Resuscitative thoracotomy

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Abstract

Traumatic cardiac arrest is a rare and generally fatal complication of major trauma. The majority of cases result from potentially salvageable pathology such as exsanguinating haemorrhage or cardiac tamponade. Resuscitative thoracotomy is a rapid, straightforward, non-specialist procedure which can be lifesaving in appropriately selected trauma patients. This article provides a detailed review of the relevant pathophysiology, indications and contraindications, necessary equipment and techniques, and factors influencing patient outcomes.

Keywords Cardiac tamponade; code red; major haemorrhage; major trauma; pre-hospital emergency medicine; resuscitative thoracotomy; traumatic cardiac arrest

Introduction

Traumatic cardiac arrest (TCA) affects approximately 0.6% of trauma patients with a mortality of over 90%.[1] Around 50% of cases are due to uncontrolled exsanguinating haemorrhage. Hypoxia, tension pneumothorax and cardiac tamponade are each responsible for 10%–15% of cases, with the remainder being caused by brain injury or other pathology. It was believed that interventions for TCA were futile, especially in blunt trauma. However, alongside recent advances in trauma systems and damage control resuscitation, there has been increasing use of resuscitative thoracotomy (RT) in selected patients with growing success.

Ideally, patients requiring an emergency thoracotomy undergo this in an operating theatre with a specialist cardiothoracic surgeon. However, traumatic cardiac arrest requires immediate intervention by the available trauma team, which usually consists of practitioners from diverse backgrounds with limited cardiothoracic experience. Resuscitative thoracotomy is therefore intended to be a rapid and uncomplicated procedure which can be performed by non-specialists located in the emergency department (ED) or pre-hospital (PH).

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Rationale

The established role of RT is the release of cardiac tamponade and repair of cardiac injuries following penetrating trauma.

Needle pericardiocentesis is rarely successful in trauma due to the presence of thick clot in the pericardial sac and ongoing bleeding from the underlying cardiac wound. RT may also be used to directly control sources of intrathoracic haemorrhage, compress the descending thoracic aorta to improve coronary and cerebral perfusion and/or control infradiaphragmatic haemorrhage, provide internal cardiac massage, and treat or prevent air embolism.

Indications and contraindications

Traumatic cardiac arrest can be defined as an unconscious trauma patient with agonal or absent respiratory effort and no palpable carotid pulse. This equates to a systolic blood pressure of <50 mmHg, at which point the patient has lost meaningful cardiac output. Salvageable pathology is generally associated with pseudo-pulseless electrical activity (pseudo-PEA) and a state of profoundly diminished cardiac output, as opposed to ventricular fibrillation or asystole where there is no cardiac output at all.[2] The heart's electrical system and muscle are functioning normally and it is trying to beat, but it cannot fill sufficiently due to hypovolaemia (exsanguinating haemorrhage), obstructed venous return (tension pneumothorax), increased intrapericardial pressure (tamponade) or air embolism.

Recognition of patients at risk of TCA can be challenging. Bleeding patients often compensate until a point of sudden deterioration with cardiovascular collapse and loss of consciousness, yet this imminent 'peri-arrest' state is poorly defined and heterogeneous. In addition, the actual moment of arrest can be hard to determine because accurate assessment of pulses is difficult during hypotensive resuscitation, most patients arrest prior to insertion of an arterial line, and ECG monitoring may show a normal rhythm.

It is important to rule out other causes of cardiac arrest unrelated to tamponade or exsanguination prior to embarking upon RT. Hypoxia can be excluded by optimizing airway and ventilatory support and checking an arterial blood gas. Tension pneumothorax is a key diagnosis often missed. Chest X-ray and extended focused assessment with sonography for trauma (eFAST) are useful assessment tools, but if there remains any doubt, bilateral thoracostomies should be performed to empirically decompress both pleural cavities. eFAST may also detect cardiac tamponade, haemothorax and intra-abdominal free fluid and allows assessment of cardiac motion. Other pathologies to consider include brainstem herniation, neurogenic shock, reperfusion with hyperkalaemia in crush injuries, and medical causes.

