STS expert consensus for the resuscitation of patients who arrest after cardiac surgery

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Executive Summary	451 words
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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 including 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 MEDLINE with keywords, “cardiac surgery, resuscitation, guideline, thoracic surgery, cardiac arrest, 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 STS Workforce on Critical Care was enlisted in this process to provide a wider variety of experience and backgrounds in an effort to reinforce the opinions.

We start with the premise that external massage is ineffective in tamponade or extreme hypovolemia, and that 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.

Secondly, because internal massage is more effective than external massage, it should therefore be used preferentially if other quickly reversible causes are not found.

We present a protocol for the arrest situation that includes the following recommendations: 1) successful treatment of a patient who arrests following cardiac surgery is a multipractitioner activity with at least 6 key roles that should be allocated and rehearsed on a regular basis; 2) patients who arrest with ventricular fibrillation should immediately receive 3 sequential attempts at defibrillation prior to external cardiac massage(ECM), and if this fails emergency resternotomy should be performed; 3) patients with asystole/extreme bradycardia should have an attempt to pace if wires are available prior to ECM, then optionally external pacing followed by emergency resternotomy; 4) pulseless electrical activity should receive prompt resternotomy once quickly reversible causes are excluded. Finally, we have determined that full doses of epinephrine should not be routinely given due to the danger of extreme hypertension if a reversible cause is rapidly resolved and a lack of proven efficacy.

Protocols for excluding reversible airway and breathing complications, for left ventricular assist device (LVAD) emergencies, for the non-sternotomy patient and for safe emergency resternotomy are given. 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.

Keywords : Cardiac surgery, resuscitation, guideline, thoracic surgery, cardiac arrest, cardiac massage.

1. Introduction

The American Heart Association (AHA) issued its latest edition of guidelines for resuscitation in October 2015[1]. This does 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 recommend resternotomy within 5 minutes of an arrest, allowing any trained practitioner to perform this task. They warn against full dose epinephrine and allow external cardiac massage to be deferred while 3 stacked shocks are given or pacing is commenced. The ERC guidelines fully support the guideline published by the European Association of Cardiothoracic Surgery (EACTS) 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 an arrest after cardiac surgery is sufficiently different from patients in general to warrant its own treatment algorithm in order to optimise post-arrest survival in this group of patients.

Every year, more than 400,000 patients undergo cardiac surgery in the US at one of approximately 1200 centers[4-6]. The incidence of cardiac arrest after cardiac surgery is around 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 for the arrest, and their occurrence in highly monitored settings where prompt recognition and

treatment are more likely. Ventricular fibrillation (VF) is the arrest etiology in 25-50% of cases and, in the intensive care unit (ICU) setting this is immediately identified and treated. Tamponade and major bleeding account for a large percentage of the additional arrests; both conditions can be quickly relieved by prompt resuscitation and emergency resternotomy.

Prompt recognition and treatment by ICU staff well versed in managing these arrests improves survival. Practicing protocol-based arrest management has been shown to halve the time to chest reopening and reduce complications in the conduct of the resternotomy after cardiac surgery [16-18].

The protocol presented here addresses many issues particular to our specialty including the timing of emergency resternotomy, the number of attempts at defibrillation before resternotomy, the administration of epinephrine, ventilator management, infusion and pacemaker settings, emergency resternotomy sets, the use of the intra-aortic balloon pump (IABP), and cardiac arrests on the ward and in special circumstances.

This protocol applies to all patients in the ICU and includes pediatric, minimal access and transplant patients, but not patients undergoing pulmonary surgery. Issues regarding the treatment of patients in mixed specialty wards are discussed.

In the generation of our evidence we support and fully utilise the ACCF/AHA clinical practice guideline methodology [22] including their grading of recommendations as advocated by the STS.

2. The Protocol for cardiac surgical patients in the ICU

The recommended modification of the American Heart Association algorithm to be applied in cardiac arrest after cardiac surgery is presented in figure 1.

We recommend that this protocol be used in the intensive care unit (ICU) in preference to the Advanced Cardiac Arrest algorithm that is currently advocated [1] . Major differences between the protocols are addressed below. Furthermore, we recommend that emergency resternotomy is a standard part of the resuscitation protocol until 10 days post-surgery. In patients beyond day 10, the protocol should still be followed but a senior clinician should decide if resternotomy is indicated. In these later post-surgical patients, the perceived benefit of resternotomy must be balanced against the increased difficulty of open resuscitation due to the development of pericardial adhesions.

3. Defibrillation/pacing prior to external cardiac massage.

One major change recommended by this guideline 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 external cardiac massage for 2 minutes[23]. Thereafter, the rhythm is reassessed and ECM ceased if evidence of spontaneous circulation is found. The AHA makes no recommendations for the use of the temporary pacing wires in asystolic arrest.

