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REBOA and EDRT in trauma related haemorrhage – is it all in vein?

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INTRODUCTION

Trauma is a leading cause of morbidity and mortality worldwide, with haemorrhage being the predominant causative factor in 40 per cent of cases and the commonest cause of preventable trauma deaths.[1,2] Management of haemorrhage in civilian trauma borrows heavily from the military experience. Resuscitative endovascular balloon occlusion of the aorta (REBOA) is one such intervention that has its roots in the military domain. It was in 1954 in the Korean War that Lieutenant Colonel Carl Hughes first described the use of aortic balloon occlusion in three soldiers with intra-abdominal haemorrhage.[3] REBOA involves the placement of an endovascular catheter via the common femoral artery into the descending aorta and inflation of the balloon at the desired level, thus achieving aortic occlusion proximal to the injury and halting of ongoing bleeding. Limited device availability at that time resulted in it not being readily adopted, with REBOA only experiencing a resurgence in clinical use from 2011 onwards.[4] However, REBOA's role and the evidence behind its use in the civilian population still needs further clarification.[5]

Apart from REBOA, another method of achieving haemorrhage control is a resuscitative thoracotomy. In the civilian domain this is usually performed in the emergency department and is termed an emergency department resuscitative thoracotomy (EDRT, otherwise known as clamshell thoracotomy). In an EDRT, haemorrhage control occurs via open supradiaphragmatic clamping of the descending thoracic aorta.[6] The reported survival rates for EDRT are much poorer than those of REBOA, further adding to the debate and controversy regarding the optimal use of EDRT.[7,8]

The purpose of this article is to review the principles, indications, evidence, and limitations around the use of REBOA and EDRT in civilian major trauma. A brief overview of the critical issues surrounding the management of haemorrhage in trauma will also be provided along with data from the local experience in Western Australia (WA) and its unique geographical challenges.

CRITICAL ISSUES SURROUNDING THE MANAGEMENT OF HAEMORRHAGE IN TRAUMA

Pre-hospital stage

Preparation for the arrival of a trauma patient to hospital begins before the accident has even occurred. Emergency services and hospitals must have pre-existing guidelines in place to allow for the expeditious transfer of severely injured trauma patients to an appropriate trauma centre. Once a severely injured trauma patient has been identified at the scene, on-site emergency services will liaise closely with the receiving hospital which allows for the activation of a trauma call at the hospital. Trauma calls are institution specific and usually encompass a multi-disciplinary group of acute care physicians (for example, trauma surgeons, duty anaesthetists, radiologists, theatre staff, intensive care physicians) who are all involved in planning for the patient's arrival and subsequent care.[9] In the case of a severely injured trauma patient, the receiving hospital will likely be a level one trauma centre.[10] A level one trauma centre is defined by the American Trauma Society as a tertiary hospital which offers a comprehensive approach to the trauma patient, from injury through to rehabilitation.[10] These hospitals have 24-hour, in-house coverage by multiple surgical subspecialties and provide leadership, research and continuing education to the greater community, with the aim of preventing injuries from occurring. Level two to five trauma centres offer progressively more limited services.[10]

In the event of a multi-trauma casualty event, first responders will triage casualties at the scene and liaise with receiving hospitals. This may result in the activation of a Code Brown emergency at the receiving hospital(s).[11] A Code Brown emergency is called by a health service or facility when additional capability and capacity needs to be mobilised within that facility to accommodate an influx of patients due to an external emergency.[11]

Emergency department

Haemorrhage is a major cause of mortality and morbidity in trauma patients, as previously mentioned.[1,2] External and junctional haemorrhage is usually detected at the scene of the accident or during the primary survey.[9] In contrast, the precise site of internal haemorrhage may be difficult to both identify and quantify. It has been noted that mortality increases by up to 0.35 per cent for every minute definitive surgical control is delayed in hypotensive patients bleeding from abdominal injuries.[12] This is why rapidly accessible, quick, point of care tools such as extended focused assessment with sonography in trauma (eFAST) and portable X-rays are preferred over slower and less accessible investigations such as computerized tomography scans in unstable patients.[12] The expertise of the trauma team is critical to determine the likeliest source of haemorrhage and the most appropriate immediate management.

