Review

The anatomical considerations in total aortic arch replacement surgery (island technique)

Rajeevlochan Ravi

Year 2, Medicine, University of Plymouth
Email: Rajeevlochan.ravi@students.plymouth.ac.uk

Background

Thoracic aortic aneurysms (TAAs) present due to a weakened area of the aortic wall and individuals with TAAs have a poor survival rate without medical intervention. TAAs can either transect or dissect the aorta if ruptured and present as sudden chest pain, dyspnoea, hypotension, dysphagia and syncope. TAA can be diagnosed using imaging (MRI, computerised tomography [CT] scans, chest x-rays), with management available both medically and surgically.

Current surgical interventions include traditional median sternotomy, arterial cannulation and hypothermic circulatory arrest. Novel techniques, such as L-type incisions, circumvent risks involved in median sternotomy, allowing improved exploration and anatomical visuals to treat TAA successfully. In this article, the island technique (a surgical procedure) and its complications are discussed, and surgical procedures are demonstrated on a deer's heart ex vivo.

Introduction

Aortic arch surgery is one of the most technically demanding procedures in cardiac surgery, in which protection of the myocardium, brain and spinal cord are vital for patient safety.[1] The aorta can present with two main types of aneurysm: thoracic aortic aneurysm (TAA) and abdominal aortic aneurysm (AAA). The UK prevalence of TAAs is estimated to be 10.4 per 100,000 person-years and there is an estimation that there are 3000–8000 new cases of TAA each year. Therefore, further research in this field of cardiac surgery is highly important.[2-4]

TAAs mainly affect the aortic arch. They can pathologically present when the aorta increases in size and broadens due to weakness within the arterial wall lining. The healthy adult aortic diameter does not exceed 40 mm in size; TAA is diagnosed when the dilation of an aorta is at least 50% greater than 40 mm.[1] Aneurysms commonly develop in the ascending thoracic aorta (40% of cases), the descending thoracic aorta (35%), abdominal aorta (15%) and the thoracic arch (10%). Individuals with TAA present with symptoms, such as abrupt chest pain, dyspnoea, hypotension, dysphagia and syncope, and have a survival rate of 56% (without medical intervention).[5,6] Furthermore, due to the presence of a weakened aortic wall, TAAs can result in either transection or dissection of the aorta, leading to complications, such as chest pain, shock, heart failure and hypovolaemic death. Individuals may be genetically predisposed to aortic dissections (e.g. if they have Marfan's syndrome) or may be at higher risk if they are exposed to some infections, such as tertiary syphilis infection.[1,4,7]

TAAs are often diagnosed using imaging tests, such as x-ray, computerised tomography (CT) and MRI of the chest. Depending on the diagnostic test results, medical management may be provided before surgical intervention, including hypertensive medication and statins.[5] However, for aneurysms that are at risk of rupture or fatal complications, a procedure known as 'total aortic arch replacement' can be used. In this article, the complications that may arise from performing arch surgery are discussed.

Literature search and surgical procedures

Literature search

PubMed and Google Scholar were searched for relevant articles, using the search terms "Aortic Arch Surgery" AND "Island Technique". Articles were included if they were published between 2009 and 2019. The Boolean template terms, 'anatomy', 'complications' and 'pathologies' were used to rescreen the articles. In total, 20 relevant articles were found **(Figure 1)**.

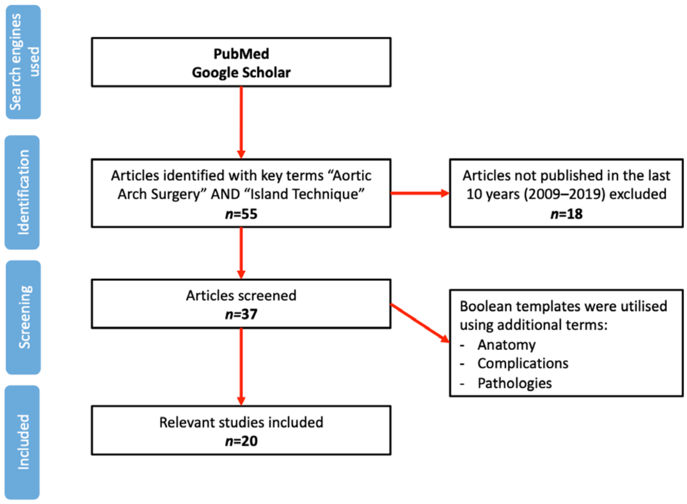

Figure 1. Article selection process. The Boolean template terms, 'anatomy', 'complications' and 'pathologies', were used to screen the articles.

