Injury, Int. J. Care Injured 46 (2015) 1431–1439

Contents lists available at ScienceDirect

Injury

journal homepage: www.elsevier.com/locate/injury

Review

Advances in the treatment of blunt thoracic aortic injuries

Dimitrios Challoumas [a,*], Georgios Dimitrakakis [b]

[a] *Cardiff University School of Medicine, Heath Park Campus, University Hospital of Wales, Cardiff CF14 4XW, UK*
[b] *Department of Cardiothoracic Surgery, University Hospital of Wales, Heath Park Campus, Cardiff CF14 4XW, UK*

ARTICLE INFO

Article history:
Accepted 29 October 2014

Keywords:
Blunt thoracic aortic injury
Trauma
Endovascular repair
Open repair
Delayed repair
Cardiovascular surgery

ABSTRACT

Blunt thoracic aortic injuries, even though rare in incidence, carry significant mortality rates and their management still remains challenging. There have been major shifts in diagnosing and treating these injuries in the last 5 decades, which proved to be beneficial in terms of mortality and complications. Endovascular repair has been increasingly used for definitive treatment and its outcomes appear to be at least equally safe and effective as those of open repair. We present a balanced review of the relevant literature regarding the most appropriate approach and definitive treatment of these pathological entities. Based on the studies analyzed, endovascular repair is increasingly being established as the choice of treatment, however, the conventional open surgical approach still remains a safe method for severe injuries; the mortality, complication rates and proven longterm results of the latter are continuously improving. Additionally, delayed repair, where appropriate, seems to be a safe option with very low mortality rates. Despite the encouraging short and midterm outcomes reported, endovascular treatment needs to be assessed in the longterm for more accurate conclusions to be drawn about its durability and safety.

© 2014 Elsevier Ltd. All rights reserved.

Contents

* Corresponding author. Tel.: +44 029 2068 8113.
E-mail address: dchalloumas@hotmail.co.uk (D. Challoumas).

http://dx.doi.org/10.1016/j.injury.2014.10.065
0020–1383/© 2014 Elsevier Ltd. All rights reserved.

Background

Blunt thoracic aortic injuries (BTAIs) are the second leading cause of death from blunt trauma, after head injury, and even thought they are quite rare, accounting for less than 1% of trauma admissions, their morbidity and mortality rates are significantly high. Importantly, pre-hospital mortality is about 85% and even of those reaching medical attention, a third will die before operative intervention [1,2].

Analysis of the National Trauma Databank (USA) by Arthurs and colleagues, in 2009, revealed that in a 5 year period, 3114 patients suffered a BTAI, representing 0.3% of all trauma admissions (n = 1.1 million) [3].

By far the most important cause of significant blunt chest trauma is motor vehicle accidents (MVAs; 18% of all MVAs), usually as a consequence of rapid deceleration and the exertion of shearing forces, and the majority of aortic injuries (55–67%) occur at the isthmus of the descending thoracic aorta [1,4].

Associated injuries, which are usually present in patients with BTAIs, depend on the nature and force of impact and they may include closed head injuries, rib fractures (flail chest), pulmonary contusions, pelvic injuries, intracranial haemorrhages, liver injuries, upper limb fractures, maxillofacial injuries, diaphragmatic ruptures and cardiac contusions in descending order of frequency, as revealed by a prospective study conducted by the American Association for the Surgery of Trauma (AAST) [2]. The extent of polytrauma and the expected mortality is defined by the injury severity score (ISS), which derives from the abbreviated injury scale (AIS) values, and is a very useful tool when comparing treatment methods. Major trauma is commonly defined as ISS over 15 [3,5,6].

The clinical features may range from no symptoms to these of severe hypovolaemic shock, therefore investigation of these patients should be staged appropriately even in asymptomatic patients after significant thoracic impact to exclude a potentially fatal BTAI [7].

CT scan has now replaced angiography, which used to be the method of choice for confirming and evaluating BTAIs in the past. This shift is one of the major advancements in the management of these patients and CT scan is now the preferred screening tool and gold standard for diagnostic confirmation and evaluation [4,7,8]. Features of a CT suggesting a BTAI include mediastinal haematoma and hemopericardium, false aneurysm, irregularity of the aortic contour, aortic dissection and haemothorax [4,7,9].

According to clinical judgement on an individual basis, treatment may be interventional (immediate or delayed, surgical or endovascular repair) or conservative. The timing of repair largely depends on the extent of injury on the thoracic aorta and the presence or absence of other injuries [7].

In general, minimal aortic injuries (intimal tear of less than 1 cm with no or minimal peri-aortic haematoma) receive conservative management [10]. Other groups of patients that may benefit from initial conservative management and/or delayed repair include those with severe head and pulmonary injuries, coagulopathies, hypothermia and acidosis, haemodynamically unstable patients (systolic blood pressure $<$90 mm Hg or drop in systolic blood pressure $>$40 mm Hg), patients who have undergone damage control procedures and those with severe medical comorbidities, burns or severe sepsis [4,11,12].

Permissive hypotension in BTAI patients is essential for the following reasons: (1) to minimize the risk of rupture prior to urgent repair and for those managed conservatively, and (2) to stabilize patients with other serious associated injuries (e.g. brain and pulmonary injuries or cardiac instability) if a delayed repair of the BTAI is planned. The idea of establishment of this permissive hypotension derived from its successful use in the management of dissecting aortic aneurysms as it reduces shear forces. β-blockers are often used, with or without nitroprusside, to ensure that the mean arterial pressure, ventricular ejection force and hence aortic shear force drop and remain low [4,13].

Although Fabian et al. (1997) and Von Oppel et al. (1994) have reported 11.6% and 10.3% mortality from rupture prior to surgical repair respectively, the aggressive antihypertensive management employed in a study in 1998 resulted in no deaths from rupture in 71 patients [2,13,14]. The authors of the latter study recommended maintenance of systolic blood pressure at 100 mm/Hg and pulse rate under 100 beats/min with the use of intravenous labetalol or esmolol combined with sodium nitroprusside if needed [14]. Vasodilators should only be used in conjunction with β-blockers, only if the latter do not yield adequately low systolic blood pressure, as they can produce tachycardia which is associated with increased shear forces [13].

Other groups aimed at and advocate systolic blood pressures of as low as 80 mmHg, however, maintaining the pulse rate under 100 seems to be universally accepted [15–17].

Definitive treatment

BTAIs can be either repaired surgically [open repair (OR)] or with an endovascular approach [thoracic endovascular aortic repair (TEVAR)], which is increasingly gaining popularity and is now the treatment of choice [4,7,9].

Open repair

This can be performed through emergency median sternotomy or thoracotomy depending on the desired operative site [4].

The clamp and sew technique that was used in the past is now preferred very rarely due to the high incidence of paraplegia [7].

Cardiopulmonary bypass is used as a safe method of proper support, which has the advantages of decompression of the heart, circulatory support, distal perfusion and reduction in paraplegia rates, as well as dealing with unexpected life-threatening bleeding during the operation with the use of an integral pump sucker. Finally, hypothermia and drainage of cerebrospinal fluid are other strategies used for cord protection [7,18].