The indications for RT are summarized in Table 1. Current guidelines advocate a selective approach based upon predictors of survival and neurologically intact recovery.[3–5]

Decision making

There is an extremely limited timeframe in any cardiac arrest before irreversible myocardial and cerebral ischaemia occur. The recognition of the need for resuscitative thoracotomy and the swiftness of intervention are paramount. However, it is also important to recognize futility in patients who are unlikely to achieve meaningful recovery. These time-critical decisions are

Indications and contraindications for resuscitative thoracotomy[3–5]

	Penetrating trauma	Blunt trauma
Indications	Cardiac arrest <15 minutes	Signs of life prior to arrest
	Profound refractory shock (SBP <60 mmHg) despite resuscitation	Cardiac arrest <10 minutes
Contraindications	Cardiac arrest >15 minutes	No signs of life prior to arrest
	Asystole/cardiac standstill in the absence of tamponade	Cardiac arrest >10 minutes
	Devastating brain injury	
	Other catastrophic trauma incompatible with life	

SBP, systolic blood pressure.
'Signs of life' include consciousness, verbalization, spontaneous extremity movements, pupillary reflexes, palpable pulse, detectable blood pressure, spontaneous non-agonal ventilation, organized electrical activity on ECG, and cardiac activity on point of care ultrasound. The key prognostic distinction is whether the patient has had a witnessed or unwitnessed cardiac arrest.
Some guidelines advise that in penetrating neck or extremity trauma, cardiac arrest >5 minutes is an indicator of non-salvageability.[4]
The potential for organ donation does not justify resuscitative thoracotomy in patients with devastating brain injury.

Table 1

challenging to make under pressure and may be influenced by many subjective human factors. Clinical guidelines and treatment algorithms can help standardize decision making and preserve objectivity, but individual patient factors such as injury patterns, frailty and comorbidities should also be considered.

Equipment

Essential items for performing a resuscitative thoracotomy are a scalpel (10/22 blade), large artery forceps (Roberts/Spencer Wells), something to cut through the sternum (Tuff Cut/plaster shears or a Gigli saw), a self-retaining rib spreader (Finochietto) and curved dissecting scissors (Mayo/Metzenbaum). These should be readily available in a dedicated resuscitative thoracotomy pack (Figure 1).

Desirable items include tissue forceps, a range of vascular clamps and artery forceps, needle holders, 2/0 Vicryl and double-ended 3/0 Prolene sutures, Teflon pledgets, a skin stapler, a Foley catheter, deep handheld retractors, plenty of swabs and packs, suction, and an operating department practitioner.

Technique[6–8]

Resuscitative thoracotomy should take place in parallel with ongoing damage control resuscitation by the rest of the trauma team.

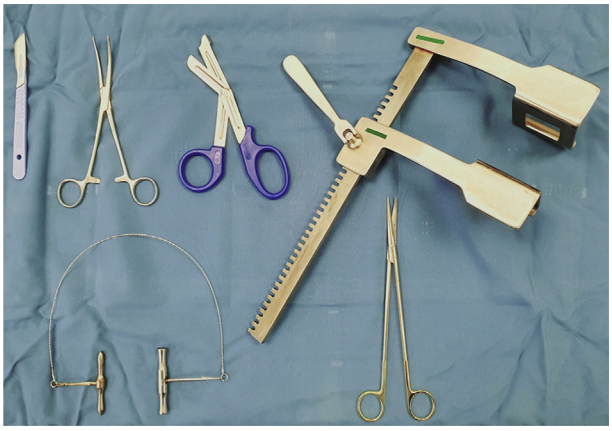


Figure 1 Essential instruments for a resuscitative thoracotomy.

The cornerstones of treatment in TCA are haemorrhage control, blood product resuscitation and release of cardiac tamponade. External chest compressions are ineffective, as there is no physiological sense in violently compressing an empty heart in an effort to improve blood pressure. External compressions may also exacerbate any existing chest injuries and hinder safe access for thoracotomy and other resuscitative interventions. Systemic vasopressors and inotropes should be avoided as their use has been associated with increased mortality.[2]

Preparation

Most patients who ultimately require RT will be designated 'code red' on their trauma pre-alert, indicating suspected major haemorrhage. The trauma team leader should also highlight this as part of the team brief and equipment should be on standby.

If RT is indicated, immediately mobilize other members of the team by asking a colleague to contact your consultant, the on-call cardiothoracic surgeon and the emergency theatre coordinator. Do not delay starting the procedure by making these calls yourself. Ask another colleague to maximize access to the chest by removing the patient's clothes, abducting their arms, and getting lines out of the way. They could also set up suction and optimize lighting.