Surgical procedures

Surgical procedures were carried out on a deer heart, with ethical considerations taken into account; the deer hearts were the by-product of the meat industry and acquired from an abattoir. Basic surgical equipment was used, as well as Dacron grafting material. Images were taken at the University Hospital Plymouth, NHS Trust (Plymouth, UK). The equipment used and the deer hearts were supplied by Medtronic (Watford, UK) and WetLabs (Warwick, UK).

Discussion of findings

Initial anatomical considerations prior to arch surgery

Healthy patient The aortic arch has three branches: the brachiocephalic artery, left common carotid and left subclavian artery.[8,9] The brachiocephalic artery forms the circle of Willis (CoW), which is a critical vascular region that supplies blood to important areas of the body, such as the upper spinal cord, brain stem, cerebellum and posterior region of the brain.[10] If the CoW is pathologically compromised, cerebral infarction may result, potentially leading to death.[11]

Patients with branchial pattern variations Patients can present with several variations of the branching patterns at the aortic arch; in 70–80% of patients, the left common carotid arises directly from the right brachiocephalic artery, known as the 'bovine-type arch'.[12] Before surgical intervention is considered, the surgical team need to assess the anatomical variations of a patient's thoracic region, which may include positional deviations of the heart and apex in the thoracic region. The patient could present with the apex of the heart on the left side of the body (laevocardia), midline (mesocardia) or on the right side of the body (dextrocardia). Each of these presentations have been associated with congenital malformations, such as atrioventricular septal defect and transposition of great arteries, which should be investigated by the surgeon.[13] Some of the anatomical considerations (and associated complications) that should be assessed prior to arch surgery are shown in **Table 1**.[10]

Table 1. The different structural locations associated with the aortic arch and complications that could happen if they were damaged during surgery.

Anatomical consideration	Location	Complication
Aortic semilunar valve	Located between the left ventricle exit and the start of ascending aortic arch[10]	Damage to the aortic semilunar valve or tricuspid leaflet can cause paravalvular leak and result in heart failure, anaemia and infective endocarditis[14]
Phrenic nerve	Located laterally to the aortic arch and the initial parts of the left subclavian artery and left common carotid[10]	Damage during surgery can result in phrenic nerve injury or palsy. This can cause diaphragmatic paralysis, preventing the patient from breathing on their own[15]
Left recurrent laryngeal nerve	A branch from the vagus nerve, located posterior to the distal aortic arch, which is seen to loop around and travel superiorly anterior to the aortic arch[10]	Damage to the left recurrent laryngeal nerve can result in voice hoarseness or vocal cord paralysis[16]
Thoracic duct	Located between the descending thoracic aorta on the left side of the heart and the azygous vein on the right[10]	Damage to the thoracic duct can result in chyle leakage and chylothorax. This could cause shortness of breath and malnutrition[17]

This table includes regions that are most prone to common complications during aortic arch surgery.

Bovine heart surgery: Derriford Hospital training room

Total aortic arch replacement The goal of surgical repair of the aortic arch is to remove the diseased arch portions and replace them with synthetic graft material (Dacron) and, concomitantly, manage the blood flow to both cerebral and down-stream end organs.[16,18] The arch repair technique was introduced by DeBakey and Cooley in 1952 and was implemented in 1955.[18] There have been various techniques that have evolved since this time, which have been trialled over the past few decades, including the island, Spielvogel, trifurcated graft and frozen elephant trunk (gold standard) techniques.[16,18] The island or En-bloc technique is further discussed herein.