Cardiac surgical patients are sufficiently different from non-cardiac surgical patients, to justify an important departure from this guideline. In recommending 3 sequential shocks for VF or the initiation of temporary pacing for asystole prior to ECM we have considered several factors:

3.1. Is ECM required before defibrillation?

Evidence was sought for 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 (ILCOR) who state that there is no benefit of external cardiac massage prior to defibrillation for in-hospital patients.[25][26]. In addition to lack of benefit of preliminary ECM, there is also potential for trauma. We identified 4 patients in the cardiothoracic literature who suffered massive hemorrhage after external cardiac massage [27][28]. However, several cohort studies of patients receiving ECM after cardiac surgery documented that there were no injuries seen due to this in their series[10] [30] . In the non-cardiac surgical literature a meta-analysis of 23 studies demonstrated that the incidence of pericardial injury after ECM was 8.9%, sternal fracture rate was 15% and post-resuscitation rib fractures was 32%[29]. They also document numerous case reports of myocardial lacerations and 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 CPR before defibrillation or pacing derives from out-of-hospital arrests. Survival after in-hospital arrest is optimised with early defibrillation. After cardiac surgery, ECM is associated with potentially fatal complications, and may not be necessary in situations where the 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 ECG shows VF/pulseless VT you may delay external cardiac massage for up to a minute to administer shocks

Class IIA, Level of Evidence: B

If the ECG shows asystole you may delay external massage for up to a minute to maximise the temporary pacemaker output.

Class IIA, Level of Evidence: C
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3.2. 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 14% for the third. Thus the likelihood of successful cardioversion declines dramatically from first to second shock, and declines further from second to third shock. We conclude that proceeding to resternotomy after the third shock is preferable due to the minimal likelihood of fourth shock success.

Suggestions

In VF or pulseless VT, 3 sequential shocks should be given without intervening ECM.

Class I, Level of Evidence: B

In VF or pulseless VT, emergency resternotomy should be performed after 3 failed attempts at defibrillation, but ECM should be started in the interim prior to resternotomy and attempts should be made to correct any reversible causes of VF or pulseless VT before resternotomy is performed.

Class I, Level of Evidence: B

4. 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 an arrest should immediately assess all monitored waveforms. In a cardiac arrest, not only will the arterial line show no pulsatility, but also the central venous pressure (CVP), pulse oximetry and pulmonary artery (PA) pressure waveforms will flatten. The ECG may show VF or asystole, which are clearly not compatible with an output (in the absence of a ventricular assist device or other mechanical support). An ECG demonstrating QRS complexes without pulsatile waveforms, should be diagnosed as a PEA cardiac arrest. Pulseless VT may also be diagnosed on the basis of the monitoring traces. 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.
Upon recognition of an arrest, there is no need to assess for 10 seconds or check that all monitoring equipment is working properly. Immediately initiate the cardiac arrest protocol and loudly and clearly call for help.

In some cases there is a viable ECG and the arterial waveform gradually diminishes as the blood pressure falls. Assuming that the arterial line is functioning well (i.e. CVP, PA 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.

Suggestions

If the ECG shows VF or asystole, call cardiac arrest immediately

Class I, Level of Evidence: C

If the ECG is compatible with a cardiac output look at the pressure traces. If arterial and other pressure waveforms are pulseless then call cardiac arrest immediately.

Class I, Level of Evidence: C

Feeling for a central pulse should only be used if there is significant doubt over the diagnosis

Class I, Level of Evidence: C

4.1. Basic life support: external cardiac massage

If a rhythm change to VF/pulseless VT is witnessed, ECM may be delayed until 3 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 100-120 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 over 60mmHg should be aimed for and the rate or depth of compressions can be increased in order to achieve this.

However, the inability to achieve an acceptable compression-generated blood pressure indicates the need for immediate emergency resternotomy (i.e., likely etiology of massive bleeding or tamponade) and chest reopening should be expedited. Notify the whole team immediately if you are unable to achieve a systolic impulse in excess of 60mmHg.

Suggestions

Inability to obtain a systolic pressure of above 60mmHg 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 of Evidence: C

4.2. Basic life support: airway

In the ICU setting, airway issues may contribute to arrest and must be quickly remedied; thus, 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 2 breaths for every 30 compressions. However, most patients will be intubated and ventilated upon arrest and the priority for the second rescuer is to immediately increase the ventilator oxygen ventilator to 100%. After this, removing positive end-expiratory pressure (PEEP) is also recommended to 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 (ETT) must be considered as a cause for the arrest. The following steps are important in ensuring a 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 fogging of the 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 for bilateral air entry.
- Check with capnography that there is CO2 excursion.
- We recommend that the ventilator be disconnected and that breaths are temporarily administered with a bag/valve connected to 100% oxygen. This 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 2nd intercostal space, anterior mid-clavicular line (located *below* the second rib. The second rib can be quickly identified as it inserts into the sternomanubrial junction). If this diagnosis is correct, the 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 (ET) tube, then ET-tube occlusion or malpositioning should be suspected. The ET-tube should be immediately removed and a bag/valve/mask with airway adjuncts used.