Obtaining haemorrhage source control

The commonest culprits for internal haemorrhage are the chest, abdomen, retroperitoneum, pelvis and long bones.[13] Source control is often challenging due to the nature of the injury.[13] Externally applied devices such as a pelvic external fixation device can be used for haemorrhage originating in the pelvis, or splinting can be used in the case of long bone haemorrhage.[9,13] EDRT can be used to gain proximal control of major haemorrhage from most sources whereas REBOA is only suitable for sub-diaphragmatic haemorrhage.[14] Angio-embolisation is another option for source control in hemodynamically stable patients.[15]

Damage control resuscitation (DCR)

DCR is the modern paradigm of haemostatic resuscitation and entails a multi-pronged approach to the resuscitation of a critically ill patient.[16,17] This approach aims to prevent the lethal triad of hypothermia, acidosis, and coagulopathy from developing and expedites definitive control of the bleeding source.[16,17] The components of this approach can be summarised as follows:

- Maintaining an adequate circulating volume through limiting crystalloid usage to less than 20mL/kg, transfusing warmed blood products in a one packed red blood cells (PRBC): one fresh frozen plasma (FFP): one platelet ratio (haemostatic resuscitation); early (within three hours from injury) administration of tranexamic acid and further blood component therapy as guided by thromboelastography (TEG)/ rotational thromboelastometry (ROTEM).[16,17] This requires large bore intravenous access such as a central sheath, rapid infusion catheter, or multiple large bore peripheral cannula attached to a rapid infuser (for example, Belmont device). The location of vascular access should also consider any anatomical disruptions as a result of the trauma.
- Allowance of permissive hypotension, balancing the risks of end organ ischaemia against the risk of uncontrolled haemorrhage.[16-18] Different trauma societies advocate for a systolic blood pressure (SBP) target of between 80-90mmHg for penetrating or blunt injury.[17,18] In the presence of brain trauma the current guidelines support a SBP of more than or equal to 100mmHg for patients 50-69 years old and a SBP of more than or equal to 110mmHg for patients 15-49 years, or 70 years and older.[19]
- Damage control surgery in the form of limited urgent surgical intervention(s) to address life-threatening injuries only.[16,17] All other surgical care is delayed until metabolic and physiological derangements have been treated (generally at least 24 hours post injury).[16,17]

DCR has been associated with improved mortality, reduction in blood product usage and reduced hospital length of stay.[16] Techniques such as EDRT and REBOA can play an additional role in haemorrhage control and resuscitation in instances wherein exsanguination is occurring faster than blood product replacement, or when all other means of control have failed.[17,20] DCR principles still apply when these two techniques are implemented, and as EDRT and REBOA are only temporising measures, damage control surgery is still required as the definitive method of controlling haemorrhage.

Goals of resuscitation

Achievement of an adequate circulating volume and/or organ perfusion may be reflected by an appropriate level of cognition in the awake patient, an acceptable measured blood pressure (permissive hypotension) or a palpable radial arterial pulse.[16,23] Surrogates used to guide resuscitation include lactate, base excess, stroke volume variation (in the ventilated patient), response to fluid boluses and/or cardiac output monitoring.[24] Table 1 is an example of resuscitation and transfusion targets in major trauma. Physiological endpoints and haemodynamic targets may need to be individualised, based on the nature of the injury and pre-existing medical co-morbidities of the patient.

Table 1. Resuscitation and transfusion targets in major trauma

Temperature	> 35°C
pH	> 7.2
Base excess	< -6mmol/L
Lactate	< 4mmol/L
Ionised Ca	> 1.12mmol/L
Hb	> 80g/L
Platelet count	> 80 x 109/L
INR	< 1.5
APTT	< 50 seconds
Fibrinogen	> 2g/L

Ca = Calcium, Hb = Haemoglobin, INR = international normalised ratio, APTT = activated partial thromboplastin time, °C = degrees Celsius, L = litre, g = gram.