Preparative anatomical considerations and surgical schematic

Before surgical intervention is commenced, the patient has to undergo specific procedural management. A schematic flowchart for successful aortic arch replacement surgery is shown in **Figure 2**. Due to the complexity of the surgery, the surgical field must be bloodless. This reduces the risk of post-operative complications, such as stroke, damage to the spinal cord, lung or kidney failure and general threat to life. The surgical procedure is completed by re-warming, reperfusion and weaning the patient off cardiopulmonary bypass (CPB).[19,20]

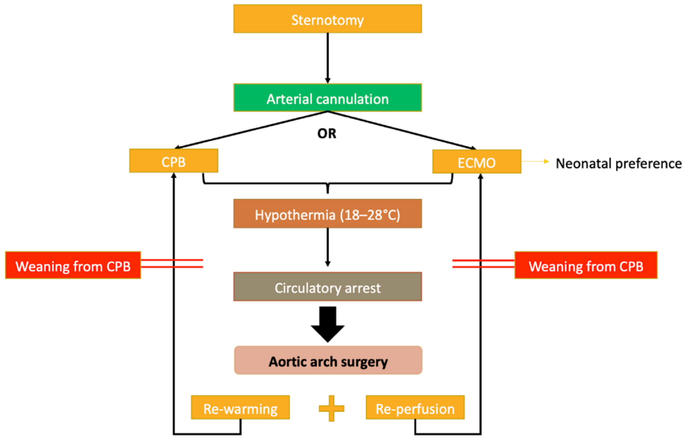

Figure 2. The pre- and post-operative procedural landmarks that are required to perform aortic arch surgery. Aortic arch surgery involves several procedures, with one of the first steps including arterial cannulation, which is vital for CPB. CPB is then carried out or, in rare cases of neonatal arch surgery, extracorporeal membrane oxygenation (ECMO) can be used. Hypothermic circulatory arrest is initiated to reduce the metabolic strain on vital organs, such as the brain, allowing general circulation around the body to be stopped. Subsequently, aortic arch surgery is conducted. Re-warming and re-perfusion are carried out after the surgery is completed. The figure was created using data from Bachet[19] and Peterss et al.[20]

Traditionally, median sternotomy is initially performed to gain access to the cardiothoracic cavity with a single incision. When conducting sternotomy, the proximity of the sternum to the heart and arteries within the thoracic cavity (bronchial, mediastinal, oesophageal, pericardial, phrenic and intercostal arteries) should be considered (see **Figure 3**). Additionally, it is fundamental to consider arterial presence (abundance of vasculature supply within the area) as there is a small risk of intercostal artery-related surgery-induced pseudoaneurysm.[1,19,21] Another complication of sternotomy includes sternal dehiscence (post-operative separation of the bony sternum), which leads to mediastinitis.[22]

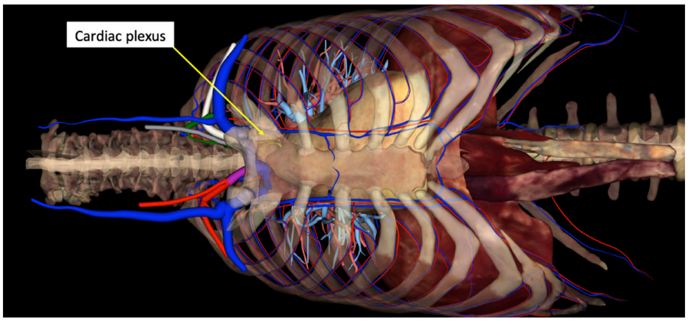

Figure 3. 3D dissection of the thoracic anatomy. This anterior view of the bony thorax (made translucent) includes the heart (within the pericardium), great vessels, diaphragm and intercostal arteries. The branches off the aortic arch are coloured as follows: brachiocephalic, pink; left common carotid, green; left subclavian, white. This image illustrates the close vicinity of the sternum to the heart, with the cardiac plexus (surrounding the arch) shown in yellow. Image acquired from Anatomage Inc. and copyright belongs to Anatomage.

Sternotomy has been shown to hinder the view of the distal aorta past the level of the lung hilum (vertebral level 5, 6 and 7) and commands a two-stage process (median and lateral anterior incisions), requiring two operations to access and replace diseased aortic regions, respectively, in patients with TAA.[23,24] Unfortunately, there is a risk of never completing the second stage of the procedure because the patient may perish either abruptly after the first-stage operation or from an aneurysm rupture while waiting for the second-stage repair. As an alternative, L-type incisions (as seen in **Figure 4**) may be used to overcome this issue. With L-type incisions, principally an anterior incision is made from the fifth intercostal space, the lateral line is incised up to the axillary line and the conventional median sternotomy (incision along the sternum) is performed. Following the median retraction, the left anterior chest wall is lifted upwards using steel wires ('open door technique'). One limitation of L-type incisions is that they are associated with higher respiratory complications, leading to tracheostomy and ventilation.[24] Additionally, in certain instances, the patient can present with extensive aortic pathology that could involve the descending aorta and aortic arch.