Suggestions

AIRWAY AND BREATHING

Immediately increase the inspired oxygen up to 100%

Class I, Level of Evidence: 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 looking for a pneumothorax or a hemothorax.

Class I, Level of Evidence: C

If you suspect a tension pneumothorax, place a large bore needle into the 2nd intercostal space, anterior midclavicular line, followed either by a chest drain or opening of the pleura at resternotomy.

Class I, Level of Evidence: C

Once adequate airway and breathing are confirmed, the patient may be reconnected to the ventilator (PEEP should be removed)

Class IIA, Level of Evidence: C

5. Administration of epinephrine or vasopressin

Evidence was sought for whether routine epinephrine or vasopressin administration is either useful or potentially harmful for patients who arrest after cardiac surgery.[3, 32, 33]. Seventeen studies were reviewed in detail in addition to current 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 but not survival benefit. This view was recently confirmed in an 851 patient RCT in 2009[34], a 534 patient RCT in 2011[35] and two 2014 meta-analyses of all published trials of vasopressors[33, 36]. Studies reporting the outcome of arrests after cardiac surgery fail to consistently or completely report use of epinephrine, providing no conclusive evidence that this was either a useful or harmful intervention. Epinephrine administration can risk severe hypertension and bleeding in patients who regain spontaneous circulation [37].

We acknowledge that epinephrine may be useful in the impending arrest or peri-arrest situation and may also be safely used in smaller doses such as 100-300mcg boluses. However, once cardiac arrest has occurred, we

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 of Evidence: C

recommend that epinephrine should only be administered by clinicians with experience in its use and it should not be included in the routine arrest protocol.

6. Infusions.

We are aware of some unpublished cases of arrest post 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 arrest. Conversely, during cardiac arrest it is unlikely that a drug running by infusion pre-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. In addition, once stability has been achieved and adequate cerebral perfusion restored, recommencing this infusion will be straightforward. 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-arrest infusions should then be stopped until an experienced doctor arrives to review each medication.

Suggestions

In an established cardiac arrest, all pre-arrest infusions should be stopped.

Class IIA, Level of Evidence: C

If there is concern about awareness, it is acceptable to continue the sedative infusions. Other infusions can be restarted as required by the clinical situation.

Class IIA, Level of Evidence: C

7. Cardiac arrest in patients with an intra-aortic balloon pump

Patients with an intra-aortic balloon pump (IABP) present special considerations. While VF or asystolic arrest are readily identified on the ECG, in PEA or asystole with an active pacemaker, the rhythm may continue to trigger the IABP resulting in an arterial waveform that remains pulsatile despite the absence of 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 CVP, PA or pulse oximetry tracings.

In an 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, the IABP should therefore be set to pressure trigger mode, with 1:1

Suggestions

In cardiac arrest with an IABP in place, it should be set to pressure trigger mode.

Class IIA, Level of Evidence: C

If there is a significant period without massage, triggering should be changed to an internal mode at a rate of 100bpm until massage is recommenced.

Class IIA, Level of Evidence: C

counterpulsation at maximal augmentation. This 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/minute.

8. Management of the cardiac arrest

We have identified 6 key roles in the cardiac arrest situation after cardiac surgery and evaluated them in manikin simulation[17]. Training should be given towards performance of these 6 key functions. When the arrest occurs, each role should be assumed by appropriately trained individuals (figure 3)

1. External cardiac massage

   Once the arrest has been established one person is allocated to ECM. This should commence at a rate of 100-120 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 prior to ECM.

2. Airway and breathing

   The 2nd rescuer increases the inspired oxygen to 100%, removes PEEP, and assesses airway and breathing per protocol specifically to exclude pneumothorax, haemothorax or an endotracheal tube problem.

3. Defibrillation

This person connects the defibrillator and administers shocks, if indicated. They are also assigned to manage pacing, and if emergency resternotomy is performed, 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 arrest, ensuring that the protocol is followed, that a person is allocated to each role, and that a team quickly prepares for resternotomy.

5. Drug administration

   This person stops all infusions once initial resuscitative efforts have failed and administers amiodarone and manages other drugs or infusions as appropriate.

6. ICU co-ordinator

   This role, typically a charge nurse or senior nursing unit leader, coordinates activity peripheral to the bedside. This includes preparing for potential resternotomy as soon as an 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 and prepare for emergency resternotomy. This should occur **immediately upon identifying an arrest**, rather than waiting until other conservative attempts at resuscitation have failed.