ROLE OF AORTO-OCCLUSIVE TECHNIQUES

Aortic occlusion, whether by REBOA or EDRT, will stop haemorrhage from a source distal to the site of aortic occlusion. A reduction, or halt in ongoing blood loss, will allow time for resuscitation and definitive surgical control. Aortic occlusion also aids in preserving cerebral perfusion and coronary filling via an increased central volume and aortic pressure which results in increased carotid, cerebral and coronary blood flow, perfusion pressure and oxygenation.[25] However, the physiological cost of non-perfused, distal areas will contribute to the metabolic acidosis and general ischaemic burden over time.[25]

REBOA

Principle and indications

The principle behind REBOA is simple; inflation of a balloon in the aorta proximal to an injury will stop the blood flow and resulting bleeding.[26] This enables definitive surgical repair of the injury and achievement of haemostasis, after which the balloon can be deflated.[26] Each of these steps is however practically complex and requires careful decision making. The first question is who would benefit from a REBOA? A REBOA can be placed in situations where there is massive haemorrhage from any amenable subdiaphragmatic cause – examples include a ruptured splenic artery, bleeding placenta accreta, or massive haemorrhage from pelvic trauma. It can also be placed pre-emptively in situations of anticipated potential major haemorrhage in patients who are rapidly deteriorating or becoming unstable.[26,27] In some institutions, a SBP of less than 90mmHg in a partial or non-responder to fluid resuscitation is a trigger for femoral access.[27] In the case of pre-emptive insertion only the femoral sheath required to place the REBOA device needs to be inserted.[27] The sheath furthermore allows for arterial pressure monitoring and avoids unnecessary placement of the catheter and the associated potential complications following balloon insufflation.[27]

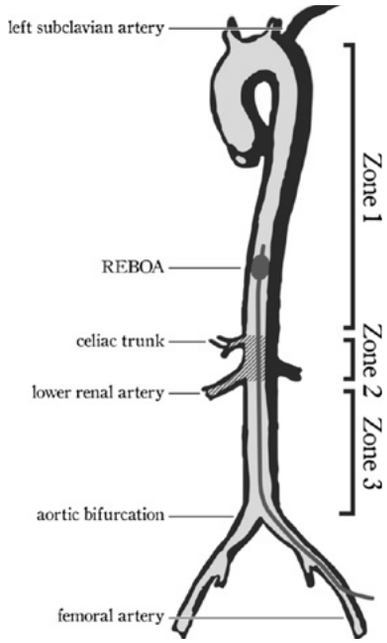
Optimum site for balloon positioning and inflation

Once the decision has been made to place a REBOA, the next question is where the balloon should be positioned in the aorta. To determine the optimum site of balloon position and inflation, the aorta is divided into three zones (Figure 1).[26]

- Zone I: Descending thoracic aorta between the origin of the left subclavian and coeliac artery.[26] Balloon inflation at zone I would physiologically resemble the application of a thoracic aortic cross-clamp. This zone is utilised for patients with intra-abdominal haemorrhage.
- Zone II: Para-visceral aorta between the origin of the celiac artery to the most distal renal artery.[26] This is a no occlusion zone due to the presence of the celiac, superior mesenteric and renal arteries. Occlusion of zone II exposes the patient to the risks of a zone I occlusion (visceral ischaemia) without providing significant benefits compared with a zone III occlusion.[26,27]
- Zone III: Infrarenal abdominal aorta between the lowest renal artery and aortic bifurcation.[26] Inflation here is used for patients with haemorrhage arising from severe pelvic fractures or other injuries at or below this level.

