Received:
31 December 2018

Revised:
18 November 2019

Accepted:
18 December 2019

<https://doi.org/10.1259/bjr.20190017>

Cite this article as:
Nicholas NW, Shaw DR, Puppala S. Pictorial review on the endovascular management of paediatric aortic injuries. *Br J Radiol* 2020; **93**: 20190017.

PICTORIAL REVIEW

Pictorial review on the endovascular management of paediatric aortic injuries

NEVILLE W NICHOLAS, MBBS FRCR, DAVID R SHAW, MBBS, MRCP, FRCR and
SAPNA PUPPALA, MBBS, MRCS, FRCSED, CBCCT, EBIR

Department of Interventional Radiology, Leeds Teaching Hospital NHS Trust, Leeds, UK

Address correspondence to: Sapna Puppala
E-mail: s.puppala@nhs.net

ABSTRACT

Paediatric aortic trauma is a rare injury which can be fatal if not identified and managed appropriately. Surgical repair remains the gold-standard in moderate to severe aortic injuries. In the last decade however, endovascular treatment has gained popularity in children who have suitable vascular anatomy for intervention and are either not fit for surgery or in whom, endovascular intervention is the only alternative that will make a difference in the clinical outcome. Children pose a unique set of challenges to endovascular therapy. In this article, we aim to illustrate the different endovascular options that are available for the treatment of acute traumatic aortic injury and visceral thromboembolisation through pictorial representation. We will also demonstrate the feasibility and the limitation of this technique.

INTRODUCTION

The estimated incidence of blunt aortic trauma (BAT) of the thoracic and abdominal aorta are 0.06–7.4%¹ and 0.05%² respectively. Traumatic aortic injury (TAI) can be catastrophic when of the severe grade, and 73% of patients die en-route to the hospital.³ Patients with TAI also have severe concurrent injuries of the cranium, torso and the extremities.⁴ Both the low incidence and the presence of multi-system trauma make recognition and management of this condition very challenging.

The growing interest in the endovascular treatment (EVT) of paediatric arterial injury with stent-grafts and embolisation techniques stems from well-established endovascular therapies in adult arterial trauma and transferable interventional skills. Our article describes five cases of paediatric TAI that were managed at our institution [Leeds teaching hospital NHS trust] (Table 1). We will describe the injury, the imaging findings, the techniques of EVT in TAI and its limitations through pictorial representation.

IMAGING AND GRADING BLUNT AORTIC INJURY

The Royal College of Radiologists (RCR)⁶ recommend chest radiograph (CR) as the first choice of imaging for blunt thoracic trauma in children (Figure 1). CT is only performed when a mediastinal injury is suspected. Indistinct or prominent aortic knob (94%), widened paratracheal stripe (71%)

and widened mediastinum (65%) are the predictors of TAI on CR.⁷ RCR recommends contrast-enhanced CT for penetrating injuries of the chest, blunt and penetrating abdominal trauma as first-line. (Figure 2) is an illustration of a CT based grading of TAI.

CT-aortogram (CTA) with multiplanar reformats (MPR) aids in the prompt detection of aortic injury. The risk of radiation-induced cancer is 1/500 in children⁸; therefore, doses should be kept to "as low as reasonably achievable" (ALARA principle).

Additional techniques such as cardiac gated-CTA and magnetic resonance aortography (MRA) are for trouble-shooting. A gated-CTA is most useful in the aortic root and ascending aortic injuries, and it can also minimise pulsation artefact in descending thoracic aorta. Unfortunately, gated-CTA results in higher radiation dose than conventional CTA. Moreover, high baseline heart rate in the paediatric population can itself interfere with image quality. Ventilation techniques can also act as an adjunct to imaging, as illustrated in (Figure 3).

