# Cardiovascular Topics

# The assessment of thoracal approaches in the treatment of aortic coarctation

Onur Işık, Gökmen Akkaya, Fatih Durak, Defne Engür, Meltem Çakmak, Ali Rahmi Bakiler, Muhammet Akyüz

## Abstract

**Objectives:** The optimal choice of surgery in coarctation of the aorta (CoA) remains controversial but it needs to be individualised. However, in most conditions, a surgical approach through thoracotomy maintains adequate exposure to create aortic patency. This study aimed to assess the efficiency and reliability of thoracal approaches in the treatment of CoA by examining the mid- and late-term outcomes, and determining the predictive factors for re-intervention.

**Methods:** Patients who underwent CoA repair through thoracotomy between September 2015 and February 2023 were included in the study, except for those with complex cardiac diseases. Medical records were retrospectively analysed and peri-operative course, follow-up findings on echocardiogram and physical examinations were obtained. The complication rate, postoperative arch gradient, need for antihypertensive medication use, and freedom from re-intervention were evaluated and then compared in terms of age at surgery.

**Results:** Overall, 98 patients including 50 neonates were reviewed. The most common surgical method was extended end-to-end anastomosis, performed in 53 patients. The median follow-up time was 4.6 years. There was one death in hospital and one late mortality in the cohort. Eight complications were observed in the cohort but all recovered well. Overall, 13 re-interventions, six redo surgeries and seven balloon angioplasties were carried out in 12 patients. Ten of the re-interventions were carried out within the first year of the initial surgery. One- and three-year freedom from re-intervention rates were 89.5 and 86.4%, respectively. However, there was no significant predictive factor for re-intervention. Comparisons according to the age at surgery did not differ, except for intensive care unit stay. The need for hypertensive medication was initially in 14 (14.2%) patients and then reduced to eight (8%) patients. The mean peak residual gradient on postoperative examination was 9 mmHg.

**Conclusion:** Thoracotomy provided feasible surgical access that led to satisfactory results with a low complication rate, negligible residual gradient, low incidence of hypertension and excellent rate for freedom from re-intervention in the treatment of CoA.

**Keywords:** coarctation of the aorta, thoracotomy, re-intervention, neonate, anastomosis

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**Paediatric Cardiovascular Surgery, Tepecik Hospital, Sağlik Bilimleri University, İzmir, Turkey**
Onur Işık, MD, dr.onur.aras@gmail.com
Gökmen Akkaya, MD
Muhammet Akyüz, MD

**Paediatric Intensive Care Unit, Tepecik Hospital, Sağlik Bilimleri University, İzmir, Turkey**
Fatih Durak, MD

**Tepecik Hospital, Sağlik Bilimleri University, Yenidoğan, İzmir, Turkey**
Defne Engür, MD

**Department of Anaesthesia and Reanimation, Tepecik Hospital, Sağlik Bilimleri University, İzmir, Turkey**
Meltem Çakmak, MD

**Paediatric Cardiology, Tepecik Hospital, Sağlik Bilimleri University, İzmir, Turkey**
Ali Rahmi Bakiler, MD

Aortic coarctation (CoA) is identified as a narrowing in the juxtaductal aorta, usually just distal to the left subclavian artery (LSA), and accounts for between 0.2 and 0.6 per 1 000 live births, representing 5 to 8% among all congenital cardiac malformations.[1,2] If left untreated, CoA is often associated with increased rates of mortality and morbidity and is one of the most common surgically treatable causes of secondary hypertension.[3]

The main surgical goals of treatment involve complete resection of the discrete segment, then construction of the aortic lumen patency without any residual gradient and avoiding late systemic hypertension. Several techniques have been introduced to achieve these optimal outcomes. However, multiple factors such as the patient's age, the severity of the CoA, co-existing cardiac diseases or genetic malformations, the diameter of the aortic arch and the length of the affected site hinder carrying out the optimal surgical method. Hence, various authors advocate a tailored approach.[3,4]

Surgery can be performed through a sternotomy or thoracotomy with or without cardiopulmonary bypass (CPB). Moreover, relief from the obstruction can be achieved in most cases by resection and end-to-end anastomosis (REEA), extended

end-to-end anastomosis (EEEA), subclavian arterioplasty, xenograft patchplasty or graft interposition.[4]

Although in isolated cases, the mortality rate is below 1%, overall life expectancy after surgery is reduced and patients are at an increased risk of developing certain pathologies such as cerebrovascular events, aneurysm formation, systemic hypertension and recoarctation. These warrant close follow up.[5,6] In this study, we aimed to evaluate the efficiency of thoracal approaches, particularly EEEA for CoA, and to determine possible risk factors for re-intervention and the need for hypertension treatment in the mid and late periods.

