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Life-saving Cannulation Strategies in High-risk Resternotomy for Pediatric Patients: A Single-center Experience

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Abstract

Aim: Despite advances in surgical experience and imaging techniques, resternotomy (RS) in pediatrics remains a high-risk procedure due to its potential for heart and major vessel injuries. This study aims to retrospectively evaluate RS cases in our clinic, focusing on high-risk patients and examining the effectiveness of various cannulation techniques.

Methods: This retrospective study,included pediatric patients under 18 years of age who underwent RS between August 2019 and December 2023. Exclusion criteria included intervals of less than 30 days between consecutive RS procedures. Patient demographics, diagnoses, and RS-related outcomes were extracted from medical records. High-risk factors for major cardiac and vascular injury during RS were identified, and patients were categorized accordingly. Major injuries and outcomes of the various cannulation techniques were analyzed.

Results: Out of 1,718 sternotomies, 157 (9.1%) were RS procedures, with 33 patients (21%) classified as high-risk. Major cardiac and vascular injuries occurred in 7 patients (4.5%), and RS-related mortality was recorded in 2 cases (1.2%). For high-risk patients, the femoral artery and vein were commonly prepared for emergent or elective cannulation, with alternative strategies employed when femoral vessels were unsuitable for cannulation. Three patients undergoing carotid artery cannulation showed no signs of neurological complications, supporting its viability as an alternative strategy in pediatric high-risk RS.

Conclusion: Resternotomy remains a challenging procedure with substantial risk for major bleeding, especially in high-risk cases. For complex cases, preparation for alternative cannulation methods remains crucial to manage unexpected complications effectively.

Keyword: Pediatrics, resternotomy, cannulation

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Yüksek Riskli Resternotomi Uygulanacak Çocuk Hastalarda Hayat Kurtaran Kanülasyon Stratejileri: Tek Merkezli Deneyim

Öz

Amaç: Cerrahi deneyim ve görüntüleme tekniklerindeki ilerlemelere rağmen, pediatrik hastalarda resternotomi (RS) kalp ve major damar yaralanması riski taşıdığı için yüksek riskli bir prosedür olmaya devam etmektedir. Bu çalışmanın amacı, kliniğimizde yapılan RS vakalarını geriye dönük olarak değerlendirmek, yüksek riskli hastalara odaklanmak ve farklı kanülasyon tekniklerinin etkinliğini incelemektir.

Yöntemler: Çalışmamız retrospektif nitelikte olup, Ağustos 2019 ile Aralık 2023 tarihleri arasında RS uygulanan 18 yaş altındaki pediatrik hastalar dahil edilmiştir. Çalışmaya dahil edilme kriteri olarak, ardışık RS prosedürleri arasındaki sürelerin 30 günden kısa olmaması gerektiği belirlenmiştir. Hasta demografileri, tanıları ve RS ile ilgili sonuçlar, tıbbi kayıtlardan elde edilmiştir. RS sırasında kalp ve major damar yaralanmalar için yüksek risk faktörleri belirlenmiş ve hastalar buna göre kategorize edilmiştir. Farklı kanülasyon tekniklerinin major yaralanmalar ile ilişkili sonuçları analiz edilmiştir.

Bulgular: 1.718 sternotomi vakasından 157'si (%9,1) RS prosedürüydü ve 33 hasta (%21) yüksek riskli olarak sınıflandırıldı. 7 hastada (%4,5) kalp ve major damar yaralanmaları meydana geldi ve RS ile ilişkili ölüm oranı 2 vakada (%1,2) kaydedildi. Yüksek riskli hastalar için femoral arter ve ven, acil veya elektif kanülasyon için sıklıkla hazırlandı ve femoral damarlar kanülasyon için uygun olmadığında alternatif stratejiler kullanıldı. Karotid arter kanülasyonu yapılan 3 hastada nörolojik komplikasyon belirtileri görülmedi, bu da pediatrik yüksek riskli RS vakalarında bu stratejinin alternatif olarak uygulanabilirliğini desteklemektedir.

Sonuç: Resternotomi , özellikle yüksek riskli vakalarda ciddi kanama riski taşıyan zorlu bir prosedür olmaya devam etmektedir. Kompleks vakalarda, beklenmedik komplikasyonları etkili bir şekilde yönetmek için alternatif kanülasyon yöntemlerine yönelik hazırlıklar kritik öneme sahiptir.

Anahtar kelimeler: Pediatri, resternotomi, kanülasyon.

INTRODUCTION

Resternotomy (RS) is a frequently performed surgical procedure by congenital heart surgeons today[1]. Although its frequency in patients with biventricular hearts has decreased over the past two decades, certain palliative procedures are still employed in early childhood for specific pathologies[2,3]. These patients often undergo at least one RS later in life as part of their complete repair treatment. In the single-ventricle pathway, multiple sternotomies are commonly performed on patients[1]. Additionally, in cases where a conduit repair or valve repair procedure was performed in early childhood, somatic growth may lead to conduit insufficiencies, or the need for re-repair or valve replacement may arise. In all such situations requiring re-intervention, RS is the most commonly used surgical approach[4,5].