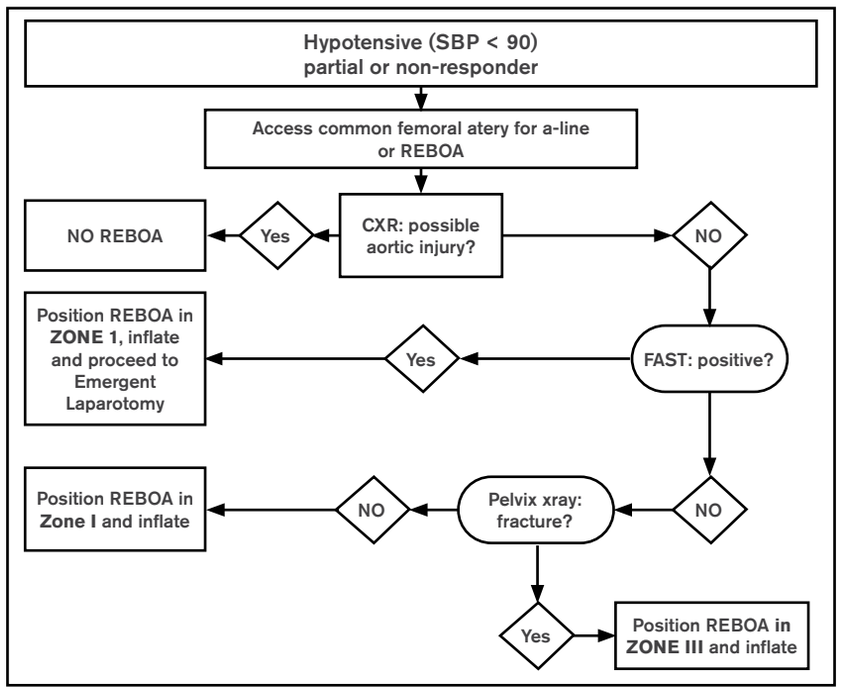
Figure 1. Anatomical aortic zones related to REBOA placement[28]

Zone I extends from the origin of the left subclavian artery to the celiac artery and is a potential zone of occlusion. Zone II extends from the celiac artery to the lowest renal artery and is a no-occlusion zone. Zone III exists from the lowest renal artery to the aortic bifurcation. Reproduced from Olsen et al.[28]



The decision-making process regarding REBOA insertion is summarised in Figure 2.

Figure 2. REBOA decision making algorithm. Reproduced from Moore et al.[29]



Procedural steps to place a REBOA device

The steps to insert a REBOA device are as follows:

1. Arterial access – usually the common femoral artery is accessed via a sheath which can be inserted either percutaneously using a landmark technique, with ultrasound guidance, or via surgical cut down.[27,28] Over time the sheath sizes have reduced, with modern REBOA devices requiring a 7 French (Fr) sheath as opposed to the 12Fr sheaths first used.[28]
2. Balloon insertion and positioning – the endovascular balloon is inserted through the sheath into the aorta.[27] The balloon is then floated into position with radiographic, fluoroscopic, ultrasound or epidemiologically based landmark guidance.[27,28] Direct comparison of the methods of balloon guidance is lacking in the literature; whilst fluoroscopy is the gold standard, it is often not available in emergency department bays or in the pre-hospital setting.[30] In contrast, epidemiological based landmark guidance is quicker but more prone to error.[30] One study reported a REBOA placement accuracy of 71.1 per cent using epidemiological based landmark guidance.[30] Of note, in this study the accuracy of placement of a REBOA device in zone I was greater than that of one placed in zone III (86.7 per cent vs 12.5 per cent respectively) due to the smaller target area in zone III.[30] As previously detailed, the intended zone of balloon placement will depend upon the suspected site of bleeding.
3. Balloon inflation – once the balloon has been sited, it is inflated to approximate against the walls of the aorta.[27,28] Balloon inflation should result in an increase in proximal SBP, with the magnitude of this differing depending on the zone of inflation.[28] Distal pulses should also be diminished. Wasicek found inflation in zone I yields a mean increase of 60mmHg whereas inflation in zone III results in a mean increase of 23mmHg.[31] Balloon inflation should be for the shortest duration possible to minimise the ischaemic time, ideally less than 30 minutes for Zone I and less than 60 minutes for Zone III.[32] Studies have shown an expected increase in mortality associated with an increased duration of balloon inflation.[25,33] The use of partial REBOA (sub-total occlusion of the aorta) or intermittent REBOA (periodic balloon deflation) may extend this ischaemic time limit however its role is still being studied.[34]
4. Balloon deflation – once haemostasis has been achieved or maximum REBOA inflation time reached, the balloon is slowly deflated.[27] Similar to the removal of a vascular cross-clamp elsewhere in the body, if there is haemodynamic instability or severe biochemical abnormalities the balloon may need to be partially or completely re-inflated for a short duration of time.[27,28] Several cycles of this may be needed before complete deflation is possible. This process requires close communication between all members of the operating theatre team. Haemodynamic instability following deflation of zone I balloons are more significant than those of zone III balloons as a result of the pronounced decrease in cardiac afterload and increased ischaemic-reperfusion injury.[35] Once haemodynamic stability has been achieved, the REBOA catheter can be removed. The sheath can remain in-situ and be used for arterial blood pressure monitoring.
5. Sheath removal – the procedure for sheath removal depends on the size of the sheath. Larger 12Fr sheaths require a femoral artery cut down with direct repair of the arteriotomy.[28] In contrast, 7Fr sheaths can be removed without surgical repair but require manual compression for at least 30 minutes.[28] Confirmation of distal perfusion should be carried out immediately post sheath removal and can be done via clinical and/or doppler and/or angiographic means.[28]