Various operative techniques may be used in an OR such as direct suture, resection and direct anastomosis, and insertion of an inter-position graft, and these depend on the nature and extent of the injury [4,14].

Endovascular repair

A femoral artery cutdown is usually performed for the placement of endovascular stent grafts, which are inserted usually into the femoral, iliac or abdominal arteries depending on their size. With the aid of fluoroscopy, a guide wire is placed across the injury and subsequently the stent graft is deployed upon angiographic confirmation of the location of the injury. The metal stents of the stent graft function by exerting a radial outward force with covered graft material that excludes flow from the injury [4]. Compared to OR, TEVAR is minimally invasive and can be performed soon after the establishment of diagnosis prior to management of other concomitant severe injuries [4].

Complications

Apart from the common peri-operative complications, spinal cord injury and stent endoleaks are widely accepted to be specific complications of BTAIs repair.

Notably, some individuals are more prone to spinal cord injury irrelevant of the treatment method used, due to their anterior spinal artery being discontinuous [4].

Paraplegia may be a pre-operative or post-operative complication. Pre-operatively, it may be the result of direct spinal cord injury from fracture or spinal dislocation, hypoperfusion or vascular injuries to the radicular arteries and especially the artery of Adamkiewicz [14]. Post-operative aetiology varies and important predictive factors include the duration of cross-clamp, the position of the cross-clamp and the aortic perfusion distal to the cross-clamp. Additionally, the cause may be decreased spinal cord perfusion pressure gradient secondary to raised cerebrospinal fluid (CSF) pressure, spinal cord temperature, reduced blood pressure and a large number of intercostal arteries damaged during surgery [4].

Notably, rates of paraplegia are substantially lower in TEVAR than those after OR, most likely due to avoidance of clamping and prolonged hypotension combined with the short segment of aorta stented [4].

The most common complication of TEVAR is endoleak of the stent, which is hence the major limitation of this treatment method [4]. It can occur as one or more of four different types as reported by Mitchell (2002): leak at anastomotic junction of the aorta and the stent graft (type I), back bleeding vessels within the aneurysm sac (type II), stent graft junction leak (type III), and leak through stent graft fabric (type IV) [19].

Compared to OR, TEVAR appears to have two important advantages: (a) it can be performed soon after the establishment of diagnosis prior to management of other concomitant severe injuries and (b) it may be superior to traditional OR in high-risk patients with coexisting severe injuries where OR can be risky, and it has been shown to be a safe alternative in this group of patients [4].

However, long-term results for TEVAR have not been described yet, therefore the durability and long-term complications of endovascular treatment for BTAIs are still questionable [20]. Based on this, Mary-Ane et al., advocate limited use of this technique to centres that are able to provide close monitoring in the follow-up period, so that more knowledge regarding the long-term outcomes of endovascular treatment can be obtained [21].

A major pitfall of endovascular repair of BTAIs is the relative inability to be used in younger patients due to their small, sharply angulated arteries. In addition, oversizing of the stent and placement along the arch may lead to graft collapse [21].

Lifelong follow-up after TEVAR is mandatory as treatment failure may occur even after years of insertion of the stent. CT angiography is recommended before discharge and will dictate the need for further follow-up at 6 and 12 months, which should be performed with MRI and CT angiography in combination with clinical follow-up [22].

Statistics of advancements in management

The report by Demetriades et al. comparing the findings of the two studies conducted by the AAST in 1997 ($n = 207$) and 2007 ($n = 193$) that describe the management of BTAIs is of paramount significance in the field [23].

In the 1997 study, angiography was performed in 87% of patients, transesophageal echocardiography (TOE) in 11.9% and CT scan in 34.8% of patients, while in the 2007 study, only 8.3% ($P < .001$) and 1.0% ($P < .001$) of patients underwent angiography and TOE respectively, while the use of CT scan increased to 93.3% ($P < .001$) [23].

In the same article, changes in the definitive treatment of BTAIs between 1997 and 2007 as well as treatment outcomes are also described. Three major shifts were reported: firstly, the time from admission to definitive treatment increased substantially from 1997 to 2007 (mean = 16.5 h vs mean = 54.6 h respectively, $P < .001$); secondly, the type of repair shifted from open surgery in 1997 (100% of cases) to predominantly TEVAR ($P < .001$) in 2007 (64.8% of cases), which were performed by cardiothoracic or vascular surgeons and interventional radiologists but not trauma surgeons; finally, a more liberal use of bypass techniques was observed during ORs in the 2007 study compared to the one in 1997 ($P = .003$) [23].

These shifts in management (both diagnosis and definitive treatment) seem to be beneficial, as mortality and procedure-related paraplegia dropped significantly between 1997 and 2007. The former decreased from 22.0% in 1997 to 13.0% in 2007 ($P = .02$) and the latter from 8.7% to 1.6% ($P = .001$). Notably, comparing exclusively ORs in the two studies, paraplegia rates fell significantly from 8.7% to 2.9% ($P < .001$), most likely due to the increasing use of distal aortic perfusion. However, a negative outcome was noted: an increase in early graft-related complications from 0.5% in 1997 to 13.5% in 2007, which included endoleaks, access vessel injuries, subclavian artery occlusions, strokes, paraplegia and partial collapse of the stent/graft [23].

Three years later, Hong et al. (2011) identified 8269 patients who were diagnosed with traumatic thoracic aortic injuries between 2001 and 2007 in the Nationwide Inpatient Sample (reflects about one-fifth of all admissions in the USA). They, then, evaluated them in terms of inpatient mortality, length of stay, and major complications based on OR, TEVAR, or non-operative management before (2001–2005) and after (2006–2007) the widespread establishment of TEVAR and found the following: (1) there was an estimated 1180 annual admissions for traumatic thoracic aortic injuries and between the two time periods, there was an increase in TEVAR ($P < .001$) with a concurrent decrease in OR ($P < .001$) in 2006–2007. (2) Improved survival was noted in the non-operative group (28.0% vs 23.2%; $P < .001$) and this contributed to a decrease in overall mortality (25.0% vs 19.0%; $P < .001$). (3) Finally, the overall number of interventions increased, while the mortality rates in the OR groups between the two time-periods were not different [24].

Study selection

For the identification of all relevant articles, a systematic literature search was conducted via MEDLINE through PubMed for studies reporting their results on the management of BTAIs. The search was performed in May 2014 for combinations of the keywords blunt thoracic aortic injuries, blunt thoracic aortic trauma, treatment, management, open vs endovascular, delayed, surgical, TEVAR and stent-graft, with no language or time restrictions. Exclusion of articles was as follows: duplicate articles, studies published before 2000, studies describing findings of one of OR or TEVAR alone and not comparing the two treatment methods. Subsequently, a manual selection of titles, first, and then abstracts followed, which resulted in 26 studies written in the English language that were included in the present article. Of these, the 15 with the largest populations and potentially most significant clinical impact were included in Table 1.