## Methods

Patients who underwent CoA repair through either left or right thoracotomy, with a diagnosis of isolated CoA or CoA and co-existing ventricular septal defect (VSD) between September 2015 and February 2023, were included in the study. Patients with associated complex cardiac defects, including complete atrioventricular septal defect, tetralogy of Fallot, transposition of the great arteries, Tuassig–Bing anomaly or variants of Shone complex, as well as those with a univentricular heart, or patients who were operated on via median sternotomy under CPB were excluded from the study.

Hospital records were retrospectively reviewed. Pre-operative data were collected from chart notes regarding demographics and physical examination findings (four-limb blood pressure records). In the case of lack of sufficient data, transthoracic echocardiographic (TTE) results were retrieved, and further imaging requiring computed tomography angiography (CTA) was done.

Associated genetic malformations, age and weight at the time of repair, particularly in terms of being neonate or not (a gestational age under 37 weeks was defined as premature, according to the World Health Organisation's definition of less than gestation[7]), clinical condition (use of prostaglandin or inotrope, need for mechanical support), and surgical type and outcomes were documented as well. Postoperative findings were acquired from routine clinic visits. In the case of multiple data points, the most recent one was obtained. The presence of complications, a need for re-intervention or hypertensive treatment were also noted.

The proximal transverse arch was measured between the brachiocephalic and left common carotid arteries, while the transverse arch represents the segment between the left carotid artery and LSA. The isthmus aorta is defined as the distal LSA and the site of ductal connection. Hypoplasia is identified if the relevant diameter of the aortic segment (in mm) is less than the weight of the patient (in kg) + 1 mm.[8] Systemic hypertension was identified when the upper extremity systolic blood pressure was greater than the 95th percentile for age and height.[9]

The study protocol was approved by the Faculty of Medicine ethics committee of the Sağlık Bilimleri University (date: 07/04/2023; no: 17439-17/8). The study was conducted in accordance with the principles of the Declaration of Helsinki. An informed written consent form was obtained from both parents of the patients.

During surgery, simultaneous monitoring was established with an invasive right radial arterial line and non-invasive cerebral and somatic oximetry. Pleural access was achieved through the intercostal fourth space, as usual, following a posterolateral skin incision. The descending aorta, ductus arteriosus, aortic arch and its branches were released and fully mobilised. Meanwhile, the vagal and phrenic nerve and ductus thoracicus were inspected and preserved. Minimum intercostal collateral arteries were sacrificed. Unfractionated heparin was administered at a dosage of 100 IU/kg.

The ductus arteriosus was doubly ligated. Then clamps were inserted on the descending aorta and at a level proximal to the LSA, mostly on the proximal arch. The pulse oximeter and online blood pressure monitor were checked on the opposite limb to avoid blocking the whole antegrade aortic arch flow. All narrowed segments and ductal tissue were removed during REEA and EEEA repair. The anastomosis site was extended by a proximal incision in the undersurface of the transverse arch and a mirror-image counter incision in the descending thoracic aorta during EEEA.

However, if proper enlargement on the anastomosis site was not achieved, the tension would be high and we opted to utilise xenograft pericardial patchplasty. In this method, an incision on the coarctation site is extended towards the proximal and distal line, then the CoA segment is covered with a tailored, fusiform-shaped xenograft patch so as to achieve sufficient augmentation. On the other hand, in elderly patients with less optimal mobilisation, we tend to perform graft interposition. Afterwards, the reconstruction is completed using 7-0 (or 8-0 low weight in neonates) polypropylene sutures with continuous stitches. Neutralisation with protamine was not routinely done, except for premature infants or patients with an increased bleeding profile.