***Contra-indications* to REBOA placement include[36]:**

- Severe atherosclerosis.
- Blunt and penetrating aortic injury – recognised by symptoms such as dyspnoea, hoarseness and cough (as a result of aortic expansion and dilation) on the background of hypotension, altered mental state and chest pain.
- Cardiac tamponade.
- Penetrating neck (or any other supradiaphragmatic) trauma (resuscitative thoracotomy is potentially indicated).
- Blunt and penetrating cardiac injury (resuscitative thoracotomy is potentially indicated).

Reported *complications* include: acute kidney injury, iliac artery intimal rupture, REBOA balloon rupture and the need for subsequent lower extremity fasciotomy, thrombectomy, or amputation.[28,37] Complications of REBOA have become less common with the smaller calibre devices now used.[28] A systematic review by Morrison et al found an overall rate of morbidity of 3.7 per cent related to REBOA use, although this review was limited by the quality and quantity of evidence available.[37]

Outcomes following REBOA placement

Studies examining outcomes following REBOA placement have been mainly lower-quality observational studies, with several systematic reviews and meta-analyses based on these studies. The majority of the observational studies do report a positive mortality or survival benefit from REBOA placement, however there are some conflicting studies.[38-41] Harfouche et al carried out a single centre, retrospective matched cohort study examining in hospital mortality in patients who had a REBOA, or not, for trauma related haemorrhagic shock. They found significantly lower in-hospital mortality in the REBOA group compared to their matched contemporary group (19.3% vs 35.1% respectively, p = 0.024).[38] Yamamoto et al did a retrospective propensity score matched study using the nationwide Japanese trauma database of 82,371 patients.[39] Of these 82,371 patients 385 had a REBOA inserted and of these 117 were selected for propensity score matching.[39] Yamamoto et al found a higher survival to discharge in patients treated with REBOA versus those treated without REBOA (45.3% vs 32.5%; odds ratio = 1.72, 95% CI = 1.01 – 2.93; p = 0.04).[39]

In contrast, there are some studies that found harm following REBOA placement. Norii et al used the same Japanese trauma database as Yamamoto et al over a slightly different time period and found an odds ratio of survival after REBOA treatment of 0.30 (95% CI = 0.23-0.4).[40] The contrast in findings between these two studies was attributed to the stricter propensity score matching algorithm and increased number of covariates used in the propensity score matching of Yamamoto et al.[39,40] This example highlights how drastically different statistical analyses can alter the findings of a study. Joseph et al carried out a large multi-centre retrospective analysis of the 2015-2016 American College of Surgeons Trauma Quality Improvement Program data set and found a higher overall mortality rate in the REBOA group compared to the matched non-REBOA group (35.7% vs 18.9%, p = 0.01).[41] However, this study was criticised for not collecting and analysing data such as indication for REBOA placement, whether a protocol was used, whether REBOA was placed early or late in the patient's admission, REBOA inflation time and whether it was placed in a high volume centre or not. These criticisms are not unique to this study, with other studies also not routinely including this information. These all contribute to the discrepancy between studies looking at outcomes following REBOA. Unsurprisingly, due to the low quality of evidence of these studies, of the three systematic reviews carried out appraising these studies one found a survival benefit associated with REBOA whereas the other two were unequivocal or slightly favourable.[5,42,43] The completed UK-REBOA trial (publication of results pending) is the first randomised controlled trial examining outcomes following REBOA and will help provide higher level evidence to guide the use of REBOA in trauma.[44]