Always wear personal protective equipment. Sharps injuries (including from broken ribs) and eye splashes pose a genuine risk of blood-borne virus infection. While gloving and gowning, rehearse the steps of the procedure in your mind. Check the rib spreader is correctly assembled and spare a few seconds to familiarize yourself with the mechanism before you start.

Quickly apply whatever skin preparation solution is available. Sterility is a luxury and there is rarely time to drape the surgical field.

Incision

A clamshell thoracotomy is the optimal incision as it allows maximal visibility and access to both pleural cavities, heart and lower mediastinum. Left anterolateral thoracotomy is less invasive but provides only limited visibility and access, making haemorrhage control more technically challenging. A clamshell thoracotomy can be performed just as quickly as a left antero-lateral and

is not associated with any increase in complications.[9,10] Median sternotomy is not feasible in the ED due to the equipment and specialist skills required.

You should aim to open the chest within 90 seconds. A speedy clamshell thoracotomy requires two people, one for each side of the chest.

Clamshell thoracotomy requires a curved skin incision along the 4th or 5th intercostal spaces on either side of the sternum. Do not waste time counting ribs as you will only confuse yourself. In men, the incision should follow the inferior border of pectoralis major just below the nipple. In women, retract the breast superiorly and incise the inframammary fold. The incision is higher than you might think — this is partly so you do not end up in the abdomen. The patient is likely to have already had bilateral thoracostomies performed, which can be used to guide your incision. If thoracostomies have not yet been done, start by making a skin incision in the 4th or 5th intercostal space from the mid-axillary line to the posterior axillary line, then bluntly dissect down and puncture the pleura with forceps as you would for an open chest drain. If you hear a hiss of air, reassess the patient before continuing as you may have decompressed a tension pneumothorax.

Incise the skin along the full length of your incision incorporating the thoracostomy sites. Remember that the ribs curve upwards anteriorly towards the sternum and posteriorly towards the spine and follow this curve. The shape should look like a curvy letter 'W' or the wires on an underwired bra (Figure 2). Next, incise the muscle layers, trying to stay below the bulk of pectoralis major. When you reach the intercostal space, use the thoracostomy puncture site to push the lung down out of the way with two fingers of your non-dominant hand, and work medially towards the sternum by dividing the intercostal muscles and pleura with scissors. Cut along the superior border of the rib below your incision to avoid damaging the intercostal neurovascular bundle. Once you have reached the sternum, divide the remaining posterolateral tissues down to the level of the bed. Finally, divide the sternum with the shears or Gigli saw, again protecting the structures beneath with your non-dominant hand. To use the Gigli saw, pass your forceps behind the sternum, use them to pull the wire through, attach the ends to the handles and saw horizontally through the bone.

Insert the rib spreader with the blades on the cut edges of the sternum and the handle directed to the right so as not to obscure the operative field on the left. Open the rib spreader as widely as possible to maximize exposure and access. If you cannot see properly, extend your incision further posteriorly.

Lift the pericardium in the midline and open it with scissors. Never open the pericardium laterally as you risk damaging the phrenic nerve, causing diaphragmatic paralysis. If there is evidence of tamponade, fully open the pericardial sac longitudinally, evacuate the blood and clots, deliver the heart and inspect it. You may need to extend your opening into an 'inverse T' shape to deliver the heart easily.

Tamponade and cardiac injury

Small injuries to the heart will bleed alarmingly but can usually be controlled by placing a finger on (not in) the hole. If this works, your job is done, so stay exactly where you are and await the cardiothoracic surgeon.

Larger atrial lacerations can be controlled with a side-biting Satinsky clamp. Larger ventricular injuries can be difficult to control with digital pressure and cannot be clamped. The use of balloon tamponade with a Foley catheter has been described, but risks extending the myocardial injury as well as reducing ventricular filling and cardiac output. If bleeding from a ventricular injury persists, you will therefore need to establish control by repairing it with interrupted 3/0 Prolene. Suturing a beating, bleeding heart can be exceptionally challenging. Be exceedingly careful when tightening knots as sutures can easily tear through the myocardium. Right ventricular repairs should ideally be reinforced with Teflon or pericardial pledgets. Left ventricular injuries can alternatively be controlled with a skin stapling device. Avoid placing sutures near coronary arteries.

