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# The Role of Patch Repair in Aortic Arch Reconstruction: Enhancing Outcomes and Preserving Growth Potential in Pediatric Patients

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## Abstract

**Objectives:** Aortic arch abnormalities are frequently observed in neonates and may be associated with other congenital cardiac anomalies. Various surgical approaches exist for the repair of these abnormalities. This study aimed to review the outcomes of aortic arch surgery in neonates and infants.

**Materials and Methods:** We retrospectively analyzed patients who underwent aortic arch reconstruction with or without intracardiac anomalies between 2017 and 2022. The subjects were categorized into two groups based on the arch reconstruction technique employed: group 1 underwent patch aortoplasty via sternotomy, whereas group 2 underwent arch reconstruction without a patch via thoracotomy. Demographic information, morbidity rates, and mortality statistics were extracted from the departmental database for the analysis.

**Results:** This study enrolled 37 patients (25 males and 12 females). Twenty-nine patients were assigned to group 1, while eight patients were allocated to group 2. No significant differences were observed in the preoperative variables between the two groups. The overall median age and weight were 11 days (range: 2-270) and 3.1 kg (range: 1.4-5.6), respectively. Nine patients had a weight <2.5 kg. Twenty-eight patients underwent concomitant cardiac procedures. The 30-day mortality rate was 10.8% (n=4), with all deceased patients belonging to STAT Mortality Category 4 (n=31). No mortality was observed in the patients with isolated hypoplastic aortic arch or concomitant ventricular septal defect repair.

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## Abstract

At a median follow-up of 27 months, three patients in group 2 developed restenosis and underwent surgical correction. In group 1, restenosis was observed in only one patient, who was treated with balloon angioplasty. The incidence of recurrent arch obstruction was significantly higher in group 2 (p=0.02).

**Conclusion:** Aortic arch repair with patch through sternotomy represents a safe and efficacious approach, offering potential for intervention in intracardiac anomalies. The implementation of a patch facilitates tension-free anastomosis and optimal arch geometry, while demonstrating an acceptable rate of restenosis.

**Keywords:** Aorta, cardiovascular surgery, congenital heart defects

## Introduction

Coarctation of the aorta (CoA) is a well-documented congenital anomaly that accounts for 6-8% of all congenital anomalies[1]. Up to 81% of patients with aortic coarctation may have a hypoplastic aortic arch (HAA), and the presence of HAA has a significant effect on the development of recoarctation after surgical repair[2]. It may be observed in conjunction with intracardiac anomalies of varying severity, ranging from a simple ventricular septal defect (VSD) to hypoplastic left heart syndrome[3,4].

The optimal surgical management of CoA with HAA remains a subject of debate. Initial surgical repair and incomplete relief of obstruction have a significant impact on coarctation recurrence, both in the intermediate and long term[5]. Commonly employed techniques for surgical repair include patch aortoplasty, direct anastomosis, sliding aortoplasty, and Extended End-to-End Anastomosis (EEEA).

Furthermore, the management of patients with intracardiac anomalies remains unclear. Although some authors have advocated staged repair, there are a increasing number of reports describing favorable outcomes of the single-stage approach[6,7].

The objective of this study was to evaluate the short- and mid-term outcomes of surgical treatment of HAA and to assess the influence of surgical techniques and the accompanying anomalies on mortality and restenosis.

## Materials and Methods

This study was approved by the local institutional Ethical Committee of University of Health Sciences Türkiye, Bursa Yüksek İhtisas Training and Research Hospital (approval no: 2011-KAEK-25 2019/12-17, date: 23.11.2011). All the procedures were conducted in accordance with the principles of the Declaration of Helsinki.

The study cohort comprised all patients who underwent aortic arch repair with or without treatment of associated intracardiac anomalies by the same surgeon at Medicana Bursa Hospital and University of Health Sciences Türkiye, Bursa Yüksek İhtisas Training and Research Hospital between October 2017 and February 2022. Patients with Hypoplastic Left Heart Syndrome, unstable clinical conditions or isolated discrete CoA were excluded from this study.

### Definitions

The aortic segment between the brachiocephalic artery and left common carotid artery was defined as the proximal arch, whereas the segment between the left common carotid artery and left subclavian artery was defined as the distal arch. Arch hypoplasia was defined as (a) a diameter < 1 mm/kg + 1, or (b) a diameter ≤50% of the diameter of the ascending aorta. Recurrent arch obstruction was defined as an invasive gradient exceeding 20 mmHg across the repair site.

During follow-up, either percutaneous or surgical intervention of the aortic arch was considered reintervention. Early mortality was defined as death occurring within 30 days after surgery.