Cases illustrated in this review

CASE 1

A 7-year-old restrained rear-seat passenger involved in a significant road traffic collision (RTC). On polytrauma CT, there were findings of head injury, displaced pelvic fractures

Table 1. Brief description of cases included in this review

Case	Age	Sex	Mechanism of injury	Type of injury	Aortic segment involved	Type of aortic injury (SVS) ⁵	Treatment	Intra op or post-operative complications
1	7	M	RTC*	BAT [^]	Aortic Isthmus	Grade-III pseudoaneurysm	16 × 16 × 39 mm Balloon mounted BM-CCPS [∞]	Nil
2	11	M	Accident when free running	BAT	Infra renal aorta	Grade-III Circumferential intimal tear with pseudoaneurysm	24 x 25mm Balloon mounted BM-CCPS	Nil
3	12	M	RTC	BAT	Aortic isthmus	Grade-III pseudoaneurysm	18 mm Talent Iliac limb stent graft	Type one endoleak which was corrected by 15 mm Palmaz Balloon mounted stent inflated to 18 mm
4	12	M	RTC	BAT	Visceral aorta between the diaphragmatic hiatus and coeliac origin	Grade-II with intimal disruption, thromboembolisation resulting in renal and splenic infarctions	Thrombus aspiration with penumbra re-perfusion catheters	Nil
5	16	M	Stab injury	PAI ^f	Visceral aorta between SMA and right renal artery	Grade-III pseudoaneurysm	Open repair	Nil

[^]BAT, Blunt aortic trauma; [∞]BM-CCPS, Balloon mounted covered Cheetham Platinum stent; M, Male; ^fPAI, Penetrating aortic injury; RTC, Road traffic collision.

and a subtle aortic injury (Figure 4). As the morphology of TAI was inconclusive on the initial study, a gated-CT scan performed the following day demonstrated a change in morphology indicating a pseudoaneurysm (Grade-III injury)(Figure 5).

Figure 1. CR of a 12-year-old boy involved in RTC with significant trauma to the chest demonstrating indistinct aortic knuckle. CR was obtained following a chest drain insertion. The radiograph demonstrates significant left sided chest injuries. This patient had a grade III aortic injury on Polytrauma CT scan- see Case 3. CR, chest radiography; RTC, road traffic collision.

An *ad-hoc* multidisciplinary team (MDT) meeting consisting of interventional radiologists, paediatric surgeon, cardiothoracic surgeon, cardiologists and vascular surgeons was organised. Anticipated difficulty in suturing the friable aortic tissue and the interference of intraoperative heparinisation with unstable pelvic fractures led to the choosing of EVT. A balloon mounted covered Cheetham platinum stent-graft (BM-CCPS) was chosen as it fit the 4 mm external iliac artery diameter and covered a short length of the thoracic aorta minimising the risk of paraplegia. The CCPS also has the added advantage of future re-expansion.

Figure 2. (a) Illustration of the different parts of the normal aorta. (b) Classification adapted from the SVS TAI grading [Ref: 5]. SVS grading helps to categorise patients into observation and intervention group. Grade-I injuries are usually managed with medical treatment and repeat imaging. Grades- II, -III and -IV injuries are managed with surgical or endovascular intervention. SVS, Society of Vascular Surgery; TAI, traumatic aortic injury.

Figure 3. Example of a multimodal approach to problem solving: A 5-year-old boy collided with a car while cycling. He had episodes of low blood pressure and reduced consciousness. (a) On the initial trauma scan, adjacent to the region of collapsed lung segment, the descending thoracic aorta has an impression of a Grade-III aortic injury seen as intimal flap and possible pseudoaneurysm (arrow). (b) 24-hour repeat MRA revealed similar findings. As imaging findings did not correlate with the patient's stable clinical status, we decided to perform additional imaging rather than proceed with open surgery. (c) Cardiac gated-CT performed a few hours later with PPV. PPV inflated the atelectatic lung and dissipated the focal loculated effusion adjacent to the aorta, demonstrating a normal aorta and prevented invasive interventions. MRA, MR aortography; PPV, positive pressure ventilation.