Intrathoracic haemorrhage

Major thoracic haemorrhage may originate from the lung hilum, lung parenchyma, thoracic aorta, innominate or subclavian vessels, azygos or hemiazygos veins, or intercostal vessels.

Bleeding from lung injuries is managed by controlling the hilum. Ask the intensivist to temporarily collapse the lungs to improve visibility and create space. Gather the lung in one hand like a bunch of flowers and manually compress the hilum with the other hand. If this fails, consider either a 180-degree lung twist or applying a Satinsky clamp to the hilum. Both of these manoeuvres require mobilization of the inferior pulmonary ligament, which risks injury to the inferior pulmonary vein.

Leave a contained mediastinal haematoma alone — this is not why the patient arrested. If the thoracic aorta is bleeding, apply direct manual pressure and consider clamping or suturing with 3/0 Prolene if this fails. Haemorrhage from the posterior chest wall or subclavian territory can be difficult to access and may involve multiple bleeding points. Attempt to control these with direct pressure or clamps. If this fails, pack the area and await specialist help.

Air embolism

This is a rare complication of thoracic trauma in which a lung injury allows air to enter the pulmonary venous circulation and embolize to the left ventricle and coronary arteries. It is managed by stopping positive pressure ventilation of the affected lung, clamping the hilum and placing the patient in the Trendelenburg position to trap air in the apex of the left ventricle, where it can be aspirated with a needle. A specialist may also aspirate the aortic root and right coronary artery to remove any bubbles trapped there.

Empty heart with no tamponade or intrathoracic haemorrhage

These findings indicate that the patient is exsanguinating from an extrathoracic source, usually the abdomen or pelvis.

Manual compression of the descending thoracic aorta is the safest way to control infradiaphragmatic haemorrhage. Place your hand into the lower left chest behind the lung, follow the curve of the posterior ribcage until you feel the vertebral column, then firmly compress the tubular structure in front of it with your fingers. Another option is to cross-clamp the descending thoracic aorta with a Satinsky or DeBakey clamp. In order to apply this effectively, you need to open the parietal pleura on either side