9. 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 8 identified papers, including three large randomised trials [39][40][41].

Amiodarone should be given as a bolus injection of 300 mg. A further dose of 150mg may be given for recurrent or refractory VF/VT followed by an infusion of 900mg over 24-hours. Lidocaine 1mg/kg may be used as an alternative but only if amiodarone is not available or contraindicated.

Suggestions

After 3 failed attempts at defibrillation for ventricular fibrillation/pulseless VT, a bolus of 300mg of intravenous amiodarone should be given via the central line.

Class IIA, Level of Evidence: A

10. Automated external defibrillators (AEDs)

For non-cardiac surgical patients, AEDs have been recommended in certain circumstances to facilitate defibrillation, despite varied results in animals and manikins that often showed a delay in defibrillation. Only 1 case report of AED use in cardiac surgery was found, and the patient was on cardiopulmonary bypass[42]. In cardiac surgical patients, the importance of rapid defibrillation

or immediate resternotomy cannot be over-emphasised. AEDs will not deliver 3 shocks as rapidly as trained clinicians and may delay the decision to perform resternotomy, thus we do not recommend AEDs for use in cardiac surgical patients in the ICU.

Suggestions

Automated external defibrillators (AEDs) should not be used in cardiac surgical patients in the ICU

Class III (Harm), Level of Evidence: C

11. 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

Automatic external compression devices should not be used on cardiac surgical patients.

Class III (Harm), Level of Evidence: C

12. Pacing

The initial arrest rhythm will be only amenable to defibrillation in 30-50% of patients. 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 (figure 1).

If epicardial pacing wires are in place, they should be immediately connected to a pacemaker. This device should be set to dual chamber pacing at a rate of 80-100 beats per minute using maximal atrial and ventricular outputs. If this fails to restore cardiac output, or if there is delay in obtaining pacing equipment beyond 1 minute, ECM must be commenced immediately.

Many pacing generators have emergency settings using a single button that delivers maximal outputs with asynchronous pacing. This is acceptable and providers should be well trained in its use.

In the absence of epicardial pacing wires, pacing can be achieved using external (transcutaneous) pacing if it seems likely that the arrest is due to an extreme bradyarrhythmia. We have prioritizedthis intervention after ECM has commenced due 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 arrest, and the patient has arrested with an ECG showing PEA 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 at 80-100 bpm at the maximum atrial and ventricular output voltages. If the pacing generator has an emergency pacing button then this may be used.

Class I, Level of Evidence: 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 of Evidence: C

13. Atropine

Despite widespread use of atropine in cardiac arrest protocols, its benefit is not well established. Five prospective non-randomised controlled trials in non-cardiac surgical patients failed to establish a survival benefit for in-hospital or out-of-hospital cardiac arrest. [43]

We were unable to find any further evidence in favor of atropine in the cardiac surgical literature. It is also now not advocated in the universal algorithm and our expert consensus group felt that an arrest due to bradycardia or asystole would ideally be treated with pacing and that atropine administration would

only create delay in the algorithm and thus we do not support atropine as a standard part of the 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 of Evidence: C

14. Emergency resternotomy after non-VF/VT arrest

In non-cardiac surgical patients, non-VF/VT arrests are associated with poor outcomes. Guidelines ask clinicians to consider the following as causes of the arrest : hypoxia, hypovolemia, hypo/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, tension pneumothorax or severe hypovolemia. Prompt treatment is associated with an excellent outcome, and delays to resternotomy should thus be minimised.

Failure to respond to pacing warrants emergency resternotomy without delay.

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 stem the bleeding. Hypo/hyperkalemia/hydrogen ions are unlikely causes of arrest after cardiac surgery as serum potassium and pH are carefully monitored. If this is the cause for arrest, a prolonged period of CPR may be needed which is more effective when performed by internal massage. Hypothermia causing arrest is unlikely but active rewarming on bypass is preferable to passive rewarming that would already have been used in the ICU prior to the arrest. 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 resternotomy and is the commonest cause of non-VF/VT arrest after cardiac surgery. Toxins are also unlikely but cessation of infusions is the preferred approach unless clinical suspicions regarding a specific drug are raised. Finally, thromboembolic or mechanical obstruction such as a pulmonary embolus, coronary thrombosis, or obstructed valve will be difficult to treat without cardiopulmonary bypass for stabilisation.

Therefore, for a non-VF/VT cardiac arrest which does not resolve with epicardial pacing and exclusion of an airway or breathing problem, prompt

Suggestions

In a non-VF/VT cardiac arrest, which does not resolve after pacing and exclusion of readily reversible causes, emergency resternotomy should be performed within 5 minutes.