An Endurant (Medtronic USA) iliac limb stent-graft was kept as a back-up for possible aortic rupture during BM-CCPS deployment. Informed consent obtained from the parents after discussing the off-licence nature of the procedure and lack of

Figure 4. Axial (a) and MPR reconstructed sagittal (b) CTA slices demonstrating a suspicious injury to the aorta at the isthmus (arrow). There was a suspicion whether this could represent a prominent ductus diverticulum; therefore, a decision was made to perform a gated-CT scan while carefully monitoring the child overnight in the intensive care unit for haemodynamic instability. CTA, CT angiography; MPR, multiplanar reformats.

Figure 5. a (axial) & b (MPR reconstructed sagittal) slice of the cardiac-gated CTA performed 24 h later demonstrated a change in the morphology of the aortic injury thus confirming Grade III aortic injury (arrows). MPR helped in identifying a calcified ductus arteriosus (arrow). CTA, CT angiography; MPR, multiplanar reformats

long-term follow-up. A BM-CCPS was successfully implanted under right ventricular pacing after surgical cutdown of the right common femoral artery (CFA) with no complications (Figure 6).

Case 2

An 11-year-old boy sustained a blunt abdominal trauma during free-running as he jumped from a bench onto a concrete bolster.

Figure 6. Intraoperative images demonstrating BM-CCPS stenting technique. (a) Catheter angiogram demonstrating traumatic aortic pseudoaneurysm (arrow) - grade III aortic injury. (b) A stiff wire was inserted from the right common femoral artery and the atraumatic tip placed in the right axillary artery (arrow) for stability during stent deployment. (c) Once the graft radio-opaque markers are placed in an appropriate position as to cover the TAI, the balloon is inflated (arrowhead) to deploy the CCPS stent-graft. (d) Post-stenting image demonstrates satisfactory stent placement and exclusion of the TAI. BM-CCPS, balloon mounted covered Cheetham Platinum stent.

Figure 7. a (axial) & b (Coronal MPR MIP): Abdominal CT demonstrating a 360° tear in the intima of the infrarenal aorta, 'target sign' with aneurysmal change. MIP, maximum intensity projection; MPR, multiplanar reformats.

The abdominal CT scan demonstrated haemoperitoneum and a 360° tear in the intima of the infrarenal aorta giving the appearance of a target ('target sign') with aneurysmal change (significant grade III injury) (Figure 7).

The MDT recommended EVT as the anticipated procedural success, and the risk of renal artery occlusion was considered similar in either surgery or EVT. The parents were consented for BM-CCPS implantation for its benefits of small access vessel compliance and future ability to re-expand. The procedure was performed under general anaesthesia by a percutaneous right

Figure 8. Intraoperative images demonstrating BM-CCPS stenting technique in the infrarenal aorta. (a) Catheter angiogram demonstrating a pseudoaneurysm of the infrarenal aorta. Grade-III aortic injury. (b, c) BM-CCPS stent deployment over a stiff support wire (arrowhead). A safety wire was placed in the right renal artery as precaution (arrow) in case of inadvertent occlusion. (d) Post-stenting image demonstrating satisfactory stent placement and patent main renal arteries. BM-CCPS, balloon mounted covered Cheetham Platinum stent.

Figure 9. Selected polytrauma CT scan slices demonstrating significant blunt trauma to the thorax. (a, b) Axial and sagittal MPR slices, demonstrating partial transection at the aortic isthmus and pseudoaneurysm formation—Grade-III aortic injury. Also see - Figure 1. A portable supine chest radiograph performed in accident and emergency following left side-chest drain insertion which demonstrates indirect signs of aortic injury. MPR, multiplanar reformats.

Figure 10. TEVAR with iliac limb stent-graft technique. (a) Catheter angiogram performed with a pigtail diagnostic catheter in the ascending aorta demonstrates the pseudoaneurysm (arrow) at the aortic isthmus. (b) 18 mm Talent iliac limb endograft implanted over a stiff wire parked within the ascending aorta. Arrow demonstrates post-implantation intra-op Type 1 endoleak. (c) The Type 1 endoleak was corrected with a 15 mm Palmaz balloon mounted stent that was post dilated to 18 mm. TEVAR, thoracic endovascular aortic repair.