**Surgical Technique**

In group 1, dissection and mobilization of the ascending aorta, arch, and brachiocephalic vessels were performed prior to the initiation of cardiopulmonary bypass (CPB). The patients were cooled to 32 °C. Following division of the ductus arteriosus, the descending aorta was extensively mobilized (Figure 1a). The heart was arrested with del-Nido cardioplegia. Branches of the arch and descending aorta were clamped and antegrade cerebral perfusion (ACP) was initiated. ACP was established either through the graft anastomosed to the innominate artery or by advancing the aortic cannula to the innominate artery, followed by aortic arch reconstruction. All ductal and coarctation tissues were excised. An incision was made along the undersurface of the arch and extended proximal to the innominate artery. To allow for a wide anastomosis, a small incision was made on the inner surface of the descending aorta. Subsequently, the lateral aspect of the descending aorta was sutured to the lateral aspect of the arch (Figure 1b). An ellipse-shaped porcine pericardium was used at the inner curvature to augment the arch (Figure 1c, Figure 1d). In group 2, a left posterolateral thoracotomy was performed. The thoracic cavity was entered through the third intercostal space. Dissection of the aortic arch, left subclavian artery, left carotid artery, and thoracic aorta was conducted. After administration of 100 U/kg heparin, the vessels were clamped. Resection of the coarctation and EEEA was performed.

Demographic and clinical data were collected retrospectively. Echocardiographic measurements were obtained from the outpatient clinic records.

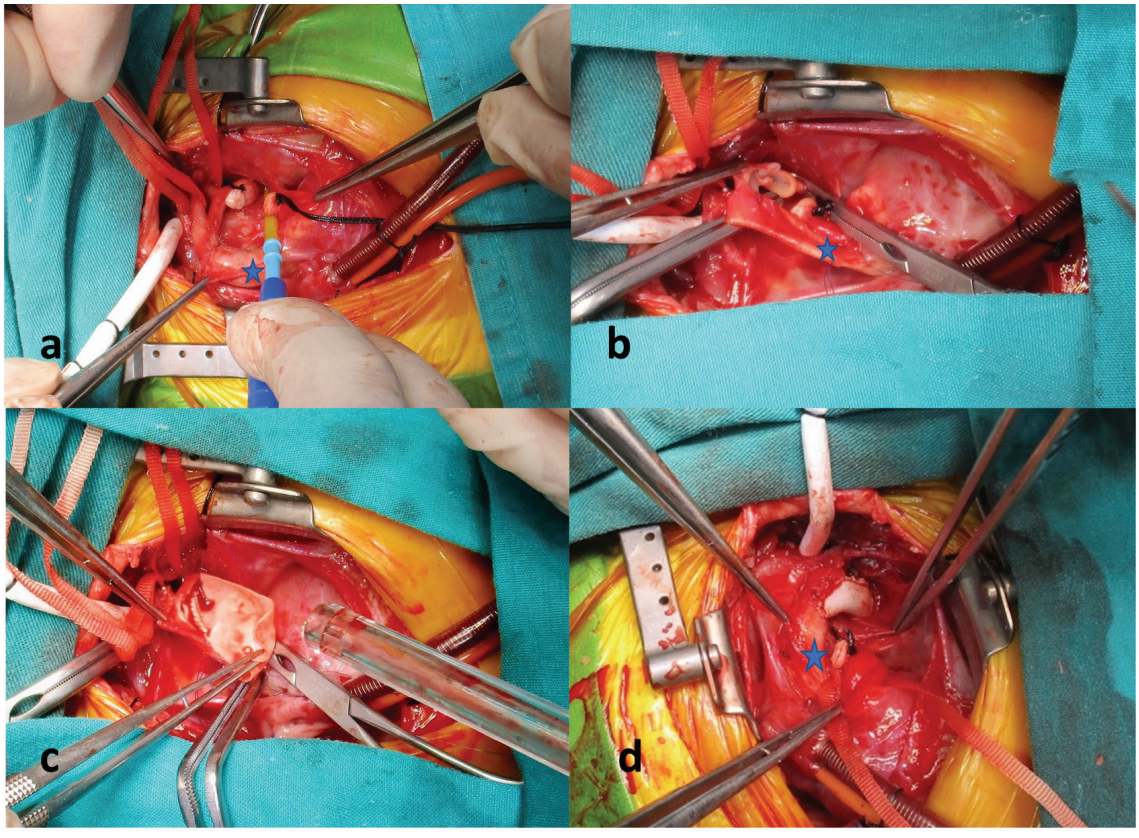


**Figure 1.** A, B, C, D) Surgical technique

### Statistical Analysis

Data were analyzed using IBM SPSS Statistics Version 21 (IBM Corp., Armonk, NY, USA). Continuous variables are expressed as the mean ± standard deviation. Non-normally distributed variables were presented as medians (Q1 and Q3). Categorical data were compared using the chi-square test or Fisher's exact test, as appropriate. Continuous variables were compared using Student's t-test or the Mann-Whitney U test. Survival and freedom from reintervention are presented using Kaplan-Meier survival curves. A Cox regression model was used for univariate analysis. Statistical significance was set at $p<0.05$.

