Short- and mid-term outcomes of aortic arch reconstruction: Beating heart versus cardiac arrest

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August 23, 2020

Abstract

Objectives: We aimed to compare the short- and mid-term results of perfusion strategies used for arch reconstruction surgery. Material and Methods: One hundred and seventy-three consecutive patients who underwent aortic arch reconstruction surgery for transverse arcus hypoplasia between January 2011 and February 2020 were retrospectively analyzed. The patients were divided into two groups, as beating heart group and cardiac arrest group. Results: The cardiac arrest group comprised 60 (35%) patients and the remaining 113 (65%) patients were in the beating heart group. The median age of the patients was 30 (IQR 18–95) days. The incidences of acute renal failure and delayed sternal closure were higher in the cardiac arrest group ($P = 0.05$,$P < 0.001$ respectively). Balloon angioplasty was performed in 5 (2%) patients and reoperation was performed in 11 (6%) patients due to restenosis. There were no statistically significant differences between the two groups in terms of reoperation or reintervention rates ($P = 0.44$ and 0.34, respectively). Conclusions: Both strategies were associated with satisfactory mid-term prevention of reintervention and reoperation. Given the lower incidence of acute renal failure and delayed sternal closure in the postoperative period and similar mid-term outcomes, we believe that the beating heart strategy is preferable.

Introduction

Surgical reconstruction of the aortic arch in newborns and infants has traditionally been performed using deep hypothermic circulation arrest (DHCA) (1-3). DHCA has a number of complications, the most important of which is neurological injury (4,5). ACP may be related with lower neurologic complications(6). However, the heart remained ischemic during cardiac arrest. Although DHCA continues to be used today, the use of ACP is preferred (7). Furthermore, using the coronary perfusion (CP) method allows archus surgery to be performed on a beating heart (BH) (8) and better postoperative outcomes have been reported with this method (9,10). BH arch reconstruction also shortens the ischemia time of the heart.

There is no definite consensus regarding perfusion strategies. In this report, we review our experience with beating heart arch surgery (BHAS) in newborns and infants undergoing arch reconstruction. We also compared BHAS to ACP and cardiac arrest (CA) perfusion strategies with regard to short- and mid-term outcomes.

Materials and Methods

Patient population

With the approval of the institution's ethics committee, 173 pediatric cardiac patients who underwent aortic arch reconstruction with cardiopulmonary bypass through median sternotomy between January 2011 and February 2020 were reviewed. We switched from the ACP and CA perfusion strategy, which was used for the initial 60 patients (35%) to the ACP and coronary perfusion strategy after November 2014. The ACP and coronary perfusion strategy was then used in a consecutive series of 113 patients (65%). The patients were divided into two groups according to perfusion strategy: BHAS group underwent the BHAS procedure and CA group underwent the ACP-CA. Cardiac patients diagnosed with hypoplastic left heart syndrome, interrupted aortic arch, and coarctation repair through thoracotomy were excluded from the study. Patients who underwent isolated arch reconstruction, ventricular septal defect (VSD) repair with arch reconstruction, or complex cardiac procedures other than VSD repair with arch reconstruction were included in the study. 49 of these patients had a PDA dependent circulation. Patients with single-ventricle physiology were also included in the study.

Definitions

Cardiopulmonary resuscitation (CPR), need for extracorporeal membrane oxygenator (ECMO), atrioventricular (AV) block requiring permanent pacemaker implantation, diaphragm paralysis, neurological complication (persistent at discharge), acute renal failure (ARF) (requiring temporary or permanent dialysis), and unplanned reoperation were considered major adverse events (MAEs) (11,12). Complications other than MAEs were defined as pulmonary complications, arrhythmia, infection (except for superficial wound infection), wound infections, recurrent nerve paralysis and delayed sternal closure.

Aortic arch Z-scores of -2 or lower indicated hypoplasia of the arch, independent of the size of other aortic parts. Catheter-base balloon angioplasty was defined as a reintervention. Surgical mortality was defined as mortality within the first 30 days postoperatively.

Surgical technique

In our clinic, we perform resection end-to-end anastomosis with left thoracotomy in patients with isolated aortic coarctation and we perform arch reconstruction via median sternotomy to all patients with transverse and proximal arcus hypoplasia.