Class I, Level of Evidence: B

resternotomy should be performed.

15. Conduct of emergency resternotomy

15.1. 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[44] and ILCOR also provided a systematic review of the topic as part of the worksheet review process[45]. These report benefits of internal cardiac massage including better coronary perfusion pressure, increased return of spontaneous circulation, superior organ blood flow and better survival rates as compared to ECM. They recommend consideration of open-chest CPR 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.

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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 in order to perform internal cardiac.

Class IIA, Level of Evidence: C

15.2. Abdominal compression to achieve external cardiac massage

Evidence was sought to assess the efficacy of abdominal only ECM compared to ECM. This search is fully documented with a summary of 10 papers [46]. 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.

15.3. The emergency resternotomy set

If a resternotomy is to be performed rapidly, ICU staff must be trained in this multi-personnel procedure. One reason for delay in emergency resternotomy is the preparation of a standard sternotomy instrument set[17] which may contain over 30 items of equipment, although only 5 items are essential: , a scalpel, a wire cutter, a heavy needle holder, a single piece sternal retractor and Yankauer sucker (figure 2). Surgical scissors and an all-in-one sterile

thoracic drape may also be useful. Larger sets are unnecessary in the setting of an emergent 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 (figure 2). 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[47].

Suggestions

A small emergency resternotomy set should be available in every ICU, containing only the instruments necessary to perform the resternotomy. This 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 Yankauer sucker. An all-in-one drape and scissors are also very useful.

This 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 of Evidence: C

15.4. Preparation for emergency resternotomy

Emergency resternotomy is required in 20-50% of cardiac arrests after cardiac surgery[8, 14] and is a multi-practitioner procedure that should ideally be

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. Hand washing is time-consuming in an emergency situation and incomplete drying of the hands will slow the donning of gloves. Therefore, hand washing 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 a gown and gloves as soon as a cardiac arrest is called, and prepare the emergency resternotomy set.

Class IIA, Level of Evidence: C

Hand washing is not necessary prior to closed-sleeve donning of gloves.

Class IIA, Level of Evidence: C

15.5. Personnel performing emergency resternotomy

Emergency resternotomy may be required in 0.8-2.7% of all patients undergoing cardiac surgery. While an experienced surgeon is optimal, there may be situations where 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. This 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 non-surgeons be trained and certified to perform emergency resternotomy. Physician's Assistants and Advanced Practice Nurses may be the ideal clinicians to undergo this training and provide the necessary coverage on site, and the Association of Physician's Assistants in Cardiovascular surgery (the APACVS) now provide training in this area.

15.6. Emergency resternotomy

- Two or three providers don a gown and gloves in a sterile fashion using the closed glove technique. 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 the thoracic drape ensuring that the whole bed is covered after a quick skin preparation or the use of all-in-one sterile drape.
-
- Recommence ECM (changeover from non-sterile ECM to sterile ECM should take no more than 10 seconds).
- When equipment is ready (figure 2), 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, with care to avoid injury to the heart or grafts from

cut ends of wires... 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 2 handed internal cardiac massage and internal defibrillation as appropriate.
- If the pericardium or mediastinal fat has been closed over the heart, the sutures use for this should be carefully and slowly cut to allow vision of the heart.

15.7. Method of internal cardiac massage

This is potentially dangerous and any personnel who may be required to perform this procedure 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(LIMA) being at particular risk. Inexperienced providers should not rush to perform internal cardiac massage after opening the chest. It is essential to remove any clot and identify structures at risk such as grafts prior to 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 (minimising 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 minimising 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 100-120bpm and look at the arterial trace to verify adequate internal massage. You should try to obtain a systolic impulse of more than 60mmHg.

15.8. Cardiac arrest protocol and emergency resternotomy outside the ICU

Emergency resternotomy outside of the ICU is associated with a poor survival although occasional patients do survive [8, 11, 48]. 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 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 an 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[48].

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 American Heart Association guidelines.

Local protocols for emergency resternotomy outside of the ICU should be drawn up and practised.

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.

15.9. How long after cardiac surgery is emergency resternotomy no longer indicated?

As the patient recovers from cardiac surgery, the chance of a cardiac arrest occurring 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. This may be due to pacing wire removal or over-anticoagulation. In addition, in cardiac arrest, several days after cardiac surgery, internal cardiac massage remains a superior method of resuscitation compared to ECM. Thus, even if a reversible cause such as tamponade is not suspected, emergency resternotomy is indicated in preference to prolonged ECM.

However this must be balanced with the danger of resternotomy once adhesions have started to form. It is the opinion of the task force that adhesions would be unlikely to be present until at least 10 days post-operatively. Therefore emergency resternotomy should form a standard part of the arrest protocol up to the 10th post-operative 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 arrest with emergency resternotomy.