Figure 11. 12-yo boy with blunt abdominal trauma. Polytrauma CT images showing aortic injury and multiorgan infarction from thromboembolisation. (a) Coronal CT slice demonstrating multiorgan infarction (spleen and both kidneys). (b) Sagittal MPR demonstrating the subtle supracoeliac anterior aortic wall Grade II injury. The presumed site for thromboembolisation and visceral infarctions. (c) Appearance of the subtle anterior wall aortic injury on axial slices (between arrows). MPR, multiplanar reformats; RTC, road traffic collision.

CFA approach. A 24 × 45 BM-CCPS stent was unwound and crimped onto a 14mm balloon-in-balloon (BIB) catheter to match patient's aortic diameter. The graft was deployed satisfactorily with no complications (Figure 8).

CASE 3

A polytrauma CT was performed in a 12-year-old boy with high impact RTC on arrival to the Emergency Department. Scan demonstrated head injury, multiple rib fractures, lung injury, pneumothorax, Grade-III aortic isthmus injury, splenic laceration and pelvic fractures (Figure 9).

The MDT recommended endovascular first approach as heparinisation for open surgery would complicate head injury and unstable pelvic fractures. The adjacent normal thoracic aorta measured 13 mm and the external iliac arteries 6 mm in diameter which led to the selection of an 18mm Medtronic Talent iliac

Figure 12. Aspiration thrombectomy with Penumbra reperfusion catheters Pre- and post-aspiration thrombectomy images of the right kidney (a, b) and the left kidney (c, d), respectively. The arrows represent acute thrombus. Following thrombectomy, there is improved renal perfusion in both kidneys. Case courtesy—Dr S McPherson

limb stent-graft. The procedure was performed under general anaesthesia after right CFA cutdown.

Although the stent-graft was deployed in a good position, an intraoperative type-I endoleak occurred due to the lack of graft conformability. The endoleak was treated with a Palmaz balloon mounted stent which was deployed within the Talent graft at 15 mm and then post-dilated to 18 mm, thus resolving the endoleak with no further complications (Figure 10).

Figure 13. Follow-up imaging of the aorta with MR-aortography and kidneys with DMSA study. (a) MRA demonstrating normal appearances to the aorta at 1-month follow-up. (b) DMSA scan to determine the split renal function and assess the extent of cortical scarring from renal infarction. Significant left kidney scarring due to extensive established infarction as seen on CT scan. DMSA, dimercaptosuccinic acid; MRA, MR aortography.

Figure 14. 16-year-old with a stab injury to the epigastrium and acute haemodynamic instability. (a) Demonstrates injury of the visceral aorta with pseudoaneurysm formation. The pseudoaneurysm is located on the right and lateral to superior mesenteric artery origin (arrow). (b) Large volume haemoperitoneum in the pelvis. (c) Pancreatic laceration with ductal injury (arrowhead), intact superior mesenteric vein. (d) Arrow is demonstrating the trajectory of the stab wound from the skin to the aorta. The patient also sustained a laceration to the liver (not shown).

CASE 4

A case of a 12-year-old seat-belt restrained passenger who sustained blunt abdominal trauma from RTC. CT scan of the abdomen demonstrated intramural haematoma (Grade-II) with likely intimal damage that resulted in widespread thromboembolisation and multi organ infarction involving spleen and both kidneys (Figure 11).

As thrombolysis was contraindicated due to acute aortic injury, for deteriorating renal functions, urgent bilateral renal artery mechanical thrombectomy was performed using CAT3 and CAT5 Penumbra reperfusion catheters. The procedure was performed by a percutaneous 6-French right CFA access. Thrombectomy halted further damage to kidneys, thereby assisting patient recovery (Figure 12). The aortic injury was managed conservatively with follow up MRA scan (Figure 13).