Since 2014 we have performed arch repair surgeries under moderate hypothermia (28°C) and on BH patients using antegrade cerebral and coronary perfusion. Prior to 2014 we performed arch surgery using antegrade cerebral perfusion under CA. After performing arch reconstruction on a BH, we performed an intracardiac repair under CA. Concomitant surgical procedures were VSD repair, atrioventricular septal defect (AVSD) repair, Glenn shunt, AV valve repair, pulmonary artery banding, arterial switch operation, atrial septectomy, VSD enlargement, aortic valve commissurotomy, pulmonary artery patch plasty, and total anomalous pulmonary venous connection repair.

Cerebral and somatic near-infrared spectroscopy monitoring and right radial artery and femoral artery catheterization were routinely used. When right radial artery catheterization could not be performed, arterial pressure monitoring was performed by left radial artery catheterization.

A median sternotomy was performed and the ascending aorta, aortic arch, and branches of the aortic arch were dissected out. ACP was provided by direct cannulation (8 Fr aortic cannula) of the innominate artery. In cases where the diameter of the innominate artery was small, ACP was achieved by anastomosing the 3.5 mm graft to the innominate artery. In cases where the right carotid and right subclavian artery were branched separately, the left or right carotid artery was used for ACP. Patients were cooled to a rectal temperature of 28°C after being initiated on cardiopulmonary bypass. Left-heart decompression via a left atrial vent was used. For CP, a cardioplegia needle was placed in the aortic root. The Y-connector was added to the antegrade arterial line and blood was delivered to the coronary arteries by the cardioplegia line (3/8 in) with the flow controlled by a single pump head (Figure 1). The arch branches, ascending aorta, and descending aorta were clamped and arch reconstruction was performed on the BH. For cerebral and coronary perfusion, 70–80 mL/kg/min antegrade flow was provided by monitoring near-infrared spectroscopy (> 65–70%) and radial artery pressure (mean pressure was maintained at 40–45 mm Hg). Coronary perfusion was assessed by observing myocardial hue and ventricular distention and by monitoring electrocardiography. Descending aortic cannulation was not applied to any of the patients. Although no myocardial ischemia was observed in any of the patients, we were prepared to apply cardioplegia.

We performed patch plasty procedures in most of our patients, as well as resections of all ductal tissue. An incision was made beginning at the descending aorta, continuing along the inner curvature and ending 1 cm from the ascending aortic clamp. Upon completion of the repair, the incision was augmented using prolene sutures and gluteraldehyde treated autologous pericardium. If autologous pericardium was not suitable, various patch materials such as a bovine-porcine pericardium, core matrix or curved patch (No react porcine pericardial, Biointegral Surgical Inc.) were used (Figure 2).

In the case of aortic coarctation, the coarcted segment was resected and an inner curvature incision was made. A cutback was made in the posterior of the descending aorta. Afterwards, the descending aorta and isthmus were anastomosed end-to-end posteriorly in an interdigitating fashion (12) and the incision in the small curvature was augmented again using patch materials (Figures 1-2). After the aortic reconstruction, coronary perfusion was stopped and cardioplegia applied via the aortic root cannula for intracardiac repair.

A delayed sternal closure decision was taken in cases of permanent hypotension when attempting sternal closure, elevation of left atrial pressure, presence of rhythm disturbances and bleeding that causing hemodynamic instability.

Follow-up

Patients were followed up by routine echocardiography. Computed tomography examinations were performed when necessary. Cardiac catheterization was performed in patients with >20 mmHg echocardiographic gradients (with diastolic extension) and patients with gradient >20 mmHg between upper and lower extremity arterial pressures. During cardiac catheterization, >10 mmHg gradient for single ventricle patients and >20 mmHg gradient for double ventricle patients were considered as indications for reintervention. However, the decision to conduct a reintervention was made by the patient's treating physicians based on the overall clinical picture. Patients with a significant gradient underwent reintervention by catheter balloon angioplasty and surgical intervention was performed if this was not sufficient or not suitable.

Statistical analyses

Statistical analyses were performed using Statistical Package for the Social Sciences (IBM SPSS Statistics for Macintosh, Version 25.0) software. The continuous data were expressed as medians (interquartile range) due to their non-normal distribution, while the categorical variables were expressed as frequencies and percentages. For the group comparisons, the Mann–Whitney Utest and Pearson'sχ^2test were used according to the data characteristics. The curves of freedom from adverse event were obtained using the Kaplan-Meier method and a log-rank test was used to compare the curves of the groups. In all statistical analyses, a P value [?] 0.05 was considered to be statistically significant.