Higher volume centres have been shown to generally be more successful in accurate REBOA placement.[45] Theodorou et al. carried out a retrospective multi-centre study from the American Association for the Surgery of Trauma (AAST) Aortic Occlusion for Resuscitation in Trauma and Acute Care Surgery (AORTA) Registry from 11/2013–01/2018.[45] They defined high volume centres as those which inserted more or equal to 80 REBOA devices (two hospitals), mid volume as those that inserted 10-20 (four hospitals) and low volume centres as those that inserted less than 10 REBOA devices over this time period (14 hospitals).[45] No hospitals inserted between 21 to 79 REBOA devices. They found increased odds of successful REBOA placement (defined as haemodynamic improvement with balloon inflation) at high volume vs low volume hospitals (OR 7.50, 95% CI 2.10–27.29, p = 0.002) and mid volume vs low volume hospitals (OR 7.82, 95% CI 1.52–40.31, p = 0.014).[45] This may be due to multiple factors such as longer time in low and mid volume centres to achieve aortic occlusion, better familiarity with the REBOA insertion procedure at higher volume centres, as well as potentially superior simultaneous resuscitation at higher volume centres.[45] Specifically with regards to insertion times, low volume hospitals had a longer median time from admission to start of REBOA placement (low volume 45 minutes, mid volume 17 minutes, high volume 11.5 minutes, p <0.00001) and to aortic occlusion (low volume 45 minutes, mid volume 36 minutes, high volume 23 minutes, p = 0.00027).[45] Procedural time from initiation to successful aortic balloon inflation has been reported as between six to ten minutes in other studies.[27,46] In-hospital mortality rates and complications were however not different between low, mid or high volume centres.[45]

WA REBOA experience

An audit was recently carried out at Royal Perth Hospital (RPH) reviewing the outcomes following REBOA and EDRT over the past 10 years (January 2012 to September 2022). During this time period 11 REBOA devices were inserted and a 36 per cent mortality was reported, which compared favourably to other studies which report a mortality of 50-70 per cent in patients who had a REBOA.[29,47,48] This is despite the RPH patient population having a median injury severity score (ISS) of 50, higher than most other literature which report a median ISS of between 30 and 35.[29,47] Additional patient demographics such as age, sex, and mechanism of injury were similar to other studies.[29,47,48] Although direct comparisons are extremely difficult to do, we speculate that the lower mortality may be a result of the expertise of the trauma surgeons at RPH and the timing

of placement. Earlier placement may result in less haemorrhage with less volume resuscitation required and shorter balloon inflation times. These two factors have been associated with improved survival.[49,50]

Another interesting point is that in general the role of REBOA is slightly more limited in Australia than that of other countries. Due to the wide geographical nature of most Australian states (such as WA), patients often need to travel significant distances before reaching a trauma centre. Insertion of a REBOA device in a peripheral hospital in WA prior to transfer to the main trauma centre is not currently practiced. Thus, a significant percentage of critically unwell rural trauma patients may not be able to benefit from this intervention and will have to rely on traditional resuscitation measures. Four of the eleven study patients who had a REBOA, in the mentioned audit, were from a rural or remote area. This may have introduced a survival bias into the mortality rates and led them to appear higher than they may have otherwise been since these patients had to travel significant distances (increasing time to balloon placement). On the other hand, some critically unwell rural patients may have deceased prior to reaching a metropolitan trauma centre, leaving the more robust patients to be included in the audit, and thus influencing the mortality rate positively. Another consideration is the relatively small number of REBOA procedures done during the audit period and the effect each additional survivor would have on mortality data.

On admission to RPH, relative to patients who had an EDRT, patients who had a REBOA had a higher mean systolic blood pressure (mean ± standard deviation (SD), 18 ± 44 vs 96 ± 48 mmHg respectively), higher heart rate (beats per minute ± SD, 22 ± 46 vs 106 ± 43 respectively) and higher Glasgow Coma Scale (GCS) (GCS (interquartile range), 3 (3-3) vs 12 (11-14) respectively). This is in keeping with the trend of these procedures where EDRT is generally reserved as a "last ditch" resuscitative effort whereas REBOA is often placed before this point.[51] REBOA patients also had a significantly lower initial and peak lactate level compared to the EDRT group (lactate level ± SD, initial REBOA 7.3 ± 3.0, peak REBOA 9.8 ± 4.6 vs initial EDRT 13.0 ± 5.7, peak EDRT 16.8 ± 10.9).