CASE 5

A 16-year-old boy presented with an epigastric stab wound and haemodynamic instability. A CTA of the abdomen demonstrated partial transection of the visceral aorta with pseudoaneurysm formation, transection of the pancreas and liver laceration (Figure 14).

After discussion with the vascular surgeons, the patient was managed with open surgical repair. The pseudoaneurysm between the right renal artery and the SMA was patched with bovine pericardium, and the aorta closed with Dacron (Figure 15). The anatomical location of the injury acted as a limiting factor to EVT due to the presence of multiple visceral artery origins.

Figure 15. Immediate post-operative and follow-up imaging. (a) The first post-operative scan performed after emergency surgery demonstrated a residual pseudoaneurysm. (b, c) The residual pseudoaneurysm was repaired on revision laparotomy. (d) 1-year follow-up MRA showing normal postoperative appearances.

DISCUSSION

Our case series describe five children between the ages of 7 and 16 years who sustained a varying degree of aortic injuries and were managed with endovascular and surgical treatment. RTC was the commonest aetiology (60%) followed by penetrating injury (20%) and sporting accident (20%). Cases 1 to 3 highlight the feasibility of aortic stent-graft in paediatric TAI and in literature, this is evidenced by a significant increase in the use of thoracic stent-grafts in the last decade.^{4,9} An important observation is that our stent-graft patients had multi-system trauma which contraindicated open surgery similar to other paediatric trauma studies^{4,9}. All patients were selected after rigorous MDT discussion, and there were no major procedure-related complications.

Despite the lack of FDA approved device in paediatric TAI, the off-label application of endografts in paediatrics has good short-term results.¹⁰ With newer, low-profile hydrophilic delivery devices for EVAR iliac limb stent-grafts and cuffs, the small diameter access vessels are no longer a challenge. The capability of the stent-graft to adapt to the somatic growth of aorta, however, is a challenge and in our opinion can be addressed with a BM-CCPS graft. The graft is initially deployed with a smaller diameter balloon and can be re-expanded with an appropriate larger diameter balloon should graft related pseudocoarctation of the aorta occur in future. BM-CCPS has its advantages for the use in children <12 years in whom, the somatic growth of the aorta can be significant. Contrary to the traditional practice of the use of self-expanding stent in TAI, BM-CCPS is safe with excellent success rates.¹¹ The short length of the graft is an added advantage that can prevent spinal ischaemia. At present, trauma to the visceral aorta (Case 5) is an absolute contradiction to EVT

due to the complex anatomy and these patients almost always benefit from open surgery.

Angioembolisation for bleeding is a standard procedure in paediatric arterial trauma.³ In contrast, thromboaspiration is rare but has been successfully performed in the pulmonary artery, iliac artery, central veins and femoral arteries^{12 13} for traumatic and non-traumatic aetiology. There is limited literature on thromboaspiration of visceral arteries which makes our case of renal artery thrombectomy unique. The penumbra device utilised for thrombectomy has literature evidence for its use in adult visceral arteries.¹⁴

The lack of long-term data on outcomes and follow-up⁴ is similar to adults and needs addressing. At present, there is not enough evidence to positively select aortic stent-graft over open surgery. Nevertheless, comparable mortality and post-operative complication risks and reduced hospital stay in stent-graft patients with

severe traumatic brain injury⁹ are common indications why EVT is being performed. In the absence of contraindications, open surgery should still be the first-line treatment. In contrast, aspiration thrombectomy is performed when this remains the only potential treatment that can limit the damage and alter the clinical outcome from the injury.

CONCLUSION

CT findings of paediatric TAI can be challenging to interpret and sometimes requires the help of additional imaging modalities and ventilation techniques. In suitable patient's, EVT in TAI is feasible with the off-label use of endografts and aspiration devices, but a MDT must make these decisions.

ACKNOWLEDGMENT

Dr Simon McPherson, Consultant Interventional Radiology* for contributing to case 4.