## Results

Thirty-seven patients (12 females, 25 males) were included in this study. In group 1, 29 patients underwent surgery via sternotomy with CPB. In group 2, eight patients underwent surgery via thoracotomy. No significant differences were observed in the preoperative variables between the two groups (Table 1). The overall median age at surgery was 11 days [interquartile range (IQR): 2.4-3.3]. The majority of patients were neonates (≤28 days; n=29; 78%), and the remaining seven (22%) were infants. The median weight at surgery was 3.1 kg (IQR: 2.4-3.3). Ten patients were under 2.5 kg. Seventeen (46%) patients required preoperative ventilatory support and 10 (27%) patients received prostaglandin E (PGE) infusion. Six patients presented with genetic abnormalities; the diagnoses included trisomy 21 (n=3), trisomy 18, Emmanuel syndrome, and DiGeorge syndrome. Only nine patients (24%) exhibited an isolated HAA. Twenty-eight patients underwent concurrent cardiac procedures, of whom 15 had VSD closures (Table 2). Five patients underwent univentricular palliative repair. There was no statistically significant difference between the two groups with respect to early postoperative variables. The median length of intensive care unit stay was nine days in both groups (Table 3). The 30-day mortality rate was 10.8% (4/37). Low cardiac output syndrome, cerebral hemorrhage, sepsis, and acute renal failure were identified as the causes of mortality. There was one case of late mortality. The patient with HAA and truncus arteriosus died 60 days after arch reconstruction and PA banding. The cause of death was determined to be sepsis. Twenty-nine patients were classified into STAT Mortality Category 4 (Figure 2). All deceased patients belonged to category 4 and underwent complex cardiac surgery. Five patients underwent concomitant univentricular palliation. Mortality was not observed in the patients with isolated arch hypoplasia, or with concomitant VSD closure. During the follow-up period, three patients (3/8) in group 2 developed restenosis and necessitated reoperation. In group 1, restenosis was observed in only one patient (1/29), who subsequently underwent balloon angioplasty. The

**Table 1.** Demographic data of patients

| | Total n=37 | Group 1 n=29 | Group 2 n=8 | p-value |
|---|---|---|---|---|
| Age at surgery, d Median (quartiles: Q1-Q3) | 11 (6-26) | 10 (6-26) | 14.5 (7.5-26.5) | 0.59 |
| Weight, kg Median (quartiles: Q1-Q3) | 3.1 (2.4-3.3) | 3.2 (2.7-3.3) | 2.6 (1.97-3.35) | 0.18 |
| Sex, Male/Female | 25/12 | 19/10 | 6/2 | 0.48 |
| PGE1 (%) | 10 (27%) | 8 (27.6%) | 2 (25%) | 0.63 |
| Ventilatory support, % | 17 (45.9%) | 13 (44.8%) | 4 (50%) | 0.55 |
| Low weight (<2.5 kg) | 10 (27%) | 6 (20.7%) | 4 (50%) | 0.11 |
| Single ventricle | 5/32 (13.5%) | 5/24 (17.2%) | - | 0.27 |

*PGE: Prostaglandin*

difference was statistically significant. Figure 3 illustrates the freedom from reintervention throughout the follow-up period. No aneurysms or bronchial compressions occurred during the follow-up period. Junctional ectopic tachycardia, managed through medical intervention, was observed in four (12%) patients in group 1. One patient

**Table 2.** Concomitant cardiac procedures

| | n | % |
|---|---|---|
| VSD repair | 15 | 40.5 |
| Atrial septectomy + pulmonary artery banding | 3 | 8.1 |
| ASD repair | 2 | 5.4 |
| Pulmonary artery banding | 2 | 5.4 |
| Arterial switch operation + VSD repair | 2 | 5.4 |
| Damus kaye stansel procedure | 1 | 2.7 |
| Subaortic membrane resection | 1 | 2.7 |
| Aortopulmonary window repair | 1 | 2.7 |
| AVSD repair | 1 | 2.7 |