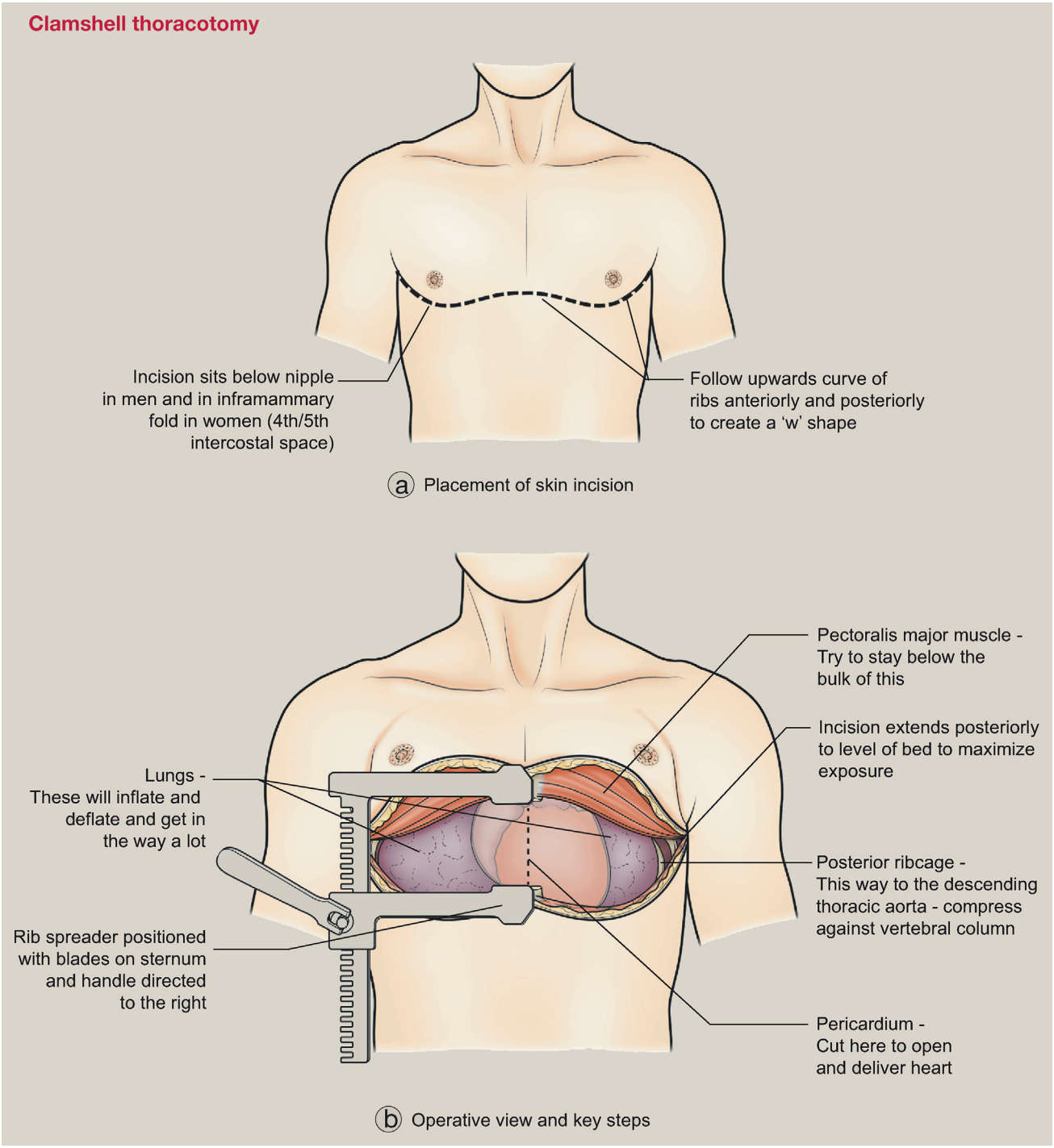


Figure 2

and bluntly dissect around the aorta with thumb and fingers to separate it from the oesophagus and prevertebral fascia. Cross-clamping may damage the aorta or oesophagus, and also carries risks of visceral, spinal cord and lower limb ischaemia. It should be utilized for a maximum of 30 minutes.

Resuscitative laparotomy in the ED is associated with dismal outcomes and is almost never appropriate, with the exception of perimortem caesarean section.

Ongoing cardiac arrest

Gently flicking the heart may stimulate physiological contraction. If this fails, start internal cardiac massage, and get an assistant to apply manual descending aortic compression to improve coronary blood flow. Defibrillate shockable rhythms with internal paddles applied directly to the myocardium using shocks of 10–20 J. If internal paddles are not available, remove

the rib spreader, approximate the chest wall, and defibrillate externally with chest pads.

Perform internal cardiac massage by placing your hands above and below the heart and apposing your wrists. Gently massage blood upwards from the apex by bringing palms then straight fingers together in a clapping motion at 80 beats per minute. Avoid using bent fingers or thumbs as these may perforate the heart. Continue internal cardiac massage while the patient receives blood products and IV calcium. If asystole persists despite the heart being adequately filled, administer 0.5−1 mg of adrenaline directly into the left ventricle as a last resort.

If the patient remains in cardiac arrest despite release of tamponade, control of intrathoracic haemorrhage, aortic cross-clamping, blood product resuscitation and internal cardiac massage, the situation is almost certainly unsalvageable and a discussion involving the whole team should consider cessation of resuscitative efforts.

Return of spontaneous circulation

If cardiac output is successfully restored, damage control resuscitation should continue and the patient should be transferred to an operating theatre as soon as possible for formal exploration and repair of their injuries. The logistics of this may depend upon the availability of a cardiothoracic surgeon. The patient will start bleeding from the cut edges of their chest wall as their blood pressure improves, particularly from the severed internal thoracic arteries. These can be controlled with clips or sutures. The patient may regain consciousness if they were not anaesthetized prior to cardiac arrest and the team should anticipate the need for prompt anaesthesia.

Closure

A cardiothoracic surgeon can show you how to properly close a clamshell incision if your patient gets to theatre.

Performing a resuscitative thoracotomy is a uniquely stressful event. For most trainees, the first time they do it is in a real patient having had minimal experience of the procedure beforehand. Debriefing with colleagues afterwards can provide valuable support.

Pre-hospital resuscitative thoracotomy

The basic principles of resuscitative thoracotomy are virtually identical in the ED and pre-hospital settings. However, performing a maximally invasive procedure in the street is clearly vastly different to performing it in a well-equipped ED resuscitation bay.