### Statistical analysis

Descriptive data are expressed in numbers and median or mean values with range, whereas qualitative variables are presented in numbers and percentages. Continuous variables without a normal distribution are reported as median (interquartile range). To compare the findings among the three subgroups, categorical variables were compared with the chi-squared test. Continuous data with a normal distribution were assessed using the one-way analysis of variance (ANOVA) test, and abnormally distributed continuous data were compared using the Wilcoxon rank test. The data were recorded on a computerised database and analysed using the SPSS version 20.0 statistical software program (SPSS Inc, Chicago, Illinois, USA). A $p$-value $< 0.05$ was considered significant.

## Results

Overall, 98 patients were included, with 50 neonates. The age gap was considerabe (two days to 17 years) among the patients. The demographics are summarised in Table 1. There were only two missing data regarding patients who were immediately transferred to the epicentre in the follow-up period. The median follow up was 4.6 years (three months to 7.5 years).

One of five surgical options, predominantly EEEA, was utilised, considering the age at surgery, associated diseases, urgency and other factors. In the early era, heparin administration was not routinely applied in our clinic, especially in premature neonates or patients with a high bleeding risk. However, in a

**Table 1. Demographics and pre-operative features**

| *Demographics* | *Total* (n = 98) |
|---|---|
| Age (days) | |
| Median (IQR) | 58 (4–1017) |
| Mean ± SD | 384 ± 840 |
| Weight (kg) | |
| Median (IQR) | 3.5 (2.9–7.88) |
| Mean ± SD | 7.0 ± 7.4 |
| Gender | |
| Male | 46 |
| Female | 52 |
| Stage, *n* (%) | |
| Neonate | 50 (51) |
| Infant | 26 (26.5) |
| Premature | 21 (21) |
| Genetic disorder, *n* (%) | |
| Turner | 2 (2) |
| Down | 2 (2) |
| VACTERL | 1 (1) |
| Other | 4 (4) |
| Cardiovascular defects, *n* (%) | |
| BAV | 56 (57) |
| VSD | 22 (22) |
| Distal arch and istmus hypoplasia | 48 (49) |
| ARSA | 8 (8) |
| Bovine arch | 6 (6) |
| Right arcus aorta | 1 (1) |
| Pre-operative PGE, *n* (%) | 65 (66) |
| Pre-operative inotropes, *n* (%) | 20 (20) |
| Pre-operative intubation, *n* (%) | 14 (14) |
| Pre-operative procedure, *n* (%) | 2 (2) |
| Co-morbid medical condition*, *n* (%) | 17 (17.3) |

IQR: interquartile range, SD: standard deviation, VACTERL: (V) = (costo-) vertebral abnormalities, (A) = anal atresia, (C) = cardiac (heart) defects, (TE) = tracheal-oesophageal abnormalities, including atresia, stenosis and fistula, BAV: bicuspid aortic valve, VSD: ventricular septal defect, ARSA: aberrant right subclavian artery, PGE: prostaglandin E
*Pulmonary hypertension, Chiari I malformation, cerebral disorders, tracheomalacia, congenital diaphragmatic hernia, meconium aspiration, hypothyroidism, multicystic kidney, gastrochisis, corpus callosum agenesia, etc.

**Table 2. Operative data and follow up**

| *Operative data* | *Total* (n = 98) |
|---|---|
| Surgical type, *n* (%) | |
| EEEA | 53 (54) |
| REEA | 36 (36.7) |
| Patchplasty | 5 (5) |
| Reverse subclavian flap | 1 (1) |
| Bypass (interposition graft) | 3 (3) |
| Urgent procedure, *n* (%) | 19 (19.3) |
| Simultaneous intervention, *n* (%) | |
| PAB | 12 (12.2) |
| ARSA division | 8 (8) |
| ECLS[a] | 1 (1) |
| Complications, *n* (%) | |
| Septicaemia | 1 (1) |
| Wound infection | 3 (3) |
| Chylothorax | 2 (2) |
| Phrenic nerve injury | 0 |
| Bleeding | 0 |
| Paraplegia | 0 |
| Pneumothorax | 2 (2) |
| ICU stay (days), median (IQR) | 4 (1–36) |
| Early re-operation (in 30 days) | 0 |
| In-hospital mortality, *n* (%) | 1 (1) |
| Late mortality, *n* (%) | 1 (1) |
| Hypertension at discharge, *n* (%) | 14 (14.2) |
| Recoarctation, *n* (%) | |
| Surgery | 6 (6) |
| Balloon angioplasty | 7 (7) |
| Ongoing hypertension[b], *n* (%) | 7 (8) |
| Peak gradient (mmHg), median (IQR) | 9.0 (0.0–18.0) |