EDRT

An EDRT is generally performed during peri-arrest or arrest scenarios and relies on an emergency thoracotomy and aortic cross clamp to achieve haemorrhage control.[52] Although both REBOA and EDRT result in aortic occlusion, their indications are different. For EDRT, the general indications include[52,53]:

- Non-compressible torso haemorrhage with imminent arrest.
- Persistent severe hypotension SBP less than 70mmHg, unresponsive to aggressive fluid resuscitation and/or inotropic support due to major intrathoracic haemorrhage (more than 1500ml from chest drain).
- Cardiac tamponade.
- Gas embolism with circulatory arrest.
- Massive haemothorax.
- Blunt extrathoracic trauma with witnessed cardiac arrest, less than 10 min CPR and signs of life (conditional recommendation).
- Penetrating extrathoracic trauma with witnessed cardiac arrest and less than 15 minutes of CPR (conditional recommendation).

Following the thoracotomy simple damage control manoeuvres (for example, direct pressure, packing, clamping) are used to manage visible haemorrhage and a pericardiotomy can be done to gain control of any cardiac injuries.[52] The aorta is then cross clamped followed by aggressive volume resuscitation, open cardiac massage and internal defibrillation, if required.[54] Exploration of thoracic structures to exclude other injuries will follow definitive surgical treatment.[54] An EDRT can be performed by any trained acute care physician, which at RPH is generally the trauma surgeons.[54] An EDRT procedure is discouraged in settings where an appropriately trained surgeon is not available to provide immediate definitive care, as opposed to REBOA insertion which can serve as a temporary bridge to definitive care in the appropriate patient.[52,53]

The mortality following EDRT is universally poor and survival is reported as less than 10 per cent in most studies.[7] Reasons for this include the poor patient prognosis at the time of EDRT and the invasive nature of the EDRT procedure resulting in severe physiological derangement, coagulopathy and hypothermia.[29] The highest survival rates are amongst patients with isolated penetrating cardiac injuries, followed by penetrating noncardiac thoracic injuries, penetrating abdominal and lastly multiple penetrating injuries.[7] Patients with blunt thoracic injury have a very low survival rate with EDRT, with one study reporting a survival rate of only 1.4 per cent.[7] Contra-indications to EDRT include trauma with prolonged cardiac arrest, nontraumatic arrest, severe head injury and multisystem injury.[52,53]

WA EDRT experience

The audit done at RPH reports 76 EDRTs over the past decade, with comparable age, sex and mechanisms of injury to other literature. Of note, 40 per cent of the EDRT procedures resulted from penetrating mechanisms of injury with the remaining 60 per cent due to blunt mechanisms of injury. The median ISS in this population was 30, similar to that of other literature. Twelve of these 76 patients were from a rural or remote area and only one of the 76 patients survived to discharge.

Factors influencing success with REBOA or EDRT

Whilst caseload is one component of success, there are many other factors which influence institutional success with REBOA or EDRT:

1. Multi-disciplinary leadership including representatives from emergency medicine, trauma surgery, vascular surgery and nursing. Of note, REBOA and EDRT should only be employed as part of a larger system of damage control resuscitation - it is not a definitive treatment. Twenty-four hour availability of interventional radiology, theatre and ICU should be present to facilitate definitive treatment.
2. Regular reviews of the trauma pathway to ensure key performance targets are being met (for example, time to REBOA insertion) and optimisation of care pathways.
3. Regular team based and operator skill training to ensure technical and non-technical skills are achieved and maintained.[46] Consideration should be given to requiring recognised course completion before being credentialled to carry out these procedures.
4. A quality assurance process which regularly conducts audits of trauma care in both patients who do and do not receive REBOA and EDRT procedures, to identify areas of improvement.
5. Audits, and any other future studies, should include information on the indication for REBOA insertion, the proceduralist, the time taken to insert the device, the inflation time and associated complications as a result of REBOA placement. For EDRT this includes information such as the specific indication, the proceduralist and duration of CPR pre-EDRT.