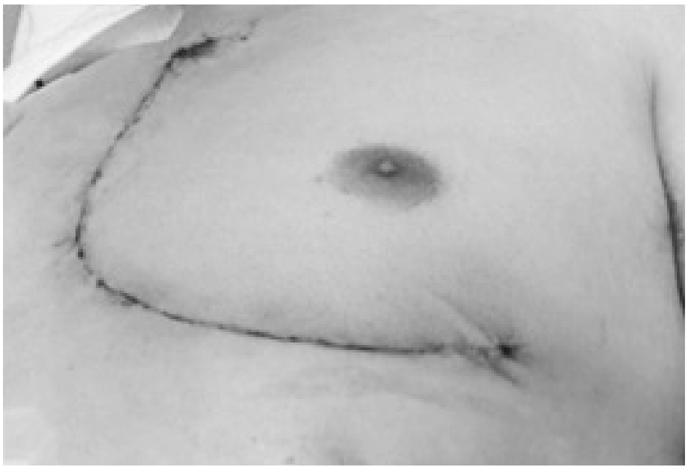

Figure 4. An L-type incision. Universally, the median sternotomy is preferred for arch surgery due to the rapid and secure procedural protocol. However, the L-type procedure provides an exceptional vision of the anterior aorta, which is required for TAA surgery. Image reprinted from Tokuda et al,[24] by permission of Oxford University Press.

For this article, the islet method was carried out on a deer heart to illustrate the complications that may arise and the final outcome of the procedure. It was noted that the deer heart had an extensive, thicker aortic arch than the human heart and a single brachiocephalic artery branch **(Figure 5)**.

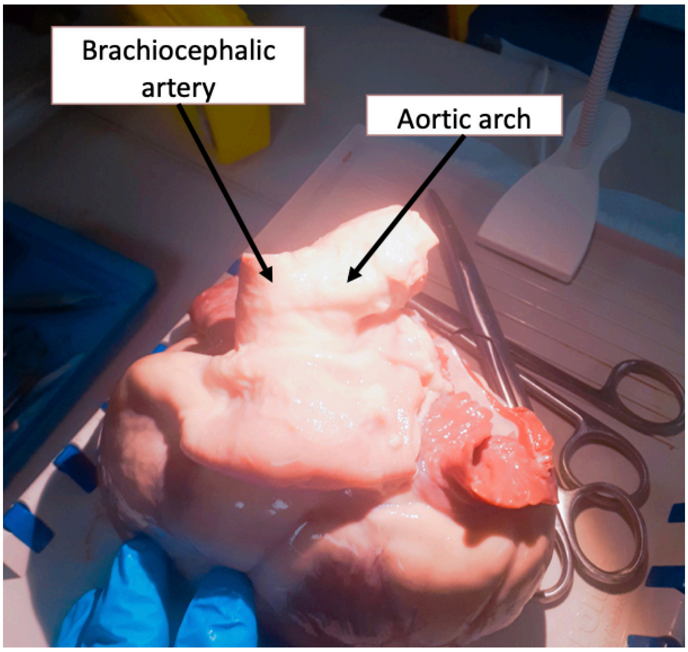

Figure 5. Deer heart. The deer heart has a thicker aortic arch compared with a human heart and a single brachiocephalic artery branching from the arch (instead of the three in the human heart).

Island technique The island technique is a surgical technique that re-implants the arch vessels from diseased aorta onto an artificial (Dacron) graft. The first step of the island technique involves the identification of the branched arteries (innominate [also known as brachiocephalic], left common carotid and left subclavian), which form the 'island', and the diseased aorta to be excised.[16] The next step includes excision of the aortic arch's branched arteries, which will form the 'island' or 'dome'. On the deer heart **(Figure 6)**, the single brachiocephalic artery forms the 'island', which is to be excised.[10]