Evidence

Recently published studies and meta-analyses are in favour of the endovascular method as definitive treatment over OR in patients with BTAIs and in support of delaying treatment where possible [1,3,24–49].

Table 1
The key studies reviewed with their outcome measures and most significant findings. TEVAR: thoracic endovascular aortic repair; OR: open repair; BTAIs: blunt thoracic aortic injuries; n.s.: not stated [3,25,26,33,34,36,39,41,42,44–49].

	Authors, date	Population number	Study type	Outcomes	Key findings
1	Hoffer et al., 2008 [44]	638	Meta-analysis	-Mortality -Paraplegia -Endoleaks	-Lower mortality rates with TEVAR than OR (P = .001) -Lower paraplegia rates with TEVAR than OR (P = .01). -4.2% endoleak incidence with TEVAR.
2	Takagi et al., 2008 [48]	565	Meta-analysis	-Mortality -Paraplegia	-Lower mortality rates with TEVAR than OR (P = .009) -Lower paraplegia rates with TEVAR than OR (P = .01).
3	Tang et al., 2008 [47]	699	Meta-analysis	-Technical success -Mortality -Paraplegia -Stroke	-Equal technical success rates of TEVAR and OR (P = .58) -Lower mortality rates for TEVAR than OR (P = .0076) -Lower paraplegia rates for TEVAR than OR (P < .0001) -Lower stroke rates for TEVAR than OR (P = .0028)
4	Xenos et al., 2008 [45]	609	Meta-analysis	-Mortality -Paraplegia	-Lower 30-day mortality with TEVAR than OR (P = .005) Lower overall procedure-related mortality with TEVAR than OR (P = .002) -Lower paraplegia rates with TEVAR than OR (P = .037)
5	Xenos et al., 2009 [46]	859	Meta-analysis	-Mortality -Paraplegia	-Lower mortality rates with TEVAR than OR (P = .005) -Lower paraplegia rates with TEVAR than OR (P = .005)
6	Murad et al., 2011 [49]	7768	Meta-analysis	-Mortality -Stroke -Spinal cord ischaemia -End-stage renal failure	-Lower mortality with TEVAR compared to OR and no treatment group (P < .01) -No difference in stroke rates -Higher risk of spinal cord ischaemia in OR group compared to TEVAR and no treatment groups (P = .01) -Higher risk of end-stage renal failure in OR group compared to TEVAR and no treatment groups (P = .01)
7	Demetriades et al., 2008 [42]	193	Prospective	-Mortality -Paraplegia -Transfusion units	-Lower mortality with TEVAR than OR both in patients with and without extra-thoracic injuries (P = .04 and P = .002 respectively) -No difference in paraplegia rates -Fewer transfusion units required with TEVAR than OR (P = .004)
8	Demetriades et al., 2009 [36]	178	Prospective	-Mortality -Complications -Length of stay in ICU	-Lower mortality in stable BTAIs with late repair than early repair but insignificant (P = .06) -Higher complication rates in late repair group compared with early repair in patients with no major associated injuries (P = .04) -Longer ICU stay with late repair compared to early (P = .02).
9	Azizzadeh et al., 2011 [41]	106	Prospective	-Complications (incl. in-hospital mortality) -Costs -Length of hospital stay	-Lower estimated odds ratio for complications with TEVAR than OR (P = .045) -Similar mean adjusted total and fixed costs -Similar mean adjusted length of hospital stay
10	Arthurs et al., 2008 [3]	114	Retrospective	-Survival rates -Paraplegia rates -Other complications	-Equal survival rates for TEVAR and OR but lower mortality with TEVAR than OR in delayed repairs (P < .05) -Similar paraplegia rates for TEVAR and OR (P = n.s.) -Higher cardiopulmonary complication rates for OR and higher incidence of acute renal failure for TEVAR
11	Estrera et al., 2010 [25]	145	Retrospective	-Mortality -Paraplegia	-Lower mortality rates for TEVAR than OR (P < .03) Lower mortality with delayed repair compared to immediate open repair (P < .02) Lower mortality with distal aortic perfusion in OR than with no distal aortic perfusion (P < .02) -No differences in paraplegia rates between TEVAR and OR -Higher paraplegia rates for OR without distal aortic perfusion than OR with perfusion and TEVAR (P = n.s.)
12	Patel et al., 2011 [33]	109	Retrospective	-Freedom from re-intervention	-Higher freedom from re-intervention rates at 4 years with OR compared to TEVAR (P = .03)
13	Estrera et al., 2013 [26]	175	Retrospective	-Early mortality -Paraplegia -Late survival	-Lower early mortality rates with TEVAR compared to OR with crossclamping (P < .002) but not to OR with distal aortic perfusion (P = n.s.) Lower early mortality rates with delayed repair than immediate repair (P = .004) -Higher paraplegia rates for OR with crossclamping compared to OR with distal aortic perfusion and TEVAR (P = n.s.) -Survival at 1 and 5 years: 76% and 75% for OR and 92% and 87% for TEVAR (P = n.s.)
14	Riesenman et al., 2012 [34]	100	Retrospective	-Mortality -Endograft-related complications	-Lower intraoperative (P < .05) and in-hospital mortality (P < .05) rates with TEVAR than OR -19.2% of TEVAR patients experienced endograft-related complications
15	Di Eusanio et al., 2013 [39]	77	Retrospective	-Mortality -Paraplegia	-Delayed repair is used as first-line treatment for BTAIs in their centre and was associated with very positive outcomes (mortality only 3.9%) -No difference in mortality rates between OR and TEVAR groups (P = .398) -No difference in paraplegia rates between OR and TEVAR groups (P > .05)

Cohort studies

Retrospective studies

OR vs TEVAR. In the aforementioned study by Hong et al. (2011), overall in-hospital mortality between TEVAR and OR was not significantly different (10.6% vs 12.4%), while this was highest in the non-operative group (26.7%) [24]. Hospital length-of-stay was shorter for patients who underwent TEVAR compared to those treated surgically (15.7 vs 22.9 days; $P < .001$) and there were no differences in paraplegia rates or renal failure. Importantly, the TEVAR group had higher rates of brain injury (26.1% vs 20.6%; $P = .008$), lung injury (25.0% vs 17.7%; $P < .001$), haemothorax (32.5% vs 21.7%; $P < .001$) and stroke (1.9% vs 0.7%; $P = .021$) compared to the OR group, whereas the latter group had more respiratory complications (43.9% vs 54.2%; $P < .001$). Interestingly, according to the authors, the increased utilization of TEVAR is associated with improved overall mortality; the absence of a significant difference in their study probably reflects the multi-system nature of injury and greater preoperative risk in those selected for TEVAR [24].

Estrera et al. (2010), in their 12-year single institution experience of 145 patients with BTAIs, described 0% mortality in patients treated with endovascular repair compared to 17% in those where an operative intervention was used ($P < .03$). Delayed repair (41% of patients) was safer in the same study, with a mortality rate of 2% vs 28% in those treated immediately ($P < .02$), after adjusting for ISS which was, as expected, significantly lower in the "delayed repair" group. With regards to OR, the use of distal aortic perfusion yielded lower mortality than repair without use of distal perfusion (14% vs 31%, $P < .02$). Finally, paraplegia was not seen in any patients treated with TEVAR or with an OR and distal aortic perfusion, compared to a rate of 10% in those treated operatively without distal aortic perfusion. ISS between the different "immediate treatment" groups was statistically similar [25].