By addressing these pillars, hospital survival associated with the REBOA and EDRT procedures may be continually improved on. The positive outcomes RPH has had with REBOA have been attributed to several factors. The technique was first introduced in 2014 with a specific patient subgroup in mind; this subgroup was the peri-arrest trauma patient who needed to be stabilised to allow transfer from the emergency department to interventional radiology or theatres. Prior to implementation, two of the senior RPH trauma surgeons had training on how to insert REBOA devices. The presence of staff skilled at conducting the technique cannot be overstated. Another important consideration is the timely ability to conduct the procedures. For our local institution, the trauma surgeons who were trained in the technique and supportive of integrating it into the hospital's trauma services all lived close to the hospital, enabling a consultant trauma surgeon to be in the ED ready to place a REBOA within 10 minutes of being called in. Furthermore, prior to the introduction of REBOA, collaboration was done with other departments in the hospital (for example, interventional radiology) on efficient and accurate insertion and device troubleshooting. Pre-enrolment collaboration also included high fidelity simulations with the emergency department trauma multi-disciplinary team. These simulations are repeated on a continuous basis, to maintain familiarity and proficiency across the multitude of team members that are essential in effectively providing this intervention. With increasing familiarity over time, insertion became quicker, and the balloons are now only inflated for the minimum time necessary to allow for safe transfer. With time, our trauma surgeons have also become more experienced in rapidly assessing the patients suitable for a REBOA (age, co-morbidities), trauma (type, injury pattern) and appropriately selecting the supporting resources needed (trauma surgeon, theatre and ICU availability and expertise). Having hospital wide engagement in supporting this system is essential for appropriate insertion, management, and follow-up of REBOA devices.

CONTROVERSIES

REBOA as part of a damage control resuscitation package varies between hospitals and from case to case with regards to REBOA device use, triggers for insertion, insertion techniques, time taken to achieve aortic occlusion, methods of verifying REBOA position and inflation times.[5,42,43] This expected variability contributes to heterogeneity in the literature and may confound comparisons between different studies.[5,42,43] Detailed reporting of these variables should be done in future studies, aiming at technique standardisation which should result in improved patient survival.

Although attempts have been made to do so, it is extremely difficult to compare outcomes following EDRT and REBOA. EDRT is generally done in patients who are close to or have already arrested, whilst REBOA is generally utilised at an earlier stage.[51] Inherently this means that REBOA patients generally have less

physiological derangement than patients who require EDRT. Randomised controlled trials to compare the two have never been done and are unlikely to ever occur. There have however been several observational studies on the topic. Brenner et al. found a survival benefit in an unmatched observational study when comparing REBOA to EDRT, concluding that REBOA offered a survival advantage over resuscitative thoracotomy in patients not requiring cardiopulmonary resuscitation.[6] Furthermore, systematic reviews by Castellini et al and Borger van der Burg et al also found a survival benefit to REBOA when compared to EDRT.[5,44] However, the findings of these studies must be taken in the context of the low quality evidence they were based on and the inherent selection bias present in these studies. Additionally, the difference in indications and patient selection for EDRT and REBOA may make direct outcome comparisons inappropriate.

CONCLUSION

Management of trauma related haemorrhage has advanced significantly over the past few decades. New concepts such as damage control resuscitation and haemostatic transfusion have drastically improved patient outcomes. REBOA and EDRT are techniques which, when properly applied, may theoretically improve outcomes even further in a select group of patients. REBOA in particular has some promising low-quality evidence backing its use, however the studies forming the basis of these findings are mainly retrospective and non-randomised.[5,43,44] The UK-REBOA study will help determine future directions for this technique and may also help to elicit further specific indications for REBOA. For the time being, REBOA and EDRT both remain potentially useful tools in our arsenal against uncontrolled haemorrhage. In Western Australia the use of REBOA in a designated trauma centre which is proficient and experienced in its use, most likely leads to better patient outcomes. Regular future auditing and quality control procedures are essential to ensure the procedures being carried out are to a comparable standard to other high performing centres.

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