Although congenital heart surgeons are becoming increasingly familiar with the RS approach, it still presents certain challenges and risks due to its nature. In recent years, with the growing frequency of this approach and the experience gained, significant reductions in procedure-related mortality and morbidity have been reported. These improvements are attributed not only to increased surgical experience but also to the more frequent use of preoperative imaging techniques and advancements in perfusion techniques. Despite these supporting factors, some RS cases remain at risk for intraoperative heart and vascular injuries[4-6].

The aim of this study is to retrospectively examine the RS cases performed in our clinic, share our experiences with high-risk patients for cardiac and vascular injury during RS, and

evaluate the outcomes of the cannulation techniques we employed in these patients.

METHODS

This study was a retrospective observational study approved by the Ankara Bilkent City Hospital Ethics Committee with the decision number 608/2024 on 25.09.2024. The study included all pediatric patients under the age of 18 who underwent surgery with an RS approach in our clinic, between August 2019 and December 2023. Patients with an interval of less than 30 days between the RS and the previous sternotomy were excluded. Perioperative data of the included patients were obtained from the medical information system and written records. Demographic data, diagnoses and the number of RS procedures each patient had undergone were recorded. Surgery notes were reviewed and patients who experienced major cardiac and vascular injuries during RS were documented.

Major injuries were defined as those occurring from the start of RS until cannulation was completed, which could not be controlled by simple suturing and led to hemodynamic instability, requiring fluid replacement therapy, inotropic support, or emergency CPB assistance. All available preoperative imaging studies (CT, MRI, Doppler USG) of the patients were retrospectively reviewed. Factors posing a high risk for major cardiac and vascular injury during RS were identified and patients were categorized into two groups based on the presence of these factors. The risk factors were as follows: 1) multiple previous RS operations, 2) presence of an RV-PA conduit, 3) presence of true or pseudoaneurysms originating from mediastinal major vessels, 4) significantly dilated right atrium and ventricle and 5) history of mediastinal infection or radiotherapy. The characteristics and outcomes of patients who experienced major bleeding among the two groups were analyzed. The outcomes of different cannulation strategies used in high-risk RS patients were also examined.

Surgical procedure

All patients undergoing RS were monitored with cerebral NIRS regardless of age, and both femoral regions were sterilized and draped for emergency vascular access. In some cases, based on the primary surgeon's preference, a right inguinal incision was made to quickly initiate femorofemoral bypass if needed, and the femoral artery and vein were exposed before starting RS. For patients with small, stenotic, occluded femoral arteries, or hypoplastic vessels insufficient for full flow, a neck incision was made to access the right carotid artery and internal jugular vein (IJV) for cannulation.

The RS procedure began with the removal of sternal wires, and the sternum was lifted using towel clamps placed on each side of the midline. Initially, a free retrosternal plane was created in the subxiphoid region, followed by the release of thoracic connections on each side. The anterior and medullary layers of the sternum were then gradually cut from inferior to superior with an oscillating saw. Medullary bleeding was controlled as much as possible using bone wax and electrocautery. Next, the posterior layer of the sternum was cut with sternal scissors, and dissection continued slowly and carefully along the retrosternal plane, freeing the sternum towards the superior direction. Throughout each stage, thoracic connections on both sides were released as much as possible, and medullary bleeding was managed. The pleural spaces were opened as early as possible. Once the sternum was fully opened, both thoracic walls were gently elevated one at a time using towel clamps.

Mediastinal adhesions in the retrosternal and retrothoracic regions were carefully dissected until a safe plane was identified, with sharp dissections freeing the endothoracic fascia

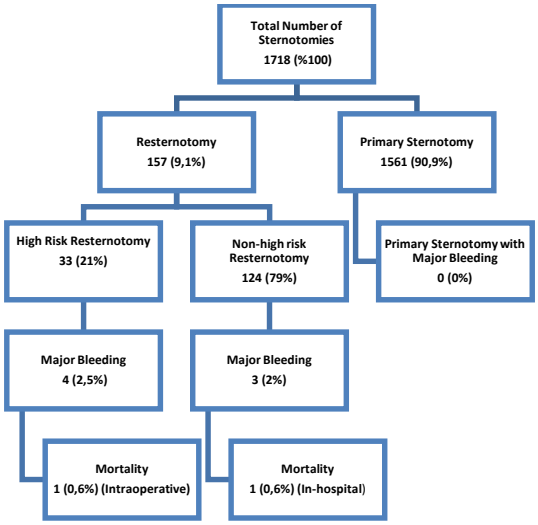
along the sternum and thorax. During the release of thoracic adhesions, special care was taken to avoid damaging the internal mammary artery (IMA) and phrenic nerve, especially in the superior portions. While opening the sternal retractor, tension on the left innominate vein was palpated and managed by releasing adhesions around the vessel as needed.