An update of the same study 3 years later reported early mortality rates of 17% for all ORs, 4% for TEVAR, 31% for ORs with aortic crossclamping, and 14% for OR with distal aortic perfusion. Statistical significance was only detected between mortality after TEVAR and after OR with crossclamping ($P < .002$). Survival was 76%, 75%, 72% and 68% at 1, 5, 10 and 15 years post-operatively respectively for OR, while for TEVAR rates of 92% and 87% at 1 and 5 years follow-up respectively were observed. Again, mean ISS were not statistically different between groups [26].

Outcomes of another single institution experience (26 patients) by Yamane et al. (2008) showed no difference in mortality and morbidity between the use of OR and TEVAR, suggesting that the latter is at least as safe as the former. The number of associated injuries and ISS on presentation was not different between the two treatment groups. The only complication was a recurrent laryngeal nerve palsy in a patient treated operatively. There was no treatment-related paraplegia in either of the two groups and 1-year survival was similar (93% with OR and 92% with TEVAR). More re-interventions were required in the OR group, mean operating room time was 80 min lower for patients treated with TEVAR, and no differences were noted in hospital stay and the total blood products administered in the two groups [1].

A larger single institution experience of 76 patients was published by Buz and colleagues in 2008, which is in favour of endovascular repair [27]. All patients had associated injuries which were similar between groups, and so was the ISS. Both hospital mortality and peri-interventional complications were significantly higher with surgical repair ($n = 35$) compared to the endovascular approach ($n = 39$). Twenty percent (20%) of the former group died in hospital, in most cases due to brain death in severe trauma patients, compared to 7.7% of the endovascular group, in which no complications were observed except for a single case that needed to be converted to conventional surgery. In contrast, five patients experienced 10 surgical complications in the OR group, namely respiratory insufficiency, pulmonary infection, recurrent nerve palsy, repeat thoracotomy, and compartment syndrome. No paraplegia was reported in either groups and two patients of the endovascular group had to undergo surgery 15 days and 4 months post-intervention due to injury of the aortic wall by the stent and development of an aneurysm respectively [27].

Watson et al. (2013) presented their 14-year experience in managing BTAIs and their outcomes are similar to those described above [28]. Of the 59 patients treated, 33 underwent OR, 14 endovascular repair, 9 simultaneous procedures and 3 were managed non-operatively. Mean ISS and revised trauma scores were similar between the OR and the TEVAR groups. The OR group had substantially higher 30-day mortality rate, complications rate and hospital stay compared to the TEVAR group [28]. Similarly, Klima and colleagues found that patients treated with TEVAR ($n = 28$) had favourable outcomes in terms of both 30-day mortality and overall complications compared to those treated operatively, despite similar ISS, however, hospital length of stay was similar between the two groups [29].

Two French studies in 2004 and 2011, showed that TEVAR is at least as safe and effective as OR in treating aortic traumatic ruptures [30,31]. In the first ($n = 19$), zero mortality and procedure-related complication rates were observed in the TEVAR group ($n = 9$) and CT scans 3 months postoperatively showed complete disappearance of pseudoaneurysm in all 9 patients. On the other hand, one patient died in the OR group ($n = 11$) and 3 experienced surgical complications. However, the comparability of the groups in this study may be in question as ISS and number of associated injuries may have not been compared, and 2 vs 6 patients received a delayed repair in OR and TEVAR groups respectively [30]. The authors of the second study, that was significantly larger ($n = 75$), reported lower overall mortality rates in the TEVAR than in the OR group (11.4% vs 2.5%), which however did not reach statistical significance ($P = .06$) most likely due to underpowering. Morbidity, on the other hand, was slightly higher in the TEVAR group (20% vs 14.2%) and included 1 proximal type I endoleak, 2 stent collapses, 1 iliac rupture, 1 vertebrobasilar insufficiency and 3 intraoperative inadvertent coverage of supra-aortic trunks. In the surgical group, complications were 3 recurrent nerve palsies and a false anastomotic aneurysm. In contrast to the other French study described above, the two groups were comparable both in terms of ISS and number of associated injuries [31].

Similarly, Celis et al. in 2012 reported the superiority of TEVAR over OR according to their experience in terms of favourable mortality rates, although the difference was borderline statistically insignificant ($P = .06$) [32]. Of 91 patients who presented with a traumatic aortic injury, 41 were treated operatively and the remaining 50 underwent TEVAR; mortality in the former group was higher (19.5% vs 6.0%) and overall morbidities incidence was similar between the two groups (42% vs 50% respectively). Noteworthily, 2 patients in the OR group developed paraplegia postoperatively compared to none in the TEVAR group, and importantly, both ISS and comorbidities (hypertension, peripheral arterial disease, diabetes mellitus and coronary artery disease) were compared and found to be similar in the two groups [32].

In the analysis of the National Trauma Databank (USA), Arthurs et al., in 2008, reported equal survival rates between TEVAR (82%) and OR (81%) in 114 patients with BTAIs [3]. The two intervention techniques also had similar paraplegia rates (2% for OR and 1.6% for TEVAR), however, OR resulted in higher rates of cardiopulmonary complications, which included acute respiratory distress syndrome, pneumonia and myocardial infarction. TEVAR, on the other hand, was associated with higher incidence of post-intervention acute renal failure. Notably, delayed repairs (>72 h) resulted in 0% mortality when treated by TEVAR and 16% when OR was used ($P < .05$) [3].

With regards to factors that influenced survival, aortic repair (by either OR or TEVAR) was the only one correlated with improved survival, as opposed to physiological variables, associated injuries and type of repair. Finally, parameters that had a negative impact on the outcome of patients with BTAIs included increasing age, hypotension at presentation, hypothermia at presentation, major head or abdominal injury and ISS higher than 25 [3].

Patel et al. (2011) evaluated the late outcomes after open and endovascular repair in 107 patients with BTAIs and found that 30-day mortality was 4.6% with early morbidity including spinal cord ischaemia, stroke, and need for permanent dialysis [33]. The most significant determinants of early mortality were identified to be age over 60 years, increasing preoperative creatinine and occurrence of postoperative sepsis. Notably, the type of repair used was not shown to affect late mortality, which was primarily associated with age over 60 years, increasing creatinine and spinal cord ischaemia. Freedom from re-intervention at 4 years was shown to be higher in patients treated with OR compared to those treated with TEVAR (100% vs 94%, $P = .03$). Groups were comparable in terms of ISS and other associated injuries [33].