Results

A total of 173 patients underwent arch reconstruction: 32 (18%) had single-ventricular defect and the remaining 141 (82%) had double-ventricular physiology. While 60 (35%) patients were operated on using ACP-CA, the remaining 113 (65%) patients were operated on using BHAS. Thirty-three (19%) patients underwent surgery for isolated transverse aortic arch (TAA) hypoplasia and the procedure was performed in this group without inducing CA. Arch reconstruction and VSD closure were performed in 63 (36%) patients. Seventy-seven (45%) patients underwent surgery for either arch reconstruction as well as non-VSD pathologies (Table 1).

Demographic data

The median age of the patients was 30 days (IQR 18–95 days). The median weight was 3.8 kg (IQR 3.3–5.0 kg). Ninety-nine (56%) of the patients were neonatal, and 56% of the patients were male. There was no statistically significant difference between the groups in terms of weight, age, or gender (P = 0.09, 0.45, and 0.33, respectively). The median proximal TAA Z-score was -3.3 (IQR -4.5—2.8). There was no statistically significant difference between the groups in terms of proximal TAA Z-scores or Aristotle basic, Aristotle comprehensive, mortality score, mortality category, or complexity level scores (P = 0.26, 0.30, 0.11, 0.06, and 0.79, respectively) (Table 1).

Operative data

Patch augmentation was performed in 165 (95%) patients, 20 (%11) of these patients had coarcted segment resection/posterior end-to-end anastomosis and anterior patch augmentation. Only eight (5%) underwent resection/extended end-to-end anastomosis. The median ACP-CP time was 45 minutes (IQR 36–56 min), the median CA time was 46 minutes (IQR 25–73 min), and the median descending aortic clamp time was 45 minutes (IQR 40–57 min). As expected, the ascending aortic clamp time was longer in the CA group (median 35 vs 61 min, $P = < 0.001$), but there was no statistically significant difference between the groups in terms of cardiopulmonary bypass time and descending aortic clamp time (P = 0.32 and 0.75, respectively) (Table 2).

Postoperative data

Morbidity: MAE was observed in 41 (23%) patients. Ten patients (5%) needed unplanned reoperations, four (2%) needed CPR, 16 (9%) needed ECMO, two (1%) experienced neurological complications, eight (5%) required the implantation of a permanent pacemaker, five (2%) experienced ARF, and one (0.6%) experienced diaphragm paralysis. The incidence of ARF was higher in the CA group and the difference between the groups was found to be statistically significant ($P = 0.05$). The incidence of delayed sternal closure was also higher in the CA group ($P < 0.001$). The incidence of wound complications was higher in the BHAS group ($P = 0.03$). There was no statistically significant difference between the groups in terms of total incidence of MAE, mechanical ventilation time, intensive care, or hospital stay time (P = 0.65, 0.99, 0.46, and 0.34, respectively) (Table 3). Recurrent nerve paralysis was observed higher in the BHAS group (3% vs 0 p= 0.14). All of these patients had unilateral paralysis. In none of our patients we observed oral feeding problems at discharge.

Mortality: Mortality was observed in 21 (11%) patients, 13 (62%) of whom had undergone concomitant complex cardiac procedures other than VSD repair. 3 (14%) patients had isolated arch reconstruction , 5 (23%) had arch reconstruction and concomitant VSD closure. Eight (38%) of them were single ventricle patients.

There was no statistically significant difference between the groups in terms of mortality ($P = 0.58$). One (0.7%) patient with single-ventricle physiology died 5 years after the operation.

Mid-term reoperation and reintervention: Follow-up data were available on 145 patients (95%). The follow-up period of the BH group was 2.3 ± 1.7 years. The follow-up period of the BH group was 4.8 +- 1.7 years. Balloon angioplasty was performed in five (2%) patients and reoperation was performed in 11 (6%) patients due to restenosis. There were no statistically significant differences between the groups in terms of reoperation or reintervention rates (P = 0.44 and 0.34, respectively) (Table 4). In terms of reoperation and reintervention rates, we did not observe a statistically significant difference between single ventricle and double ventricle patients (P = 0.59 and 0.41, respectively).

Freedom from reintervention rate for 1 year and 8 years was 98% (Figure 3). Freedom from reoperation rates were 96% for 1 year and 93% for 8 years (Figure 4). There were no statistically significant differences between the groups in terms of freedom from reoperation or reintervention (P = 0.47 and 0.76, respectively) (Figures 3 and 4).