REEA: resection end-to-end anastomosis, EEEA: extended end-to-end anastomosis, PAB: pulmonary artery banding, ARSA: aberrant right subclavian artery, ECLS: extracorporeal life support, ICU: intensive care unit, IQR: interquartile range.
[a]Simultaneous extracorporeal life support insertion due to congenital diaphragmatic hernia.
[b]Patients with postoperative follow up over 12 months (81/96 patients, 84% of cohort).

neonate patient, following EEEA, adequate blood pressure could not be achieved in the descending aorta. The clamps were therefore immediately re-inserted. When the stitches were removed, the surgeons observed thrombus formation in the anastomosis site. Consequently, our preference was changed in favour of routine heparin administration. However, no bleeding complication was observed in our cohort.

There was only one in-hospital mortality and one late mortality. The in-hospital mortality that occurred on postoperative day two during repetitive re-intubation attempts necessitated atelectasis. The late mortality occurred due to associated genetic disorders without cardiac events. That patient had unophthalmia, right forearm agenesis, atypical facial appearance and rib anomalies. Although a blood sample was taken for detailed genetic analysis, no specific genetic disorder was identified among the currently known syndromes. The other complications did not cause any morbidity or mortality.

Wound infections were healed after local debridement and the patient with septicaemia recovered thanks to prolonged intravenous anti-biotherapy. Chylothorax was terminated following somatostatin infusion and the pneumothorax did not recur after the secondary chest tubes were removed. No phrenic recurrent nerve injury was observed or paraplegia, as well as post-coarctation syndrome in the intestines. The surgical methods and postoperative findings are presented in Table 2.

Overall, 13 (13.5%) patients required re-intervention and six of these underwent redo surgery. Five of the six redo surgeries and the majority of the balloon angioplasty procedures (5/7) were performed within the first year of the primary surgery. In all redo cases, xenograft patchplasty was applied as a secondary

**Table 3. Comparisons according to age at operation**

| *Variables* | *Overall* (n = 98) | *Neonate* (n = 50) | *Infant* (n = 26) | *Toddler/teen* (n = 22) | p-*value* |
|---|---|---|---|---|---|
| Complications, *n* (%) | 8 (8.3) | 4 (4) | 2 (2) | 2 (2) | 0.334 |
| ICU stay (days), median (IQR) | 4 (1–36) | 6 (1–63) | 4 (1–25) | 3 (1–18) | < 0.001 |
| Re-intervention, *n* (%) | | | | | |
| Surgery | 6 (6.1) | 4 (4.1) | 1 (1) | 1 (1) | 0.105 |
| Balloon angioplasty | 7 (7.2) | 4 (4.1) | 2 (2) | 1 (1) | 0.089 |
| Ongoing antihypertensive therapy, *n* (%) | 7 (7.2) | 3 (3) | 2 (2) | 2 (2) | 0.475 |
| Peak systolic gradient (mmHg), median (IQR) | 9.0 (0–16) | 10.0 (0–17) | 11.0(0–18) | 14.0 (0–18) | 0.612 |
| Overall mortality, *n* (%) | 2 (2) | 1 (1) | 1 (1) | 0 | 0.155 |

ICU: intensive care unit, IQR: interquartile range.

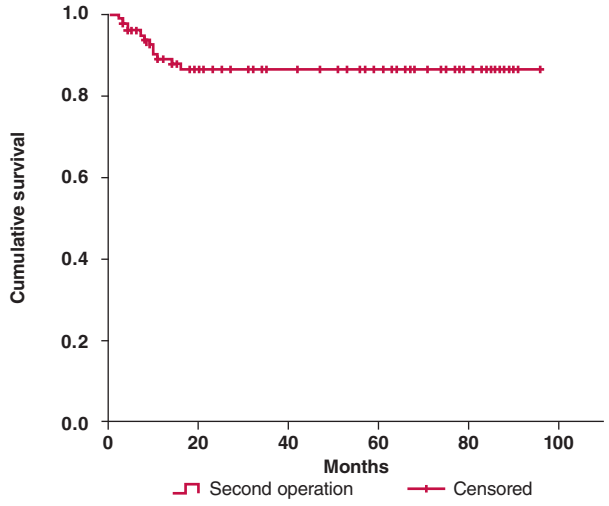


**Fig. 1.** Kaplan–Meier curve for freedom from re-intervention.

surgery. One patient required a third attempt to achieve sufficient release.