Riesenman et al. in 2012, supported the superiority of TEVAR over OR by showing lower rates of intraoperative (0% vs 18% respectively, $P < .05$) and overall hospital mortality (12% vs 37% respectively, $P < .05$) rates in patients treated by endovascular stents ($n = 26$) compared to those treated surgically ($n = 60$), in a study where all measures of traumatic injury were similar between groups [34]. Furthermore, TEVAR was associated with shorter operative times, less estimated blood loss and smaller amounts of intraoperative blood transfusions compared to OR. Importantly, however, 5 TEVAR patients required re-intervention for procedure-related complications that included malapposition to the aortic arch, midendograft stenosis, and left upper limb ischaemia [34].

Delayed repair. Multiple trauma patients have always been challenging with regards to the right order and timing of different interventions. A widely accepted definition of delayed repair does not exist in the literature; studies have used different timeframes to define their "delayed repair" group such as 16 h, 24 h, 72 h or even a few days post-injury [35–39].

Karmy-Jones et al. (2011) recommend timing of repair to be documented in the following categorization: within 8 h of injury (immediate), within 24 h of injury (emergent), within 24 and 48 h of injury (urgent), more than 3 days but less than 7 days (subacute), more than a week (elective) [40].

An early paper by Langanay et al. in 2002, calls for reappraisal of the timing of treatment and strongly supports delaying the intervention (OR) where possible [37]. Out of 50 patients who presented at their centre between 1976 and 1990, 10 underwent a delayed open repair (6–60 days post-injury) either due to late diagnosis or coexisting life-threatening lesions that substantially increased the operative risk. Notably, there were no sudden deaths or aortic ruptures in this group of patients. The authors conclude that the choice for the immediate management of patients with acute traumatic aortic rupture should largely depend on the associated injuries, as these could be worsened by the use of cardiopulmonary bypass, and additionally on the need for life-saving measures [37].

Duwayri and colleagues are in accordance with the above authors and advocate delayed repair in hemodynamically stable patients as this was not associated with increased risk of aortic rupture in their small study in 2008 [37]. Surgery was delayed (>24 h) in 6 out of 9 patients who were hemodynamically stable and mortality in this group was zero [38].

A recent retrospective study by Di Eusanio et al. (2013) describes their 18-year experience of 77 patients, having delayed repair as first-line management for BTAIs [38]. According to their results, delays in management (15–302 days post-injury) of these patients was associated with satisfactory outcomes, both short and long term, with a total hospital mortality of only 3.9% and no significant differences in outcomes between OR and TEVAR ($P = .398$). After adjusting for ISS, the mortality rate of delayed repair appeared to be more than 10 times lower compared with that of immediate repair. Although there was one death (mortality 2.3%) and one complication incidence (stroke) associated with TEVAR compared to none with OR, they advocate the use of TEVAR due to its reduced invasiveness and its effectiveness in unstable patients as well as its ability for earlier repair in stable patients, allowing for easier surgical repair of concomitant non-aortic injuries [39].

Prospective studies

OR vs TEVAR. A prospective study of 106 patients by Azizzadeh and colleagues in 2013 reported an increasing proportion of patients who underwent TEVAR compared with OR from 0% to 100% over 8 years [41]. The OR group had three times higher odds for complications including in-hospital mortality compared to TEVAR ($P = .045$). The mean adjusted fixed and total costs were similar between the two treatment groups and so was the length of hospital stay. ISS and probability of survival were not different between the OR and TEVAR groups [41].

The outcomes of another prospective study also favour the use of TEVAR for patients with BTAIs [41]. Demetriades et al. (2008), in a series of 193 patients, reported favourable outcomes associated with TEVAR compared to OR in terms of mortality (both in patients with and without extrathoracic injuries; $P = .04$ and $P = .002$ respectively) and mean difference in transfusion units required ($P = .004$), while the difference in paraplegia rates was statistically insignificant. In addition, there were significantly fewer systemic complications ($P = .001$) and local complications ($P = .033$) and the hospital lengths of stay were shorter ($P = .005$) in centres with high volume of endovascular procedures compared to the low-volume ones. Mean ISS were similar in the two groups and even though the TEVAR group had a greater rate of significant associated extra-thoracic injuries, adjustment was made in the analysis [42].

However, device-related complication rates were as high as 20% in the TEVAR group and the vast majority were endoleaks that subsequently needed OR. Notably, this multicentre study showed that most surgeons use TEVAR for BTAIs irrespective of age, severity and associated injuries and even though its mortality and transfusion requirement rates have been reported to be lower than OR, the available endovascular devices need to be improved in order to decrease the relatively high device-related complication rates [42].

Delayed repair. Demetriades and colleagues (2009), in their prospective study, analyzed the outcomes of 178 patients with BTAIs who underwent either early ($n = 109$) or late ($n = 69$) repair and reported improved survival of stable BTAIs with delayed repair and this was not associated with the presence of major coexisting injuries. The disadvantage of delayed repair (>24 h post-injury) was, however, a longer stay in Intensive Care Unit compared with early repair, as well as higher complication rates in the group of patients who had no major coexisting injuries [36].

Meta-analyses

A review of 4 meta-analyses (level of evidence III) was performed by Barnard et al. (2009) as part of the construction of a best-evidence topic. The details and outcomes of these 4 studies are as follows [43]:

(1) Hoffer et al. (2008) reviewed the outcomes of 19 retrospective studies (638 patients) and found that both mortality and paraplegia rates were significantly lower for TEVAR compared to OR ($P = .001$ and $P = .01$ respectively), however, TEVAR was associated with an incidence of early endoleaks of 4.2% [44].
(2) Xenos et al. (2008) is in accordance with the above findings, as in their analysis of 17 retrospective studies that included 609 patients, they supported the significantly better outcomes of TEVAR compared to OR in terms of 30-day mortality ($P = .005$), procedure-related mortality ($P = .002$), and postoperative paraplegia rates ($P = .037$). Even though ISS was higher in the TEVAR group ($P < .001$) [45].
(3) Xenos et al. (2009) updated the latter meta-analysis with the addition of another 5 studies (22 retrospective studies of a total of 859 patients) and reported lower mortality rates ($P = .005$) and paraplegia rates ($P = .005$) in patients with BTAIs treated with TEVAR than those treated with OR [46].
(4) Finally, Tang and colleagues (2008), having analyzed 33 articles (699 patients), described reduced stroke rates (0.85% with TEVAR and 5.3% with OR, $P = .0028$) in addition to the lower mortality (7.6% in TEVAR and 15.2% in OR, $P = .0076$) and paraplegia rates (0% for TEVAR and 5.6% for OR, $P = .0001$) associated with TEVAR compared to OR, despite similar ISS [47]. The commonest intervention-related complications were iliac artery injury for TEVAR and recurrent laryngeal nerve injury for OR, while total complication rates were higher in the OR group (17.0% vs 13.1% in TEVAR). Additionally, the authors identified equal technical success rates of the two procedures ($P = .58$) however differences in interval repair between the groups were not reported. Despite the clear differences, the authors highlight that the long-term effectiveness of TEVAR still remains in question due to the lack of adequate evidence [47].

Taking into consideration the results of their analysis, Barnard et al. conclude that these obvious benefits of TEVAR over OR are not without a cost, highlighting the requirement for long-term surveillance, the importance of the uncertain medium and long term outcomes and the high procedure-related complication rates [43].