Current pre-hospital guidance[11] recommends that teams consider the four Es − elapsed time, expertise, equipment and environment − before proceeding with resuscitative thoracotomy. Elapsed time acknowledges the general rule that thoracotomy should take place within 10 minutes of loss of vital signs. The team must have the necessary expertise and equipment available to both open the chest and deal with their findings. The procedure is often limited to the release of cardiac tamponade as any other intervention is unlikely to be feasible.[12] Point-of-care ultrasound can aid decision making. The environment could be anywhere and will pose additional challenges in the form of access, lighting, and external hazards. Ensuring the safety of the team and the patient is the absolute priority. The team should also consider the transport time to a trauma centre and whether this is likely to be longer than 10−15 minutes.

Outcomes

Survival and functional recovery following resuscitative thoracotomy is highly dependent upon injury location, injury mechanism and the presence of signs of life prior to arrest. Even if the procedure is technically successful and cardiac output is restored, many patients suffer cerebral hypoxia and visceral ischaemia which jeopardize their recovery.

Overall survival to hospital discharge has been reported as 7%−8.5%, with neurologically intact survival rates of 6% −7%.[5,7,13] The best outcomes are achieved in patients with a stab injury to the chest, who have a 20%−30% chance of survival.[4] Patients with penetrating extrathoracic injuries have around a 15% chance of survival. High energy penetrating mechanisms (such as gunshot or blast wounds) and blunt polytrauma tend to inflict greater injury burdens and more complex patterns of destructive injuries. Consequently, survival rates fall to 3%−5% in gunshot wounds[14] and 0.5%−2% in blunt trauma. Penetrating trauma patients without signs of life prior to arrest are significantly more likely to die or have poor neurological outcomes, although they still have a 3%−5% chance of a good neurological outcome. Blunt trauma patients without signs of life prior to arrest have a <0.1% chance of neurologically intact recovery.[5]

Alternatives

Resuscitative endovascular balloon occlusion of the aorta (REBOA) is a less invasive alternative to the aortic cross-clamping performed during RT. It involves placement of a balloon catheter via the femoral artery into the aorta to temporarily limit bleeding and improving cerebro-coronary perfusion to bridge patients to definitive haemorrhage control interventions. The balloon can be inflated above the coeliac axis (zone 1) to manage torso haemorrhage or at the aortic bifurcation (zone 3) to manage pelvic or lower limb bleeding.

Despite conflicting evidence on its efficacy, REBOA is used in capable centres for traumatic, life-threatening haemorrhage below the diaphragm. However, a recent multi-centre randomized controlled trial showed it may increase early mortality in exsanguinating trauma patients due to it delaying time to definitive haemorrhage control, raising questions over its use as an alternative to RT.[15]

