in that an "arrest" may be due to mechanical failure. In this situation, there may be steps particular to the device that should be taken and rehearsed. Of note, we summarized the evidence for ECM in patients with ventricular assist devices [55]. There are isolated case

reports of successful ECM without damage to the ventricular assist device, but the evidence is limited to individual case reports at this time. External massage may be particularly useful to decompress a nonfunctional right ventricle in cardiac arrests, and often the right ventricle may be the cause of the situation.

Patients with an implantable left ventricular assist device such as a HeartMate or HeartWare device should have the same algorithm followed as the universal algorithm for cardiac arrest after cardiac surgery. The rhythm should be ascertained: patients with VF should be defibrillated; asystole should receive pacing; and in patients with pulseless electrical activity, it should be verified that there is not underlying VF. Massage should be performed if immediate resuscitative efforts fail. Importantly, the airway and breathing checks should always be performed, as described earlier.

There may be difficulty confirming an arrest in these patients. A patient with invasive monitoring should be considered to have arrested if the arterial line reads the same as the central venous pressure line. In extubated patients without invasive monitoring, if the patient has no signs of life and is not breathing normally, then they should be considered to have had a cardiac arrest. Transthoracic or transesophageal echocardiography, waveform capnography, or Doppler flow readings in a major artery may assist in the diagnosis of whether there is meaningful perfusion. Also, these devices display pump flow, and that should be used to assist in the diagnosis of whether there has been a genuine loss of blood flow, or whether there is just a low-flow situation with reduced level of consciousness.

Resternotomy should be performed in cases of an established arrest less than 10 days after surgery, and after this time, either resternotomy or ECMO is a reasonable option. If ECMO is initiated, the left ventricular assist device must be shut off.

Also of note, it is possible for a patient to have asystole or VF but adequate cerebral blood flow due to adequate and continued pump flow. If the patient is conscious and responding, then you will have more time in which to resolve this arrhythmia and ECM will not be needed.

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Patients Undergoing Nonsternotomy Cardiac Surgery

Some cardiac operations avoid a full sternotomy. They may range from a partial sternotomy, port access surgery with a minithoracotomy, or minimally invasive coronary artery bypass surgery to totally endoscopic coronary artery bypass surgery. It is appropriate to follow this guideline, and it is important that the ICU have only one protocol for the initial management of a cardiac arrest.

The operating surgeon should, however, ensure that the staff members are fully aware of how an emergency reopening should be performed should cardiac arrest occur. In these cases, it is acceptable for the operating surgeon to indicate that a reopening should not occur unless a senior surgeon familiar with the particular operation is present. That should be discussed with the ICU on admission from the operating room.

It should be noted that internal cardiac massage is difficult to perform from a right thoracotomy, such as that used in port access mitral surgery, and therefore it is likely that, in the event of a cardiac arrest, these patients should receive a sternotomy by an experienced surgeon rather than rethoracotomy.

If sternotomy is the chosen protocol in a unit, then a sternal saw should be available immediately on the ICU for these patients. The ICU staff should practice setting up the saw and getting it to work, as it may otherwise cause further significant delays in performing the sternotomy. Of note, the saw must only be used by surgeons who are experienced in its use, and while they are awaited, the team should continue ECM. Alternatively, urgent 24-hour access to an operating room should be available should this be necessary.

Similarly, a patient undergoing coronary artery bypass grafting through a minimally invasive coronary artery bypass surgery incision should undergo a sternotomy rather than extending the incision laterally in a cardiac arrest. The sternotomy allows full access to the heart and is most familiar to the resuscitation surgeon and team. It should be noted that the left internal mammary artery may not have been fully harvested from the chest wall, and extra care should be taken if internal massage or cardiac manipulation is required.

For nonsternotomy patients with previous cardiac surgery, a sternotomy will not be possible. In that case, femoral cannulation or ECMO may be required. Experienced surgeons performing nonsternotomy surgery may also consider ECMO as an alternative to sternotomy for their minimally invasive patients, and that is also acceptable as a written protocol and is proven to be of benefit [56].

Suggestions

- Surgeons who perform nonsternotomy surgery should make their ICU staff aware of their preferences for management during a cardiac arrest, preferably by means of a written protocol.
- Options include sternotomy in the ICU, sternotomy in an operating room, or ECMO. Preparations should be made for these eventualities.
- Patients who arrest after minimally invasive coronary artery bypass surgery, totally endoscopic coronary artery bypass surgery, robotic endoscopic coronary artery bypass graft surgery, port access mitral surgery, ministernotomy, or minithoracotomy aortic valve surgery should undergo a full sternotomy after following our protocol, but only by experienced clinicians trained in sternotomy. An acceptable alternative is ECMO. (Class IIA, Level C)

Protocol Implementation

The transition phase of modifying resuscitation protocols in the ICU represents a time of high risk to both patients

and staff. In particular, there are clear dangers in changing from a single-shock protocol followed by cardiac massage to a three-sequential shock protocol. The change should be discussed in advance as a team responsible for care on the unit. Ideally, training should be given in advance of a practice change. Online resources, such as www.csu-als.com, for training and certification can assist in this effort.

We recommend that all care providers and units caring for cardiac surgical patients practice this protocol on a regular basis and document competencies.

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