Suggestions

Emergency resternotomy should form an integral part of the cardiac arrest protocol up to the 10th post-operative day.

Class IIA, Level of Evidence: C

Beyond the 10th post-operative day, a senior clinician should decide whether emergency resternotomy should still be performed.

Class IIA, Level of Evidence: C

16. Cardiopulmonary bypass after emergency resternotomy

If a 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[49] documented a 56% survival in 16 patients with refractory VF despite open chest CPR 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 an arrest. In addition to an immediate dose to the patient of 30,000 iu of heparin as early as possible prior to commencement of cardiopulmonary bypass, we recommend that 10,000 iu of heparin be added to the bypass machine reservoir. It is not necessary to check an ACT prior to commencing cardiopulmonary bypass.

Cannulae may be inserted into the aorta and right atrium without purse strings 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 from this manoeuvre.

In units who are expert in the use of ECMO, this may be instituted in preference to central cannulation and local protocols should be constructed to manage this situation and practiced 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 of heparin as early as possible prior to commencement of cardiopulmonary bypass, we recommend that 10,000 iu of heparin be added to the bypass machine reservoir.

Class IIA, Level of Evidence: C

17. Should patients after emergency resternotomy receive additional antibiotics?

Evidence was sought for whether additional antibiotics reduce the incidence of mediastinitis after emergency resternotomy. This search is fully documented and 9 papers summarized[50].

For patients who require an emergency resternotomy on the ICU, the incidence of sternal wound infection or sepsis after this emergency treatment is around 5% of survivors in these papers. Of these, 5 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 in support of this.

Suggestions

It is common practice to perform an antiseptic washout after emergency resternotomy and to give additional intravenous antibiotics.
This is reasonable and is indicated if the resternotomy has not been performed using full aseptic techniques.

Class IIA, Level of Evidence: B

18. Permissive hypothermia after resuscitation from prolonged cardiac arrest

It is well established that patients who have a significant period of cardiac arrest out of hospital should be systemically cooled to 32-34ºC for 12-24 hours. Vollroth[51] described a protocol for cooling after cardiac surgery with success and, this intervention should be considered if it is felt that there has been a significant period of poor cerebral perfusion.

19. Special considerations

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

19.1. Transplant patients

Patients undergoing heart, heart-lung or double lung transplant via a sternotomy may be resuscitated using these guidelines. Patients having a transplant procedure via a clam-shell incision or bilateral thoracotomy incisions should have an emergency re-thoracotomy through the previous particular incision using the same indications in this guideline. Only a surgeon experienced in this particular approach should perform this procedure.

19.2. Pediatric patients

The only reported series that we identified sets the incidence of cardiac arrest at 4% after cardiac surgery in children[52]. The success of resuscitation is

similar to adult patients and the causes are also similar although 11% suffered 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. Practicing for emergency situations in paediatric cardiac surgery has been shown to improve outcomes [53]

19.3. ‘Open chest’ patients

Occasionally a patient after a high-risk operation 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. We recommend that ECM 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 in open chest patients. If emergency internal cardiac massage is then indicated, full aseptic technique should be used, and this 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 thus should be carefully removed, making sure that no grafts are adherent to them if present.

19.4. Patients with a cardiac assist device

All clinicians caring for these patients should have full training in the procedures for equipment failure and the ‘cardiac arrest’ situation. They are

highly complicated due to the fact that an ‘arrest’ may be due to mechanical failure and in this situation there may be steps particular to the device that should be taken and rehearsed. Of note, we summarised the evidence for external cardiac massage in patients with ventricular assist devices[54]. 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 non-functional right ventricle in arrests and often the right ventricle may be the cause of the situation.

Patients with an implantable LVAD such as a heartmate or heartware device should have the same algorithm followed as the universal algorithm for arrest after cardiac surgery. The rhythm should be ascertained: patients with VF should be defibrillated, those with asystole should receive pacing, and in patients with PEA 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 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 CVP line. In extubated patients without invasive monitoring, if the patient is motionless and not breathing, then they should be considered to have arrested. TTE/TEE, 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 this should be used to assist in the diagnosis of whether there has been a genuine loss of blood flow, or there is just a low flow situation with reduced level of consciousness.

Resternotomy should be performed in an established arrest less than 10 days after surgery and after this timeframe either resternotomy or ECMO is a reasonable option.

Also of note, it is possible for a patient to have asystole or VF, but for there to be 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 external chest massage will not be needed.

19.5. Patients undergoing non-sternotomy cardiac surgery

Some cardiac operations avoid a full sternotomy. This may range from a partial sternotomy, port-access surgery with a mini-thoracotomy, minimally invasive coronary artery bypass (MIDCAB) to TECAB (totally endoscopic coronary artery bypass). It is appropriate to follow this guideline and it is important that the ICU has 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. This should be discussed with the ICU on admission from the operating room.