Comparisons according to age at surgery were not significantly different, except for length of stay in the intensive care unit (Table 3). One- and three-year freedom from re-intervention rates were 89.5 and 86.4%, respectively (Fig. 1).

## Discussion

In this evaluation of our experience regarding a single centre with a mean 4.6-year follow-up period, overall mortality and freedom from re-intervention rates were comparable with contemporary studies.[10-12] The age at operation was not statistically significant with regard to re-intervention. However, half of the infants (6/12) who required re-intervention were premature at the time of initial surgery and the majority of these cases had re-intervention within the first year after the primary attempt.

Although there are supportive data in the literature, certain authors found low weight and prematurity insignificant.[11-14] In a systematic review, Dias *et al.*[15] notably demonstrated that lower weight at repair was strongly associated with mortality. Nonetheless, they highlighted the ambiguity of the methodology, which greatly influences the comparability of results in this field and the comparison of scientific evidence.[15]

In addition, patients with low birth weight have other risks. One exceptionally low-weight premature infant underwent surgical re-intervention in the mid-term after the initial REEA and clipping of the patent ductus arteriosus (PDA) due to iatrogenic partial obstruction in the juxtaductal segment caused by the ductal clip that was placed adjacent to the descending aorta. The relevant clip was removed and the PDA was encircled with a purse-string suture. Afterwards, the remnant ductal tissue was excised and the aorta was constructed via a xenograft pericardial patch. A key point obtained from this case was that we began to avoid inserting ductal clips in the case of short and large PDAs in neonates. In those cases, we control the vessel from the intrapericardial segment with proline purse-string sutures.

In our series, one patient had a right arcus aorta. Although the surgical incision had to be done on the right side, which is unusual, such patients do not pose any additional problems by having complete mirror symmetry.[16]

An associated aberrant right subclavian artery (ARSA) did not cause any complications in our cohort because we sacrificed the ARSA to allow sufficient relief to the aortic arch and branches. Kaushal *et al.* reported that three of their redo cases had ARSA.[17] In their series, they preserved the ARSA routinely. Optimal mobilisation was not achieved in this case so the quality of the anastomosis was reduced. We however sacrificed this vessel after examining the size of the vertebral artery and blood supply on the relevant limb. Neither ischaemia nor growth deficiency was observed in this patient in the ongoing follow-up period. On the other hand, we agree with Kaushal *et al.* that hypoplasia in the transverse arch can theoretically be more often in the presence of ARSA.

Conversely, bovine arcus creates a real inconvenience. Bovine arcus represents the anomaly in which the left common carotid artery originates from the brachiocephalic artery, whereas the LSA arises separately from the arcus aorta. This anomaly is not rare and encountered in 13% of the population.[18] Unless identified, it may cause detrimental effects in CoA repair because the right carotid artery, a landmark between the proximal and distal arch, is misplaced. Mistakenly, the second branch of the arcus may be assumed as the right carotid artery, hence the proximal clamp may block all the antegrade flow towards the cranium.

To prevent this, Karakuş *et al.* suggested revealing every three branches of the arcus aorta separately or the use of near-infrared spectroscopy and opposite-limb pulse oximetry during surgery in the absence of CTA to exhibit the exact anatomy.[19] Nevertheless, when aggressive enlargement is necessitated, a median sternotomy with cannulation of the brachiocephalic trunk should be considered.

Median sternotomy is often reserved for patients with univentricular heart and simultaneous CoA. Although pulmonary artery banding (PAB) and CoA repair through thoracomy is an option to avoid CPB, it is associated with high mortality and re-operation rates for subaortic stenosis and aortic arch obstruction. Tchervenkov *et al.* therefore suggested that Norwood or Damus–Kay–Stensel type operations provide better results and optimise the preparation of the Fontan candidate. They state that these options will likely emerge as the first choice in the case of single ventricle and systemic obstruction.[20]

Numerous studies investigating the relationship between successful surgery and the development of distal or transverse arch and isthmus aorta have been published previously. However, this issue remains debatable. For instance, Ramachandran *et al.*[21] and Farag *et al.*[22] did not find a significant correlation between distal arch scores and re-intervention rate. Conversely, although only four of 251 patients underwent re-intervention, this relationship was found to be significant by Gopler *et al.*[23]

In collaboration with these findings, Heremans *et al.*[11] determined that while pre-operative distal and isthmic *Z*-scores did not differ among patients, postoperative *Z*-scores and peak gradient (PG) values were found to be predictive. Interestingly, among numerous parameters, Ablderahim *et al.*[24] found only postoperative PG values to be predictive for re-intervention. Therefore, we are of the opinion that a thoracotomy incision allows great access to aortic and mediastinal structures and, as long as the proximal arch is well developed, regardless of the

distal or isthmic aortic diameters, an adequate anastomosis site can be achieved.