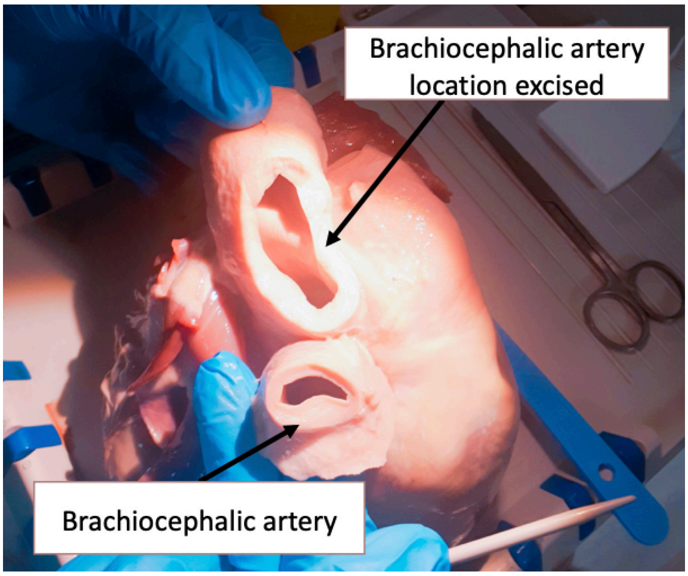

Figure 6. Removal of the brachiocephalic artery from the arch of the aorta in a deer's heart. The island would be anastomosed on a Dacron graft to replace the diseased aorta; the suturing process requires enough area on the brachiocephalic artery root to anastomose.

After excision of the brachiocephalic artery, the diseased aortic arch is removed, leaving the ascending aortic root. Subsequently, the Dacron graft is anastomosed, replacing the diseased arch (see **Figure 7**). At this stage, a potential complication of the island technique is that the aortic tissue that is left behind (island patch) can become aneurysmal and, thus, further operations may be required. This has been vastly reported in patients who present with connective tissue disorders, such as Marfan's.[1] In addition, there is a risk of anastomotic stenosis developing, depending on the suturing line employed during surgery.[9]

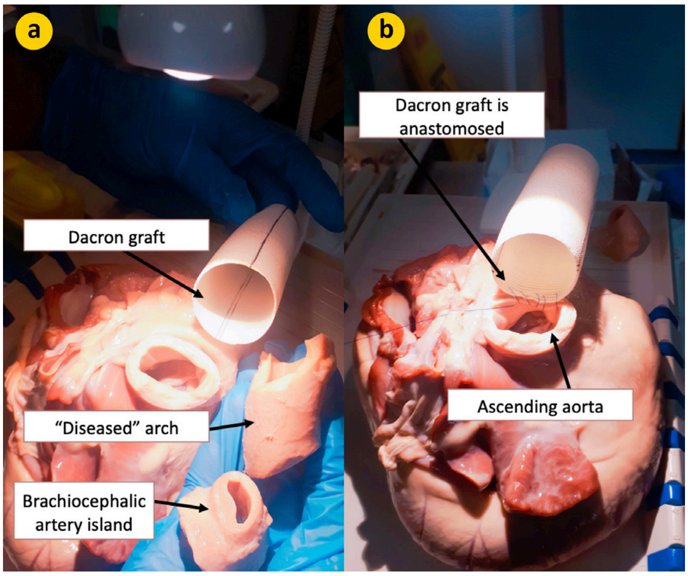

Figure 7. Dacron graft anastomosis in a deer's heart. (a) Image shows the diseased arch in comparison with the brachiocephalic artery 'island'. The Dacron graft can also be seen in contrast with the ascending aorta and the diseased aortic arch. **(b)** Image illustrates a single running suture implemented to anastomose the Dacron graft on the ascending aorta.

Post-anastomosis of the Dacron graft on the ascending root of the aorta, the brachiocephalic artery island is consequently anastomosed **(Figure 8)**. During the anastomosing of the island on the Dacron graft, it is fundamental that it is attached safely and securely without the suturing affecting the annulus. One of the complications associated with anastomosing the distal, proximal areas of the Dacron graft to the patient's healthy aorta is associated with suturing the island (branched arteries) on the graft while simultaneously keeping the patient under circulatory arrest; this has been shown to cause ischaemic strain on the body for an extended period of time, risking spinal cord damage and increasing the risk of permanent brain damage. Furthermore, complications, such as bleeding, have been shown to be harder to control after CPB has started.[25] The final outcome of the deer heart surgery using the island technique can be seen in **Figure 9.**