Discussion

The use of DHCA to repair the aortic arch in newborns and infants is decreasing as surgeons' experience and available technology increases (13), and brain, heart, and even lower-body perfusion applications have become more common (9,14). We reviewed 173 newborn and infant patients who underwent BH one-stage aortic arch reconstruction in a single-center serial study of a pediatric patient cohort, which to the best of our knowledge is the largest such study to date. In this report, we evaluated the short- and mid-term results of 113 newborns and infants who underwent BHAS with the aim of eliminating concerns about the applicability and safety of the technique. We also wanted to evaluate whether this technique had a positive effect on short and mid-term results by comparing the results of 60 newborns and infants who underwent arch reconstruction under ACP-CA at different time intervals (2011–2014).

Theoretically, this technique is expected to have a positive effect on surgical results without increasing the difficulty of the procedure (9,14). Because this technique can be used without needing to induce CA in the patient, better postoperative results are expected. Some studies have reported better postoperative results in BHAS patients (15). Lim et al. compared patients undergoing arch reconstruction under BHAS and under ACP-CA and found that the BHAS patients experienced fewer inotrope requirements, fewer delayed sternal closures, less mechanichal ventilation time, and required less time in intensive care (16). They also argued that this technique can minimize myocardial complications and related morbidities, and claimed that it could be used in patients with single-ventricle physiology (16). Turek et al. compared patients underwent Norwood procedure (which renders patients more susceptible to ischemia) in combination with both the ACP-CA and BHAS techniques (9). They observed better postoperative cardiac function in the patients, less need for ECMO, and a lower mortality rate in the BHAS group, which contributed to the popularization of this technique (9). In a more recent study, Gil-Jaurena et al. reported that this technique can be used safely and has positive effects on patient outcomes (17). We showed that this technique reduced myocardial ischemic time and did not increase descending aortic clamp time or CPB time. Although there are no definitive data to show that coronary perfusion significantly improves outcomes, there is a theoretical benefit to operating without inducing cardioplegic arrest. Greater knowledge of this BHAS technique for arch reconstruction repair could save valuable arrest time when concomitant intracardiac procedures are required. Although the preoperative data of the groups were similar, ARF and delayed sternal closure were observed to occur more often in the CA group. There was no difference between the groups in terms of mortality or incidence of MAE. Even though there was no statistically significant difference between the groups, there was higher recurrent nerve paralysis incidence in the BHAS group. This result may be related due to poor visualization.

A modification of this technique is the selective ACP-CP method, wherein coronary and cerebral flows are supplied with two separate pump heads. Luciani et al. compared BHAS with the selective BHAS method and found that cardiac morbidity was higher in the non-selective group, although they found no significant differences between the groups in terms of long-term survival or need for reintervention (18). Luciani et al.'s study was a multicenter, retrospective, and highly heterogeneous and their results were to an extent speculative (19). Although it supports our finding that coronary perfusion is beneficial, we did not find convincing evidence that it should be done selectively. We found that the non-selective CP procedure is easier to prepare, apply, and follow.

Reoperation and reintervention after arch reconstruction due to restenosis surgery is another concern. In the literature, restenosis and reintervention are reported to occur in 4–28% of cases (20-23). Gray et al. reported the freedom from reintervention rate to be 87% at 1, 3, and 5 years (20). There are several factors reported in the literature that are thought to cause restenosis. The effect of the surgical technique, patch material, and perfusion strategies on restenosis has been investigated by various authors (10,23,24). However, there is insufficient data about the effect of the perfusion strategy used on surgical quality and long-term mortality and reintervention. Fuchigami et al. compared the results of arch surgery patients with conventional arch surgery and procedures done using BHAS, and found no difference between the groups in terms of long-term survival and reintervention (10). In our study, the restenosis rate was found to be 9% (11 reoperations, 5 reinterventions). There were no statistically significant differences between the BHAS and CA groups in terms of reoperation or reintervention.

The results of this study indicate that coronary perfusion as a surgical strategy is comperable to the standard technique for protecting the heart while performing aortic arch repair (9, 16-18). Moreover, we found that simultaneous brain and heart perfusion by the same arterial line is an easy, reproducible technique that does not create surgical difficulties. As the duration of cardiac ischemia is shorter during BHAS, in theory it should reduce the likelihood of cardiac morbidity. However, there are also theoretical disadvantages such as performing the operation on a BH complicates the procedure, affects the quality of anastomosis, and leads to increased incidences of reoperation and reintervention in the short term. However, we found that there is no increase in the incidence of reoperation and reintervention in the mid-term. Although it does not fully meet our expectations of low cardiac morbidity, we have been performing BHAS routinely since 2014 because the procedure is not as complicated as thought and due to its theoretical advantages.