Suggestions

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Surgeons who perform non-sternotomy surgery should make their ICU staff aware of their preferences for management during an 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 MIDCAB, TECABG, robotic endoscopic CABG, port access mitral surgery, mini sternotomy or mini-thoracotomy 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 of Evidence: C

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 therefore be immediately available on the ICU for these patients. ICU staff should practice setting up the saw and getting it to work as this may otherwise cause further significant delays in the sternotomy. Of note, the saw must only be used by surgeons who are highly experienced in its use, and while they are awaited, the team should continue ECM. Urgent 24 hour access to an operating room should be available should this be necessary.
Similarly a patient undergoing coronary artery bypass grafting via a MIDCAB incision should undergo a sternotomy rather than extending the incision laterally in an arrest. It should be noted that the LIMA 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 non-sternotomy patients with previous cardiac surgery a sternotomy will not be possible. In that case femoral cannulation or ECMO may be required. Experienced surgeons performing non-sternotomy surgery may also consider ECMO as an alternative to sternotomy in their minimally invasive patients and this is also acceptable as a written protocol and is proven to be of benefit[55].

20. 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 3-sequential shock protocol. The change should be discussed in advance as a unit, and ideally training given in advance of practice change. An existing online resource www.csu-als.com for training and certification can assist in this effort.

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

Figure 1: STS guideline for resuscitation of a patient who arrests after cardiac surgery.