*ASD: Atrial septal defect, AVSD: Atrioventricular septal defect, VSD: Ventricular septal defect*

**Table 3.** Postoperative details

| | Total n=37 | Group 1 n=29 | Group 2 n=8 | p-value |
|---|---|---|---|---|
| ICU LOS, d Median (quartiles: Q1-Q3) | 9 (5.5-16) | 9 (6-14) | 8.5 (5-22.5) | 0.63 |
| Complex procedure, % | 12 (32.4%) | 10 (34.5%) | 2 (25%) | 0.48 |
| Arrythmia requiring medical treatment | 4 (10.8%) | 4 (13.8%) | - | 0.55 |
| Early mortality, % | 4 (10.8%) | 3 (10.3%) | 1 (12.5%) | 0.56 |
| Re-Intervention, % | 4 (10.8%) | 1 (3.9%) | 3 (42.9%) | 0.023 |
| Follow-up (month) median (quartiles: Q1-Q3) | 27 (14-43) | 21 (14-40) | 37.5 (10.75-54.25) | 0.24 |

*ICU: Intensive care unit, LOS: Length of stay*

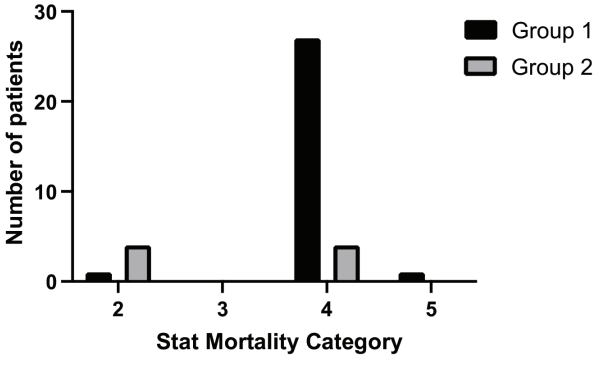


**Figure 2.** Stat mortality category

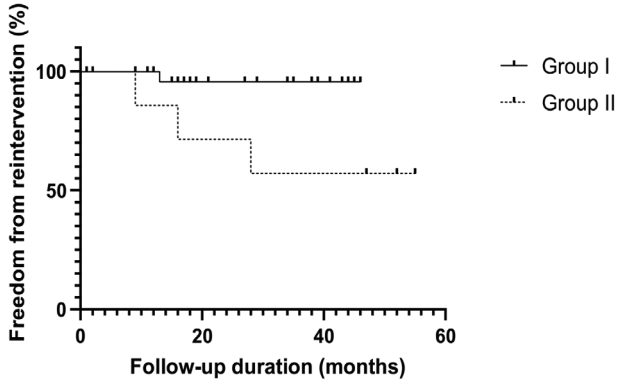


**Figure 3.** Freedom from reintervention

required a permanent pacemaker. Only one patient exhibited vocal cord dysfunction, and hoarseness was observed; the hoarseness subsequently resolved during the follow-up. Arch reconstruction without patch was identified as a risk factor for restenosis and reintervention ($p<0.05$). Preoperative ventilation, PGE1 infusion, or low birth weight (<2500 g) was not found to be risk factors for mortality or restenosis. Univariate analysis revealed that concomitant univentricular palliation was a significant predictor of mortality ($p=0.005$). However, this association was not significant in multivariate analysis after adjusting for other variables ($p=0.11$). Patients requiring univentricular palliation often represent a subgroup with a higher surgical complexity, which could explain the initial association with mortality.

## Discussion

This retrospective study demonstrated that aortic arch reconstruction with patch through median sternotomy is an efficacious surgical technique that enables the addressing of all sites of the arch, facilitates tension-free anastomosis, and allows intervention in combined cardiac lesions.

Various surgical techniques have been employed to address aortic arch reconstruction. However, the best method for managing CoA associated with HAA remains controversial. One prevalent theory suggests that enhancing the HAA is unnecessary, as hypoplasia or residual arch obstruction is believed to resolve naturally after resection and EEEA[8]. Nevertheless, incomplete resolution of arch obstruction may increase the likelihood of recurrent obstruction. Studies have shown that recurrent coarctation rates after EEEA range from 2% to 31%[9,10]. Rakhra et al.[11] found that patients who underwent arch repair via thoracotomy had a lower 10-year freedom from recurrent arch obstruction (61%) than those who underwent arch repair via sternotomy (92%). In our cohort, the incidence of restenosis was significantly lower in patients who underwent arch reconstruction via sternotomy with patch augmentation (1/29), which aligns with the findings of Rakhra et al.[11]. This supports the hypothesis that the sternotomy approach offers better long-term patency, possibly due to improved exposure and more precise arch geometry during reconstruction.