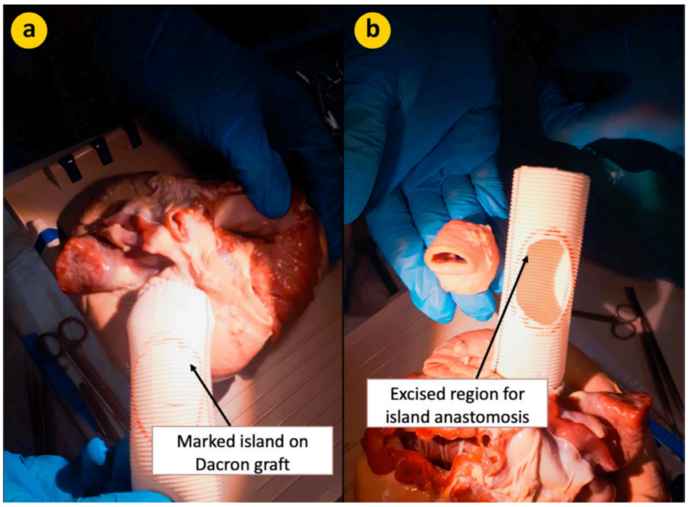

Figure 8. A Dacron graft, which is anastomosed on the ascending aortic root. (a, b) The anastomosed Dacron graft has been marked with a pen (red circle), displaying the location at which the brachiocephalic artery island is to be anastomosed. **(b)** Image shows a comparison of the excised region with the brachiocephalic artery.

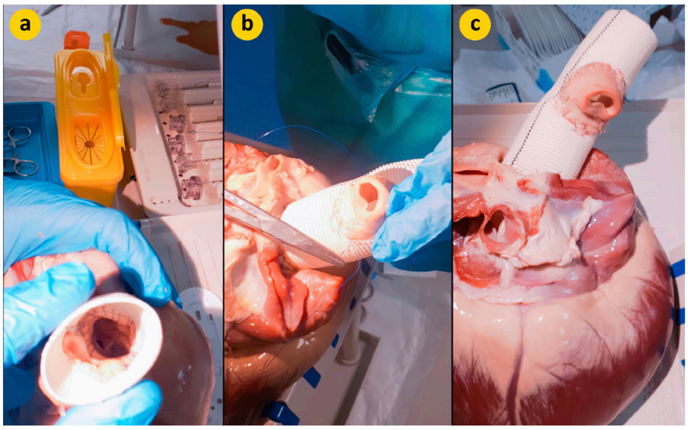

Figure 9. Outcome of the deer heart surgery using the island technique. (a) Bird's-eye perspective of the Dacron graft anastomosed on the root of the ascending aorta; the single running suturing can be seen. **(b)** Image illustrates the island anastomosing on the Dacron graft. **(c)** The outcome of the surgery, illustrating the replaced arch of the aorta and complete anastomosis of the island on the graft.

Conclusion

Cardiac surgery is a rapidly developing field and has seen immense growth over the past few decades. Diseases, such as Marfan's and tertiary syphilis, pre-dispose individuals to TAAs. Pathologies like TAA require fundamental surgical intervention. TAA management is best provided by evaluating and adapting to the patient's precise anatomical variations and the extent of the pathological damage that has been caused.

Acknowledgments I want to thank Mr Unsworth-White (Consultant Cardiothoracic Surgeon and Associate Professor; Peninsula Medical School, Plymouth, UK) and Dr Siobhan Moyes (Lead in Anatomy; Peninsula Medical School, Plymouth, UK) for their guidance. Furthermore, I want to thank WetLabs and Medtronic for the equipment and the deer heart provided for this project.