Takagi et al. (2008) included 17 studies (565 patients) in their meta-analysis and found that mortality in the TEVAR group was significantly lower compared to OR (8.1% vs 20.8%; $P = .009$) and so was post-intervention paraplegia ($P = .01$). The two groups had similar pre-operative variables including mean ISS [48].

Finally, in accordance with the findings discussed above is another more recent and much larger meta-analysis (139 studies, 7768 patients) by Murad et al. in 2011 [49]. After adjusting for ISS and associated injuries, they found that mortality was lower in the group treated with endovascular repair than the group treated operatively and those who received no treatment (9%, 46%, 19% respectively; $P < .01$). Stroke incidence was similar in all three groups, while the risks of spinal cord ischaemia and end-stage renal failure (9%, 3%, 3% respectively; $P = .01$; and 8%, 5%, 3% respectively; $P = .01$) were higher in the OR group compared to the TEVAR and no-treatment groups. Graft infections and systemic infections, finally, were encountered more frequently in the OR group than the TEVAR group [49].

Non-systematic reviews

Only one reliable paper reviewing the relevant literature (between 2005 and 2010) was identified [40]. Karmy-Jones and colleagues (2011) included 62 retrospective reviews and 6 meta-analyses in their well-presented non-systematic review and in their conclusion they highlighted the need for guidelines specific to the trauma population for better risk adjustment and easier choice of optimal intervention [40].

Reviewing the papers that compared TEVAR with OR ($n = 25$), they concluded that TEVAR patients had a lower mortality and lower incidences of paraplegia compared with OR although the former was performed in older patients, however, a statistically significant survival benefit was reported only in 4 papers. Importantly, the fact that unstable patients mostly underwent surgical repair biases the outcomes, according to the authors [40]. Even though ISS were similar between the groups, the authors found that only about half of the studies included described injury severity by ISS and about a third provided details on haemodynamic stability. Finally, they recommend the use of the ASCOT (A Severity Characterization of Trauma) score to compare treatments, which is a useful tool to provide "expected" mortality risk after considering age, gender, presenting physiology and injury severity [40].

As far as delayed intervention is concerned, based on the findings of Demetriades et al. (2009) described above, Karmy-Jones et al. suggest delaying repair for patients with either significant injury or reversible physiologic derangement [36,40].

The key articles discussed are summarized in Table 1 [3,25,26,33,34,36,39,41,42,44–49].

In conclusion, although TEVAR is generally associated with more favourable outcomes compared with OR in the literature, it is important to consider the short follow-up periods described, especially where only in-hospital mortality and complications are reported. The lack of definitive long-term results of the effectiveness and safety of the endovascular approach should be carefully taken into account when comparing the two methods of repair and especially when one should be chosen over the other in clinical practice.

Guidelines

Based on the meta-analysis by Murad and colleagues (2011), the Society for Vascular Surgery recently published clinical practice guidelines, according to which TEVAR should be used preferentially over OR or non-operative management and repair should be performed urgently (<24 h). They advocate expectant management for minimal aortic injuries with serial imaging for type I injuries, and for young patients, endovascular repair is recommended regardless of age if anatomical criteria are permissive. Additionally, they suggest selective revascularization of the left subclavian artery and routine heparinization at a lower dose than in elective TEVAR. General anaesthesia should be used, routine spinal drainage is not recommended, and open femoral exposure should be the femoral access technique of choice [50].

With regards to the use of TEVAR exclusively, the guidelines by the European Association for Cardio-Thoracic Surgery (EACTS) and the European Society of Cardiology (ESC), in collaboration with the European Association of Percutaneous Cardiovascular Interventions (EAPCI), in 2012, suggest that TEVAR is indicated for patients with complete transaction of the aortic wall and haemorrhage into the mediastinum and those with pseudocoarctation syndrome, while limited disruption of the aorta with intact intima and media should be managed expectantly with conservative treatment [22].

According to the Society for Vascular Surgery, some issues regarding the use of TEVAR still remain unresolved. These are: (a) poor conformation of the stent to the arch, (b) need for covering the left subclavian artery, (c) uncertain natural history of the repair given the younger age of trauma victims and the morphologic age-related aortic changes, (d) ideal follow-up method that may be used for several decades, considering the risks of radiation exposure, (e) timing of repair, and (f) the need for intraoperative heparinization in cases of multiple traumatic injuries [50].

Similarly, the EACTS, ESC and EAPCI, in their TEVAR guidelines article, conclude with pending questions about the use of TEVAR. Regarding endoleaks, most of them may be avoided by careful selection relevant to morphological details such as the length of the landing zone, the use of multiple stents, the length of the overlapping segments and severe angulation/aortic calcification [22].

For TEVAR-induced strokes, reduction in incidence may be possible by aggressively maintaining antegrade cerebral perfusion through prior vascular transposition. Even though overstenting of the left subclavian artery may increase the risk of stroke in elective cases, it is still permissive in emergency cases, including BTAIs [22].

In order for TEVAR-induced paraplegia to be prevented, collateral blood supply should be maintained via the left subclavian artery, lumbar arteries and hypogastric arteries, and preventive CSF drainage is advocated in high-risk patients [22].

Vascular complications are uncommon when anatomy is used correctly and the use of hydrophilic delivery sheaths has enhanced the insertion of devices in small access vessels [22].

TEVAR short and midterm outcomes

Khoynezhad et al. (2013) describe the favourable early outcomes of endovascular repair of BTAIs in their well-designed, prospective study (RESCUE trial). Short-term results of the 50 patients who were enrolled and will be followed for 5 years are promising, as 100% successful device delivery and deployment was reported, as well as no conversion to open repair and no need for endovascular reintervention. Despite the high ISS (70% of injuries were grade 3 or higher), 30-day mortality was only 8% and procedure-related complications only 12%, with no paraplegia or strokes. Concluding, the authors stress the importance of long-term follow-up to assess the effectiveness and safety of TEVAR in treating BTAIs [51].

Similarly, the society for Vascular Surgery Outcomes Committee reported acceptable outcomes of TEVAR for traumatic aortic transections at 30 days and 1 year post-injury [51]. Of 60 patients with a mean total ISS of 39 treated with endovascular repair, all-cause mortality was 9.1% at 30 days and 14.4% at 1 year. Major adverse events (including death) occurred early in 20% of patients (of which 41.7% was death) and late in 3.6% of patients (of which 100% was death), and included pulmonary (16.7%), neurologic (13.3%) and vascular (11.7%) complications. Importantly, the authors conclude that future device and procedural developments may lead to even more favourable results in the future [52].

Finally, a recent study by Azizzadeh and colleagues in 2014 significantly supported the effectiveness and safety of TEVAR in BTAI patients, reporting very encouraging midterm outcomes (median follow-up 2.3 years, range 0–7 years) [52]. Eighty-two patients with a mean total ISS of 34 underwent treatment with endovascular stent grafts with in-hospital mortality and stroke rates of only 5% and 2.4% respectively. Device-related complications occurred in 2.4% of patients and survival at 30 days, 1 year, 2 years and 5 years was 95%, 88%, 87% and 82% respectively [53].