For this reason, in the presence of adequate *Z*-scores for the proximal arch and ascending aorta, we do not calculate distal and isthmic scores. We recommend considering postoperative measurements instead. However, measuring the proximal arcus size is mandatory. Proximal hypoplasia warrants a sternal approach, otherwise we advocate thoracotomy.

Extensive dissection may also protect from late scar tissue retraction and hence can reduce the re-coarctation rate without related complications.[25] However, flexible neonate tissue does not assure event-free results. Surgeons therefore should be aware of potential risks. A well-known complication is termed the 'Gothic arch', which means a sharp angle between the ascending and descending aorta after reconstruction, and the left bronchus may be under pressure. This adverse event occurs when the descending aorta is excessively moved up towards the proximal and medial direction. In one case, we experienced this phenomenon. Fortunately, the narrowness and the symptoms were not severe and it did not require a re-intervention.

Inspiringly, Callahan *et al*.[26] pushed the limits to performing EEEA by partially clamping the innominate artery in patients with proximal hypoplasia. They claimed that they got better results and they support the liberal use of thoracotomy in proximal arch hypoplasia. In light of such advancements, this method has been performed more often lately, with precautions involving examination with a cerebral non-invasive bedside monitor and pulse oximeter in our clinic. Nevertheless, it should always be kept in mind that the cost of avoiding re-operation is coupled with the risk of cerebral injury.

The observed hypertension rate in our cohort was reduced from 14.2 to 8% thanks to medication. Our choice was to administer esmolol in the hospital and early postoperative period, then to continue antihypertensive treatment with enalapril or captopril. Our data correlate with current studies, which report the hypertensive treatment rate at around 18 and 5.3%.[11,20,21] However, this discrepancy is attributed to various factors, especially the age of the patient at surgery. Farag *et al.*[22] determined a significantly increased rate of hypertension in patients who were operated on at a year or older. Similarly, five of seven patients with ongoing hypertensive treatment were a year or more old.

Despite optimal medical therapy, even after successful surgery, systolic hypertension persists in occasional cases, therefore we perused recent studies to better understand the underlying mechanisms of the ongoing histochemical process.[27] Lee *et al*.[28] suggest considering CoA as a systemic vascular disease rather than a problem in a specific area because established neurohumoral abnormalities continue to trigger the existing hypertensive mechanisms.

Anticoagulation or antiplatelet therapy after surgery are also being debated. There is no consensus on this subject and many centres apply medication according to their past experiences. We tend to administer acetyl-salicylic acid 5 mg/kg/day in small neonates or when aortoplasty with xenograft or graft interposition has been performed. However, the arterial healing process and its relationship with tissue factors and the coagulation cascade have been widely investigated.

Beyond antiplatelet activity, aspirin has well-known effects on smooth muscle cell proliferation and the development of intimal hyperplasia.[29,30] Promising studies with new anticoagulants and other agents have been conducted in this regard.[31,32] Nevertheless, there is still a long way to go before these drugs become routinely used in children.

This study has inherent limitations arising from its retrospective nature and non-comparative design. The presentation of the single-centre experience contains a limited number of patients with a relatively short follow-up period. Moreover, the distribution of the demographics, particularly age, was considerably varied. Also, several surgical approaches were used. The lack of some data hindered further statistical analysis.

## Conclusion

We found that the thoracotomy incision provided sufficient surgical exposure to perform optimal mobilisation of the arcus aorta and its branches, and the surgical process could be accomplished with satisfactory results and acceptable re-intervention rates, and low mortality and morbidity rates. However, the precise anatomy needs to be revealed pre-operatively and the treatment options should be tailored according to the clinical features. Re-intervention after surgery is not exceptional and patients therefore require close follow up, neonates in particular.

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