References

1. Zanotti G, Reece TB, Aftab M. Aortic arch pathology: surgical options for the aortic arch replacement. *Cardiol Clin,* 2017; 35(3):367–385.
2. Sastry P, Hughes V, Hayes P, et al. The ETTAA study protocol: a UK-wide observational study of "effective treatments for thoracic aortic aneurysm." *BMJ Open,* 2015; 5(6):1–8.
3. Paulo N, Cascarejo J, Vouga L. Syphilitic aneurysm of the ascending aorta. *Interact Cardiovasc Thorac Surg,* 2012; 14(2):223–225.
4. Aronow WS. Treatment of thoracic aortic aneurysm. *Ann Transl Med,* 2018; 6(3):66.
5. Harris C, Croce B, Cao C. Thoracic aortic aneurysm. *Ann Cardiothorac Surg,* 2016; 5(4):407.
6. Clouse WD, Hallett JW, Schaff HV, et al. Improved prognosis of thoracic aortic aneurysms. A population-based study. *J Am Med Assoc,* 1998; 280(22):1926–1929.
7. Czerny M, Schmidli J, Adler S, et al. Current options and recommendations for the treatment of thoracic aortic pathologies involving the aortic arch: an expert consensus document of the European Association for Cardio-Thoracic Surgery (EACTS) and the European Society for Vascular Surgery (ESVS). *Eur J Vasc Endovasc Surg,* 2019; 57(2):165–198.
8. Saliba E, Sia Y. The ascending aortic aneurysm: when to intervene? *IJC Hear Vasc,* 2015; 6:91–100.
9. Hua Q, Lin Z, Hu X, Zhao Q. Tracheal compression caused by a mediastinal hematoma after interrupted aortic arch surgery. *Int Heart J,* 2017; 58(4):629–632.
10. Scanlon VC, Sanders T (2014) Essentials of anatomy and physiology. 7th edn. F.A. Davis, Philadelphia, PA, pp 172-342.
11. David FL, O'Banion MK, Maida MS (2016) Netter's atlas of neuroscience. 3rd edn. Elsevier, pp 99.
12. Hanneman K, Newman B, Chan F. Congenital variants and anomalies of the aortic arch. *RadioGraphics,* 2016; 37(1):32–51.
13. Haththotuwa HR, Dubrey SW. A heart on the right can be more complex than it first appears. *BMJ Case Rep,* 2013:bcr2013201046.
14. Smolka G, Wojakowski W (2010) Paravalvular leak – important complication after implantation of prosthetic valve. Available from: www.escardio.org/Journals/E-Journal-of-Cardiology-Practice/Volume-9/Paravalvular-leak-important-complication-after-implantation-of-prosthetic-valv. Accessed: 15 December 2019.
15. Akhtar J, Siddiqui MA, Khan NA, et al. Right phrenic nerve palsy: a rare presentation of thoracic aortic aneurysm. *Malaysian J Med Sci,* 2013; 20(4):96–99.
16. Shelstad RC, Reeves JG, Yamanaka K, et al. Total aortic arch replacement: advantages of varied techniques. *Semin Cardiothorac Vasc Anesth,* 2016; 20(4):307–313.
17. Kitahara H, Yoshitake A, Hachiya T, et al. Management of aortic replacement-induced chylothorax by lipiodol lymphography. *Ann Vasc Dis*, 2015; 8(2):110–112.
18. Cooley DA, DeBakey ME. Resection of the thoracic aorta with replacement by homograft for aneurysms and constrictive lesions. *J Thorac Surg*, 1955; 29(1):66–104.
19. Bachet J. Open repair techniques in the aortic arch are still superior. *Ann Cardiothorac Surg*, 2018; 7(3):328–344.
20. Peterss S, Pichlmaier M, Curtis A, et al. Patient management in aortic arch surgery. *Eur J Cardio-thoracic Surg*, 2017; 51(Suppl1):i4–i14.
21. Fernandez Alonso S, Azcona CM, Heredero AF, et al. Post-sternotomy intercostal artery pseudoaneurysm. Sonographic diagnosis and thrombosis by ultrasound-guided percutaneous thrombin injection. *Interact Cardiovasc Thorac Surg*, 2009; 9(4):722–724.
22. Tewarie LS, Menon AK, Hatam N, et al. Prevention of sternal dehiscence with the sternum external fixation (Stern-E-Fix) corset –randomized trial in 750 patients. *J Cardiothorac Surg*, 2012; 7:85.
23. Tian DH, Croce B, Hardikar A. Aortic arch surgery. *Ann Cardiothorac Surg*, 2013; 2(2):245.
24. Tokuda Y, Oshima H, Narita Y, et al. Extended total arch replacement via the L-incision approach: single-stage repair for extensive aneurysms of the aortic arch. *Interact Cardiovasc Thorac Surg*, 2016; 22(6):750–755.
25. Shrestha M, Martens A, Behrendt S, et al. Is the branched graft technique better than the en bloc technique for total aortic arch replacement? *Eur J Cardio-thoracic Surg*, 2014; 45(1):181–187.