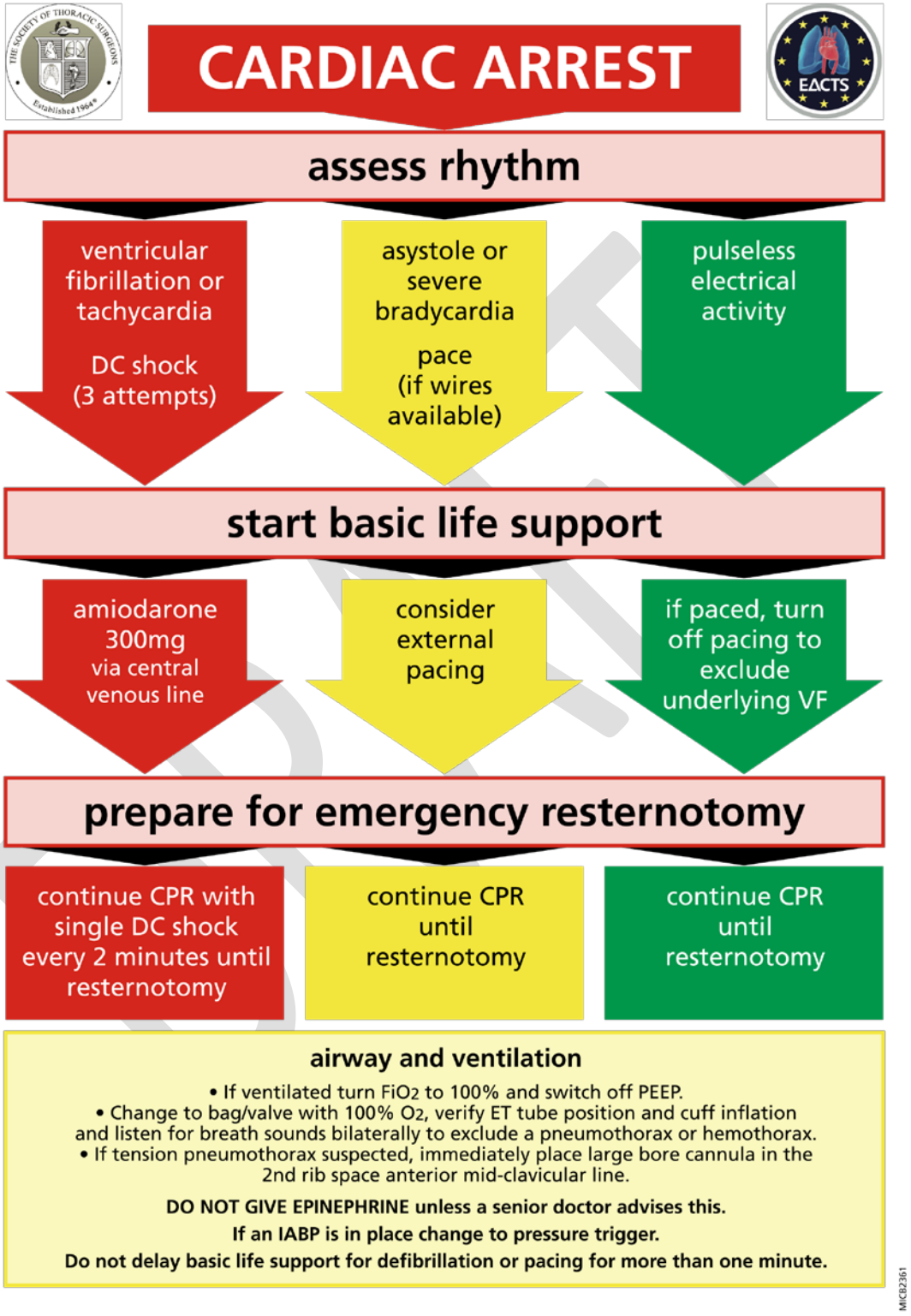
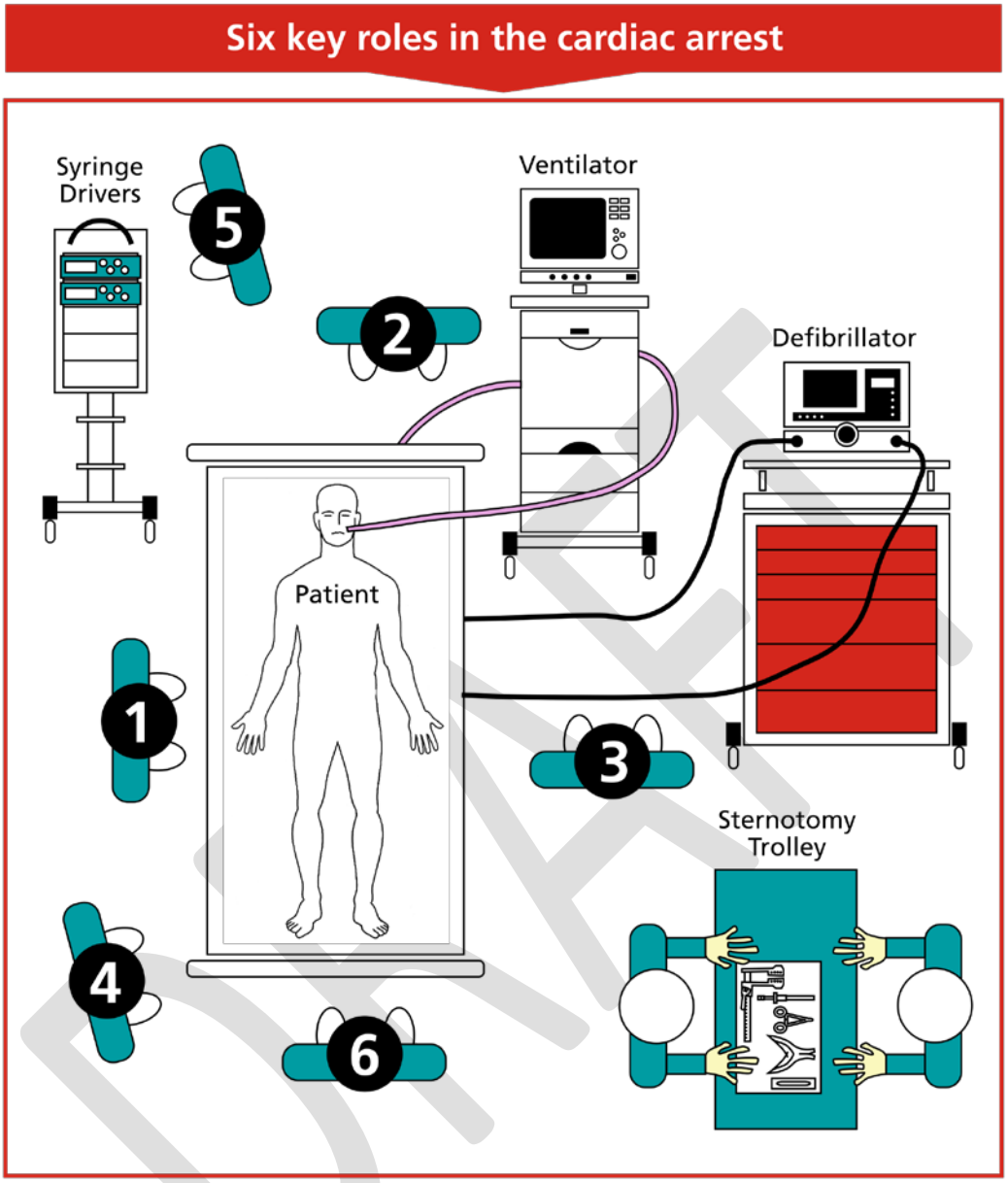


Figure 2. An example of a recommended emergency resternotomy set

Figure 3 : 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

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