Limitations

Although the preoperative data of the groups are similar, the heterogeneity of the patient group, the presence of single-ventricle physiology in the patient population, and the presence of patients with complex pathologies requiring intracardiac repair make it difficult to evaluate survival and early complications. Some changes of the surgical team during the study period, the learning curve and better postoperative care may have an impact on results. In addition, our study has the disadvantages of being single-center and retrospective. We believe that the rate of reoperation and reintervention may be affected due to the relatively short follow-up times and the majority of patients being operated on within the last 3 years.

Conclusion

BHAS reduces myocardial ischemic time, which can be very valuable, especially when long and complex intracardiac procedures are required. Both strategies are associated with satisfactory mid-term reduction of reintervention and reoperation rates. Given the lower incidence of ARF and delayed sternal closure in the postoperative period and similar mid-term outcomes, we believe that the BHAS strategy should be preferred technique for aortic arch repair in neonatal patients.

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Figures and Legends

Figure 1: Innominate artery and asending aotic cannulation. After coarcted segment resection, descending aorta and isthmus were anastomosed end to end posteriorly in an interdigitating fashion.

Figure 2: Patch augmentation

Figure 3: Freedom from reintervention

Figure 4: Freedom from reoperation

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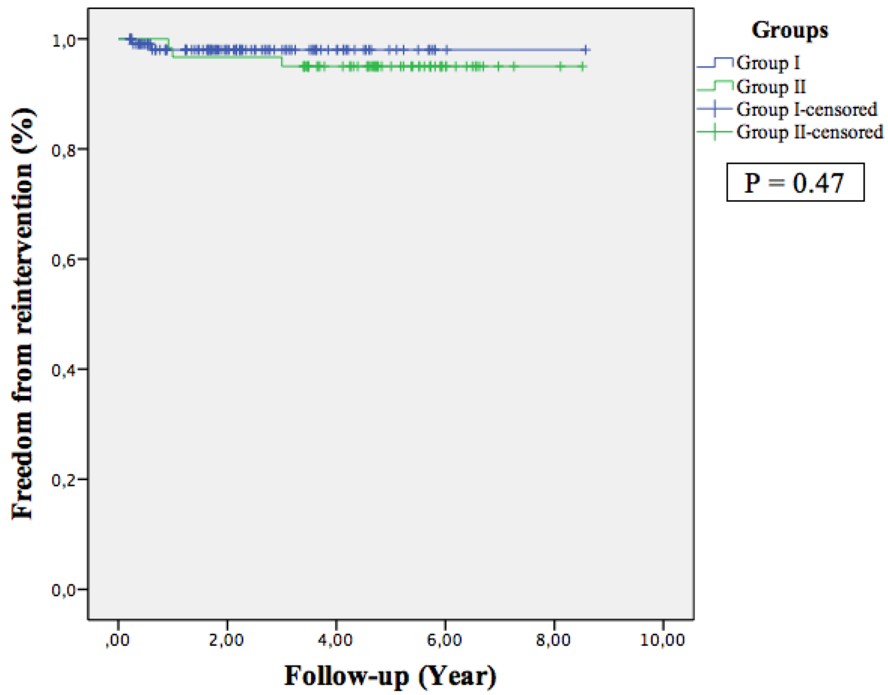