Although EEEA via thoracotomy might be perceived as less invasive, it has several drawbacks. These include limited operating space and restricted aortic clamp time. Furthermore, clamping the proximal aortic arch during anastomosis may impair cerebral blood flow, and achieving complete relief of arch obstruction can be difficult. Studies with long-term follow-up have shown that the arch tends to remain relatively small[12]. Furthermore, residual aortic arch obstruction has been identified as a risk factor for post-repair hypertension[13]. In contrast, the midline sternotomy approach overcomes these challenges by providing safe and sufficient exposure.

Various surgical techniques, including aortic arch advancement, end-to-side anastomosis, and patch augmentation, have been described via median sternotomy[7]. Our preferred approach is the patch augmentation via sternotomy with CPB. The entire isthmic region and ductal tissue can be resected safely and easily to reduce the risk of recoarctation. The use of a patch for the inner curve of the arch following partial anastomosis of the aortic tissue ensures tension-free reconstruction of the arch and a favorable geometry. Consequently, arch obstruction is effectively resolved, even in severely HAA, and the arch retains its growth potential.

One of the important issues that has been overlooked is the type of aortic arch. Three types of aortic arches have been identified: gothic, crenel, and normal[14]. Gothic arch is characterized by acute angulation between the ascending and descending aorta and suggesting increasing the hypertension risk[1,14]. End-to-end or end-to-side anastomosis results in a more gothic arch shape post-surgery, increasing the risk of hypertension[14]. Furthermore, end-to-side anastomosis or sliding aortoplasty techniques, which preclude the use of patch material, are hypothesized to optimize the growth potential of the arch. However, direct anastomosis may

induce excessive tension between the two aortic ends, potentially resulting in bronchial compression. Roussin et al.[15] observed higher rates of restenosis and bronchial compression in the native tissue repair group compared to the patch aortoplasty group. We observed no bronchial compression and a low restenosis rate during follow-up in the sternotomy group, as patch repair provided favorable geometry of the arch, tension-free reconstruction. Additionally, there were no aneurysms, although such cases have been described after patchplasty[16]. Concerns about the potential risks of CPB and ACP in neonatal cardiac surgery are often raised. However, this study supports the safety of these techniques when they are performed under controlled conditions. Only one patient experienced neurological complications. These findings are consistent with contemporary literature, which suggests that modern CPB and ACP protocols, when carefully managed, pose minimal risks and provide critical benefits, including improved exposure and the ability to address concomitant cardiac defects[9,17].

Although some surgeons have expressed concerns about performing single-stage repair for cardiac and aortic arch abnormalities, this method has gained prevalence following successful reports[10,11]. Our experience supports these reports, as the single-stage approach enabled us to successfully address both arch and intracardiac anomalies, resulting in promising short-term and long-term results.

### Study Limitations

However, it is important to acknowledge the limitations of our study, including the small sample size, particularly in the EEEA group, which may have affected statistical power. The retrospective and non-randomized design restricts the ability to establish causality and introduces potential bias. Furthermore, follow-up evaluations relied primarily on echocardiographic measurements, which may have underestimated subtle cases of restenosis. Additionally, the use of multiple definitions of HAA in the study might have introduced variability, underscoring the need for standardized diagnostic criteria in future research[18].

## Conclusion

In conclusion, patch aortoplasty via sternotomy is a reliable and effective technique for aortic arch reconstruction, particularly in neonates with complex cardiac anomalies. This approach offers superior outcomes in terms of restenosis, geometric optimization, and mortality while providing the flexibility needed for long-term success. Future prospective studies with standardized protocols and advanced imaging follow-up are essential to validate these findings and further refine the surgical strategies in this high-risk population.

### Ethics

**Ethics Committee Approval:** This study was approved by the local institutional Ethical Committee of University of Health Sciences Türkiye, Bursa Yüksek İhtisas Training and Research Hospital (approval no: 2011-KAEK-25 2019/12-17, date: 23.11.2011). All the procedures were conducted in accordance with the principles of the Declaration of Helsinki.

**Informed Consent:** Retrospective study.

### Footnotes

### Authorship Contributions

Surgical and Medical Practices: Seçici S, Öncü SB, Concept: Seçici S, Design: Seçici S, Data Collection and/or Processing: Seçici S, Öncü SB, Analysis and/or Interpretation: Seçici S, Öncü SB, Literature Search: Seçici S, Writing: Seçici S, Öncü SB.

**Conflict of Interest:** The authors declare no conflicts of interest concerning the authorship or publication of this article.

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