Conclusion

BTAIs are most commonly encountered after MVAs and even though their incidence is relatively rare, their early mortality is extremely high. Therefore, these patients need a precise approach and choosing the most appropriate method to manage them is extremely crucial.

Within the last 5 decades, there have been major advancements in diagnosing BTAIs and definitively treating them. CT scans are now more widely used compared to angiography that was the gold standard in the past.

Selected patients are now initially receiving conservative medical treatment, in order for their more severe concomitant injuries to be dealt with first. Where an intervention is judged to be required, a major shift has been described from OR to TEVAR for the treatment of descending aortic injuries and this yielded favourable outcomes, including decreasing mortality and paraplegia rates. An important pitfall of the endovascular technique may be its relatively high graft-related complication rates, and its long-term durability is still in question due to the lack of adequate evidence. Finally, delayed repair appears to be associated with favourable outcomes and a reappraisal of the timing of treatment may be appropriate.

From the reviewed literature, TEVAR appears to be at least as safe as OR in the short-term and the guidelines in fact recommend its use over OR, however, its long-term durability needs to be assessed for accurate conclusions about its effectiveness to be drawn with certainty.

Conflict of interest

None.

References

[1] Yamane BH, Tefera G, Hoch JR, Turnipseed WD, Acher CW. Blunt thoracic aortic injury: open or stent graft repair? Surgery 2008;144(4):575–80.

[2] Fabian TC, Richardson JD, Croce MA, Smith SJ, Rodman G, Kearney PA, et al. Prospective study of blunt aortic injury: Multicenter Trial of the American Association for the Surgery of Trauma. J Trauma 1997;42:374–83.

[3] Arthurs ZM, Starnes BW, Sohn VY, Singh N, Martin MJ, Andersen CA. Functional and survival outcomes in traumatic blunt thoracic aortic injuries: an analysis of the National Trauma Databank. J Vasc Surg 2009;49(4):988–94.

[4] Nzewi O, Slight RD, Zamvar V. Management of blunt thoracic aortic injury. Eur J Vasc Endovasc Surg 2006;31:18–27.

[5] Baker SP, O'Neil B, Haddon Jr W, Long WB. The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care. J Trauma 1974;14(3):187–96.

[6] Palmer C. Major trauma and the injury severity score – where should we set the bar. Annu Proc Assoc Adv Automot Med 2007;51:13–29.

[7] O'Connor JV, Byrne C, Scalea TM, Griffith BP, Neschis DG. Vascular injuries after blunt chest trauma: diagnosis and management. Scand J Trauma Resusc Emerg Med 2009;17:42.

[8] Sturm TJ, Hankins DG, Young G. Thoracic aortograghy following blunt chest trauma. Am J Emerg Med 1990;8:92–6.

[9] Mirvis SE, Bidwell JK, Buddemeyer EU, Diaconis JN, Pais SO, Whitley JE, et al. Value of chest radiography in excluding traumatic aortic rupture. Radiology 1987;163:487–93.

[10] Neschis DG, Scalea TM, Flinn WR, Griffith BP. Blunt aortic injury. N Engl J Med 2008;359:1708–16.

[11] Nagy K, Fabian T, Rodman G, Fulda G, Rodriguez A, Mirvis S. Guidelines for the diagnosis and management of blunt aortic injury: an EAST Practice Management Guidelines Work Group. J Trauma 2000;48(6):1128–43.

[12] Sevransky J. Clinical assessment of haemodynamically unstable patients. Curr Opin Crit Care 2009;15(3):234–8.

[13] Fabian TC, Devis KA, Gavant ML, Croce MA, Melton SM, Patton JH, et al. Prospective study of blunt aortic injury. Helical CT is diagnostic and antihypertensive therapy reduces rupture. Ann Surg 1998;227:666–77.

[14] Von Oppell UO, Dunne TT, DeGroot MK, Zilla P. Traumatic aortic rupture: twenty-year meta-analysis of mortality and risk of paraplegia. Ann Thorac Surg 1994;58:585–93.

[15] Maggisano R, Nathens A, Alexandrova NA, Cina C, Boulanger B, McKenzie R, et al. Traumatic rupture of the thoracic aorta: should one always operate immediately. Ann Vasc Surg 1995;9:44–52.

[16] Pate JW, Fabian TC, Walker W. Traumatic rupture of the aortic isthmus: an emergency. World J Surg 1995;19:119–26.

[17] Warren RL, Akins CW, Conn AKT, Hilgenberg AD, McCabe CJ. Acute traumatic disruption of the thoracic aorta: emergency department management. Ann Emerg Med 1992;21:391–6.

[18] Cardarelli MG, McLaughlin JS, Downing SW, Brown JM, Attar S, Griffith BP. Management of traumatic aortic rupture: a 30-year experience. Ann Surg 2002;236:465–9.

[19] Mitchell RS. Stent graft for the thoracic aorta: a new paradigm? Ann Thorac Surg 2002;74(5):S1818–20.