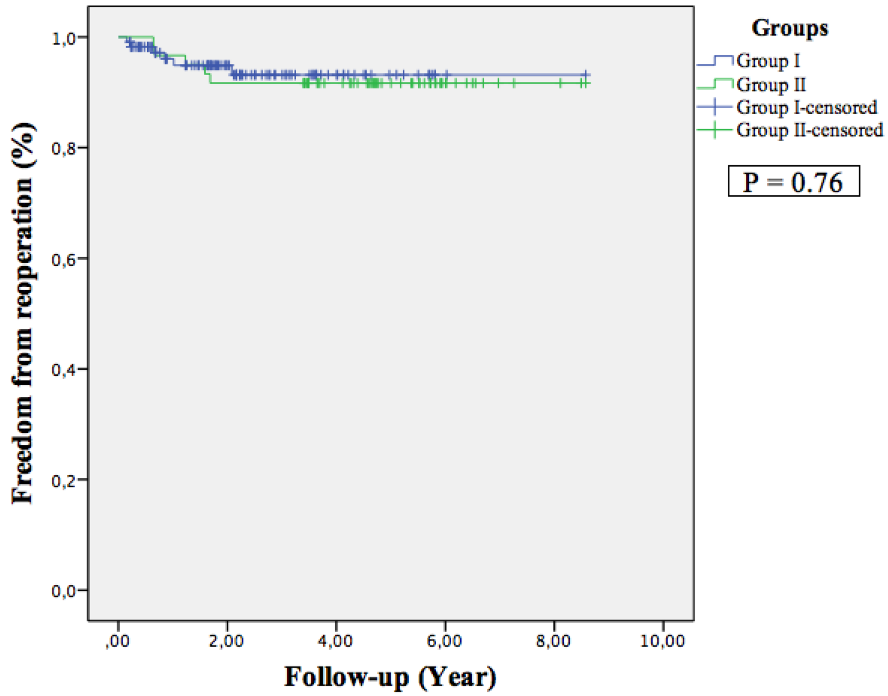
Freedom from reoperation (%)
1,0
0,8
0,6
0,4
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2,00
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10,00
Follow-up (Year)
Groups
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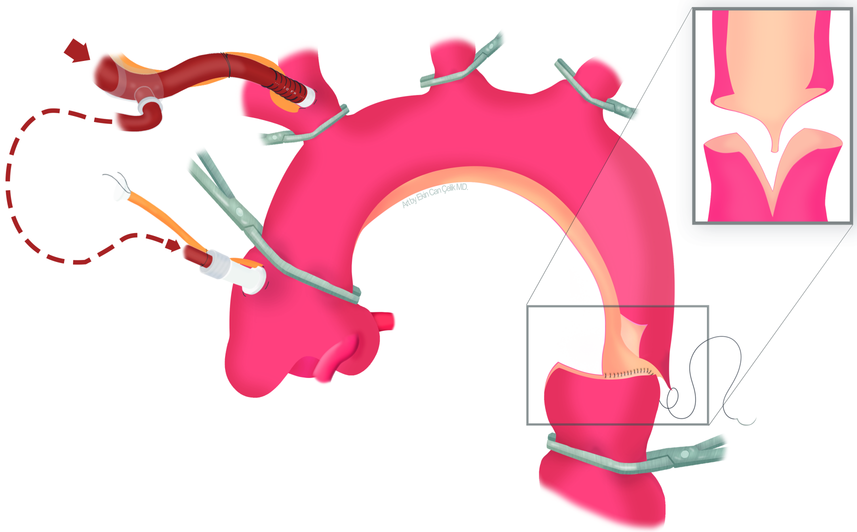
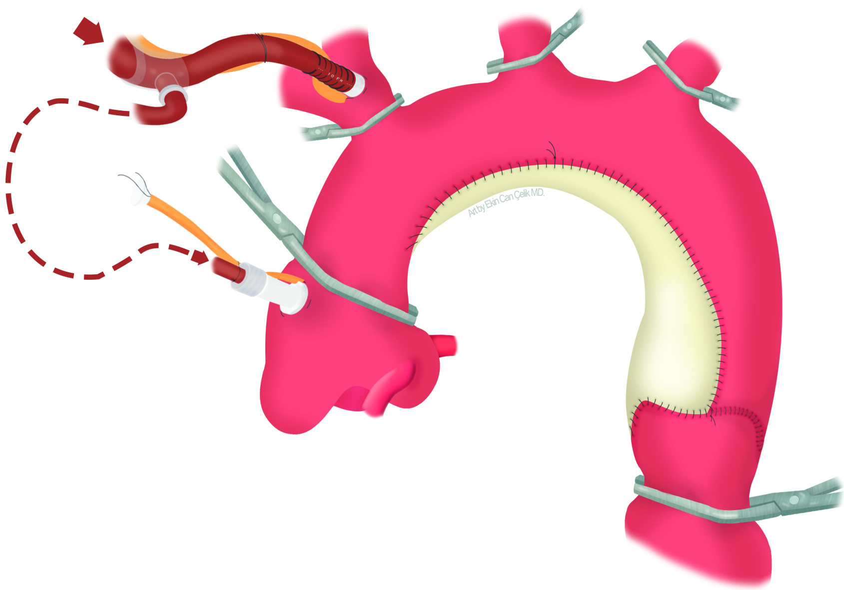
Group II-censored
P = 0.76

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