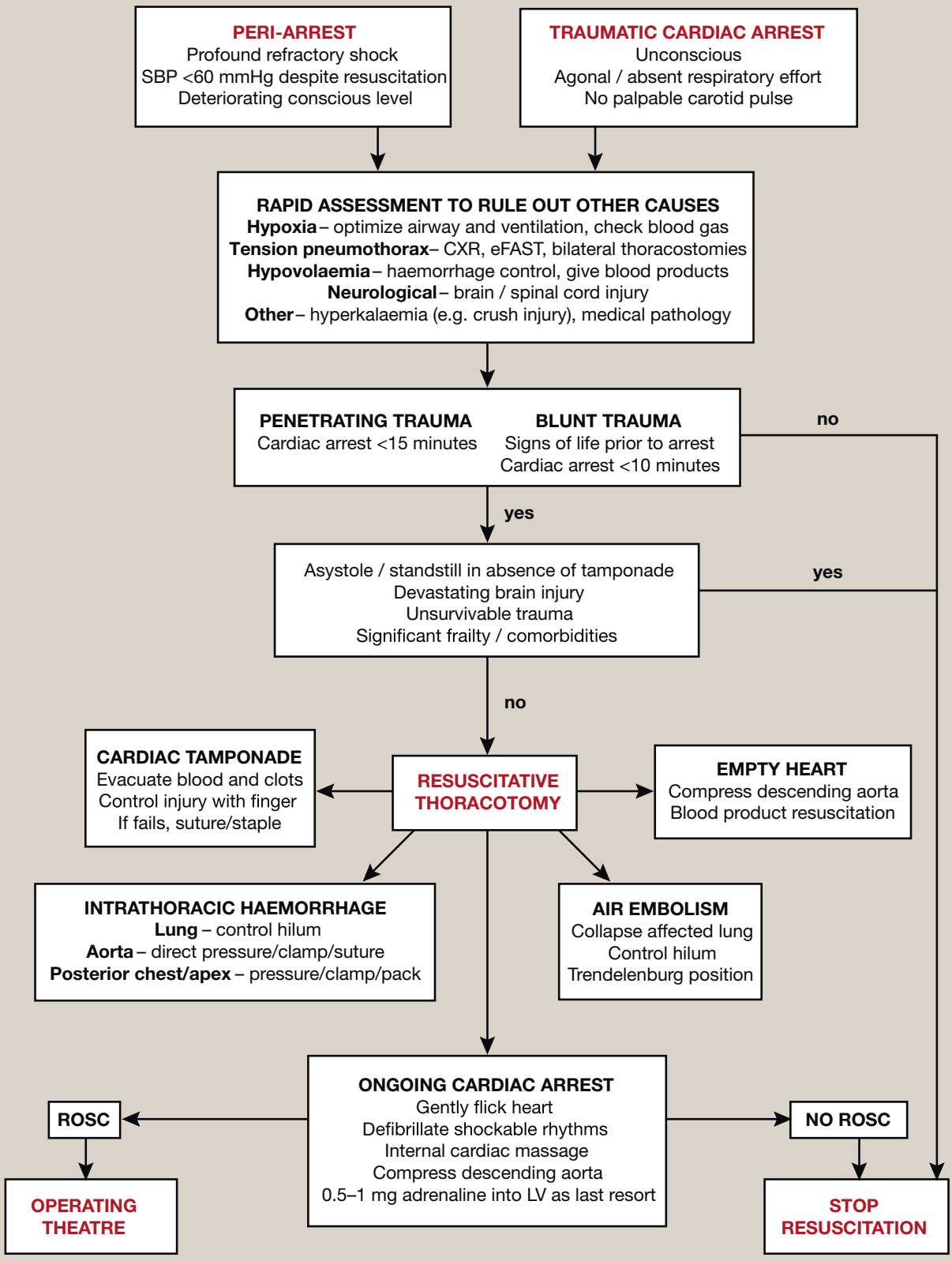
Extracorporeal membrane oxygenation, which involves oxygenating blood outside of the body and readministering it to patients, has shown to provide a survival benefit for severely traumatized patients.[16]

Other novel techniques including Selective Aortic Arch Perfusion (SAAP), extended preservation resuscitation and Chitosan (an intraperitoneal self-expanding foam) have shown promising results in animal models but await further clinical trials to prove their efficacy.[17,18]

Conclusion

Resuscitative thoracotomy is a valuable component of our growing trauma resuscitation toolkit which is delivering

Resuscitative thoracotomy decision flowchart



SBP, systolic blood pressure; LV, left ventricle; ROSC, return of spontaneous circulation. Consider REBOA for patients with evidence of exsanguinating abdominal or pelvic haemorrhage without significant chest trauma.

Figure 3

increasingly positive outcomes for patients in TCA. It should only be performed for patients whose situation is genuinely believed to be salvageable. Prolonged cardiac arrest of >15 minutes in penetrating trauma or >10 minutes in blunt trauma is associated with high mortality and poor neurological outcomes, as is the absence of vital signs prior to cardiac arrest. Decision-making should also consider individual patient factors (Figure 3). ◆

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Practice points

- The first time you do a resuscitative thoracotomy is likely to be for real – as a surgical trainee you possess the basic skills required, and you are surrounded by people who can help you
- Mobilize the holy trinity of helpers: your boss, a cardiothoracic surgeon and the emergency theatre team
- Wear personal protective equipment and take care to avoid sharps injuries
- Sterility is a luxury
- Always do a clamshell incision
- Cut higher than you think: in men just below the nipples, in women the inframammary folds
- Always open the pericardium even if it looks normal
- Your fingers are just as good as a clamp
- Only attempt repair of injuries if absolutely necessary
- Key prognostic factors are injury mechanism, duration of arrest and the presence of signs of life beforehand
- Even if you do everything right, the majority of patients will not survive – debrief with colleagues afterwards