REFERENCES

- Stringel G, Xu ML, Erb M. Endovascular repair of blunt thoracic aortic injury. *Journal of Pediatric Surgery Case Reports* 2018; **30**: 52–5. doi: <https://doi.org/10.1016/j.epsc.2017.11.013>
- Aidinian G, Karnaze M, Russo EP, Mukherjee D. Endograft repair of traumatic aortic transection in a 10-year-old. *Vasc Endovascular Surg* 2006; **40**: 239–42. doi: <https://doi.org/10.1177/153857440604000310>
- Branco BC, Naik-Mathuria B, Montero-Baker M, Gilani R, West CA, Mills JL, et al. Increasing use of endovascular therapy in pediatric arterial trauma. *J Vasc Surg* 2017; **66**: 1175–83. doi: <https://doi.org/10.1016/j.jvs.2017.04.072>
- Heckman SR, Trooskin SZ, Burd RS. Risk factors for blunt thoracic aortic injury in children. *J Pediatr Surg* 2005; **40**: 98–102. doi: <https://doi.org/10.1016/j.jpedsurg.2004.09.004>
- 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**: 187–92. doi: <https://doi.org/10.1016/j.jvs.2010.08.027>
- Royal college of radiology. *Paediatric Trauma Protocols Faculty of Clinical Radiology*. 2014. Available from: <https://www.rcr.ac.uk/publication/paediatric-trauma-protocols>.
- Pabon-Ramos WM, Williams DM, Strouse PJ. Radiologic evaluation of blunt thoracic aortic injury in pediatric patients. *American Journal of Roentgenology* 2010; **194**: 1197–203. doi: <https://doi.org/10.2214/AJR.09.2544>
- Holscher CM, Faulk LW, Moore EE, Cothren Burlew C, Moore HB, Stewart CL, et al. Chest computed tomography imaging for blunt pediatric trauma: not worth the radiation risk. *Journal of Surgical Research* 2013; **184**: 352–7. doi: <https://doi.org/10.1016/j.jss.2013.04.044>
- Hasjim BJ, Grigorian A, Barrios C, Schubl S, Nahmias J, Gabriel V, et al. National trends of thoracic endovascular aortic repair versus open thoracic aortic repair in pediatric blunt thoracic aortic injury. *Ann Vasc Surg* 2019; **59**: 150–7. doi: <https://doi.org/10.1016/j.avsg.2018.12.094>
- Hosn MA, Nicholson R, Turek J, Sharp WJ, Pascarella L. Endovascular treatment of a traumatic thoracic aortic injury in an eight-year old patient: case report and review of literature. *Ann Vasc Surg* 2017; **39**: 292. e1–292.e4. doi: <https://doi.org/10.1016/j.avsg.2016.11.001>
- Goldstein BH, Hirsch R, Zussman ME, Vincent JA, Torres AJ, Coulson J, et al. Percutaneous balloon-expandable covered stent implantation for treatment of traumatic aortic injury in children and adolescents. *Am J Cardiol* 2012; **110**: 1541–5. doi: <https://doi.org/10.1016/j.amjcard.2012.06.063>
- Qureshi AM, Petit CJ, Crystal MA, Liou A, Khan A, Justino H. Efficacy and safety of catheter-based rheolytic and aspiration thrombectomy in children. *Cathet. Cardiovasc. Intervent.* 2016; **87**: 1273–80. doi: <https://doi.org/10.1002/ccd.26399>
- Johannes G, Rilinger N, Sokiranski R, Kramer S, Pamler R. Of acute superficial arteries device. 1998; 1177–80.
- Benenati J, Saxon R, Teigen C, Adams G. Penumbra/Indigo system provides a novel aspiration thrombectomy tool in treatment of peripheral and visceral arterial occlusions: final results of the prism trial. *Journal of Vascular and Interventional Radiology* 2016; **27**: S96. doi: <https://doi.org/10.1016/j.jvir.2015.12.254>