[20] Mary-Ane C, Berthet J, Branchereau P, Mary H, Alric P. Endovascular repair of acute traumatic rupture of the thoracic aorta. Ann Thorac Surg 2003;75:1803–7.
[21] Cohen AM, Crass JR, Thomas HA, Fisher RG, Jacobs DG. CTevidence for the osseous pinch mechanism of traumatic aortic injury. AJR 1992;159:271–4.
[22] Grabenwoger M, Alfonso F, Bachet J, Bonser R, Czerny M, Eggebrecht H, et al. Thoracic Endovascular Repair (TEVAR) for the treatment of aortic diseases: a position statement from the European Association for Cardio-Thoracic Surgery (EACTS) and the European Society of Cardiology (ESC), in collaboration with the European Association of Percutaneous Cardiovascular Interventions (EAPCI). Eur Heart J 2012;33(13):1558–63.
[23] Demetriades D, Velmahos GC, Scalea TM, Jurkovich GJ, Karmy-Jones R, Teixeira PG, et al. Diagnosis and treatment of blunt thoracic aortic injuries: changing perspectives. J Trauma 2008;64(6):1415–8.
[24] Hong MS, Feezor RJ, Lee WA, Nelson PR. The advent of thoracic endovascular aortic repair is associated with broadened treatment eligibility and decreased overall mortality in traumatic thoracic aortic injury. J Vasc Surg 2011;53(1): 36–42.
[25] Estrera AL, Gochnour DC, Azizzadeh A, Miller 3rd CC, Coogan S, Charlton-Ouw K, et al. Progress in the treatment of blunt thoracic aortic injury: 12-year single-institution experience. Ann Thorac Surg 2010;90(1):64–71.
[26] Estrera AL, Miller 3rd CC, Guajardo-Salinas G, Coogan S, Charlton-Ouw K, Safi HJ, et al. Update on blunt thoracic aortic injury: fifteen-year single-institution experience. J Thorac Cardiovasc Surg 2013;145(Suppl. 3):S154–8.
[27] Buz S, Zipfel B, Mulahasanovic S, Pasic M, Weng Y, Hetzer R. Conventional surgical repair and endovascular treatment of acute traumatic aortic rupture. Eur J Cardiothorac Surg 2008;33(2):143–9.
[28] Watson J, Slaiby J, Garcia Toca M, Marcaccio Jr EJ, Chong TT. A 14-year experience with blunt thoracic aortic injury. J Vasc Surg 2013;58(2):380–5.
[29] Klima DA, Hanna EM, Christmas AB, Huynh TT, Etson KE, Fair BA, et al. Endovascular graft repair for blunt traumatic disruption of the thoracic aorta: experience at a nonuniversity hospital. Am Surg 2013;79(6):594–600.
[30] Amabile P, Collart F, Gariboldi V, Rollet G, Bartoli JM, Piquet P. Surgical versus endovascular treatment of traumatic thoracic aortic rupture. J Vasc Surg 2004;40(5):873–9.
[31] Canaud L, Alric P, Branchereau P, Joyeux F, Hireche K, Berthet JP, et al. Open versus endovascular repair for patients with acute traumatic rupture of the thoracic aorta. J Thorac Cardiovasc Surg 2011;142(5):1032–7.
[32] Celis RI, Park SC, Shukla AJ, Zenati MS, Chaer RA, Rhee RY, et al. Evolution of treatment for traumatic thoracic aortic injuries. J Vasc Surg 2012;56(1):74–80.
[33] Patel HJ, Hemmila MR, Williams DM, Diener AC, Deeb GM. Late outcomes following open and endovascular repair of blunt thoracic aortic injury. J Vasc Surg 2011;53(3):615–20.
[34] Riesenman PJ, Brooks JD, Farber MA. Acute blunt traumatic injury to the descending thoracic aorta. J Vasc Surg 2012;56(5):1274–80.
[35] Hemmila MR, Arbabi S, Rowe SA, Brandt MM, Wang SC, Taheri PA, et al. Delayed repair for blunt thoracic aortic injury: is it really equivalent to early repair? J Trauma 2004;56(1):13–23.
[36] Demetriades D, Velmahos GC, Scalea TM, Jurkovich GJ, Karmy-Jones R, Teixeira PG, et al. Blunt traumatic thoracic aortic injuries: early or delayed repair – results of an American Association for the Surgery of Trauma prospective study. J Trauma 2009;66(4):967–73.
[37] Langanay T, Verhoye JP, Corbineau H, Agnino A, Derieux T, Menestret P, et al. Surgical treatment of acute traumatic rupture of the thoracic aorta a timing reappraisal? Eur J Cardiothorac Surg 2002;21(2):282–7.
[38] Duwayri Y, Abbas J, Cerilli G, Chan E, Nazzal M. Outcome after thoracic aortic injury: experience in a level-1 trauma center. Ann Vasc Surg 2008;22(3): 309–13.
[39] Di Eusanio M, Folesani G, Berretta P, Petridis FD, Pantaleo A, Russo V, et al. Delayed management of blunt traumatic aortic injury: open surgical versus endovascular repair. Ann Thorac Surg 2013;95(5):1591–7.
[40] Karmy-Jones R, Ferrigno L, Teso D, Long 3rd WB, Shackford S. Endovascular repair compared with operative repair of traumatic rupture of the thoracic aorta: a non systematic review and a plea for trauma-specific reporting guidelines. J Trauma 2011;71(4):1059–72.
[41] Azizzadeh A, Charlton-Ouw KM, Chen Z, Rahbar MH, Estrera AL, Amer H, et al. An outcome analysis of endovascular versus open repair of blunt traumatic aortic injuries. J Vasc Surg 2013;57(1):108–14.
[42] Demetriades D, Velmahos GC, Scalea TM, Jurkovich GJ, Karmy-Jones R, Teixeira PG, et al. American Association for the Surgery of Trauma Thoracic Aortic Injury Study Group. Operative repair or endovascular stent graft in blunt traumatic thoracic aortic injuries: results of an American Association for the Surgery of Trauma Multicenter Study. J Trauma 2008;64(3):561–70.
[43] Barnard J, Humphreys J, Bittar MN. Endovascular versus open surgical repair for blunt thoracic aortic injury. Interact CardioVasc Thorac Surg 2009;9(3): 506–9.
[44] Hoffer EK, Forauer AR, Silas AM, Gemery JM. Endovascular stent-graft or open surgical repair for blunt thoracic aortic trauma: systematic review. J Vasc Interv Radiol 2008;19:1153–64.
[45] Xenos ES, Abedi NN, Davenport DL, Minion DJ, Hamdallah O, Sorial EE, et al. Metaanalysis of endovascular vs open repair for traumatic descending thoracic aortic rupture. J Vasc Surg 2008;48(5):1343–51.
[46] Xenos ES, Minion DJ, Davenport DL, Hamdallah O, Abedi NN, Sorial EE, et al. Endovascular versus open repair for descending thoracic aortic rupture: institutional experience and meta-analysis. Eur J Cardiothorac Surg 2009;35: 282–6.
[47] Tang GL, Tehrani HY, Usman A, Katariya K, Otero C, Perez E, et al. Reduced mortality, paraplegia, and stroke with stent graft repair of blunt aortic transections: a modern meta-analysis. J Vasc Surg 2008;47(3):671–5.
[48] Takagi H, Kawai N, Umemoto T. A meta-analysis of comparative studies of endovascular versus open repair for blunt thoracic aortic injury. J Thorac Cardiovasc Surg 2008;135:1392–4.
[49] Murad MH, Rizvi AZ, Malgor R, Carey J, Alkatib AA, Erwin PJ, et al. Comparative effectiveness of the treatments for thoracic aortic transection. J Vasc Surg 2011;53(1):193–9.
[50] Lee WA, Matsumura JS, Mitchell RS, Farber MA, Greenberg RK, Azizzadeh A, et al. Endovascular repair of traumatic thoracic aortic injury: clinical practice guidelines of the Society for Vascular Surgery. J Vasc Surg 2011;53(1):187–92.
[51] Khoynezhad A, Azizzadeh A, Donayre CE, Matsumoto A, Velazquez O, White R. RESCUE investigators. Results of a multicenter, prospective trial of thoracic endovascular aortic repair for blunt thoracic aortic injury (RESCUE trial). J Vasc Surg 2013;57(4):899–905.
[52] Dake MD, White RA, Diethrich EB, Greenberg RK, Criado FJ, Bavaria JE, et al. Report on endograft management of traumatic thoracic aortic transections at 30 days and 1 year from a multidisciplinary subcommittee of the Society for Vascular Surgery Outcomes Committee. J Vasc Surg 2011;53(4):1091–6.
[53] Azizzadeh A, Ray HM, Dubose JJ, Charlton-Ouw KM, Miller CC, Coogan SM, et al. Outcomes of endovascular repair for patients with blunt traumatic aortic injury. J Trauma Acute Care Surg 2014;76(2):510–6.