In cases where preoperative imaging revealed a conduit, major vessel, or cardiac structure situated directly behind the sternum and pressing against it, CPB was initiated via femoral or carotid artery access, and the patient was mildly cooled with cardiac chambers drained. After the sternum was safely opened, dissection continued off CPB based on the primary surgeon's preference. If the graft was damaged and could not be repaired primarily, a Foley catheter was inserted into the defect, inflated, and withdrawn to control bleeding. If this maneuver successfully managed the bleeding, the surgeon could either continue the dissection or complete it with CPB support if deemed necessary.

RESULTS

Between the dates of this study, a total of 1,718 surgeries were performed via sternotomy in our clinic, of which 157 (9.1%) were RS procedures. Among the RS cases, 135 (86%) were first RS procedures, and 22 (14%) were second RS procedures. Thirty-three (21%) patients were identified as being in the high-risk RS category. Major cardiac and vascular injuries were observed intraoperatively in seven (4.5%) patients, with one patient (0.6%) in the high-risk RS group experiencing intraoperative mortality. The overall surgical mortality related to RS complications was 1.2% (two patients) across all RS cases (Table I).

Table I: Distribution of Patients Who Underwent Resternotomy



The characteristics of patients with major bleeding related to RS are presented in Table II. All patients underwent preoperative CT angiography to clarify mediastinal anatomy. Based on imaging results and surgical history, four patients (57%) were categorized as high-risk and three patients (43%) as normal-risk for RS. Femoral artery and vein dissection for urgent cannulation was performed in all patients before sternotomy. Two patients had a primary diagnosis of truncus arteriosus, and one of them (Patient 3) experienced severe hemodynamic instability due to extensive graft damage during resternotomy, resulting in intraoperative death. In two patients (Patients 2 and 5), although no major vessel or cardiac injury occurred during RS, bleeding occurred during mediastinal dissection, and central cannulation was used as a rescue strategy. In the remaining five patients, femorofemoral bypass was used as a rescue strategy for bleeding control.

Table II: Characteristics of Patients with Major Bleeding during Resternotomy

	PatientNumber						
	1	2	3	4	5	6	7
PrimaryPathology	TGA(operated), PS,AR	VSD,PA(shunted)	TruncusArteriosus (operated)	SinusValsalvaAneurysm (operated)	DORV,PS (shunted)	Aorticcommissurotomy +supracoronarygraftinterposition (operated)	TruncusArteriosus (operated)
Age(y)	12	1	2	11	13	15	18
Weight (kg)	40	5,6	8,5	25	30	45	80
High Risk Resternotomy	No	No	Yes	Yes	No	Yes	Yes
Resternotomy Number	1	1	1	1	1	1	2
PreoperativeImaging	CT	CT	CT	CT	CT	CT	CT
PlannedCannulation	Aorto-atrial (two stage)	Aortobicaval bypass	Aortobicaval bypass	Femorofemoral bypass	Aortobicaval bypass	Aorto-atrial (two-stage)	Aortobicaval bypass
MajorBleedingSource	Mainpulmonaryartery	Detachment of proximalanastomosis of BT shunt	RV-PA conduit	AorticPseudoaneurysm Sac	Rightpulmonaryartery	Supracoronaryaortic graft	RV-PA conduit
RescueCannulation	Femorofemoral bypass	Aortobicaval	Femorofemoral bypass	Femorofemoral bypass	Aortobicaval bypass	Femorofemoral bypass	Femorofemoral bypass
Intraoperativemortality	No	No	Yes	No	No	No	No
Postoperativemorbidity	Prolonged ICU stay	No	n/a	Prolonged ICU stay	ECMO in ICU	Prolonged ICU stay	Prolonged ICU stay
Postoperativemortality	No	No	n/a	No	Yes	No	No

TGA; Transposition of great arteries, PS; Pulmonary stenosis , AR; Aortic regurgitation, DORV; Double outlet right ventricle, VSD; ventricular septal defect , PA; Pulmonary atresia , RV-PA; Right ventricle-Pulmonary artery , ECMO; Extracorporeal membrane oxygenation, BT; Blalock –Taussig , CT; Computed tomography , ICU; intensive care unit

In one case (Patient 4), due to a large aortic pseudoaneurysm located posterior to the sternum (Figure 1), CPB support was initiated before starting sternotomy, and the procedure was performed under deep hypothermic circulatory arrest (DHCA). In other cases, CPB support was initiated after the onset of major bleeding.

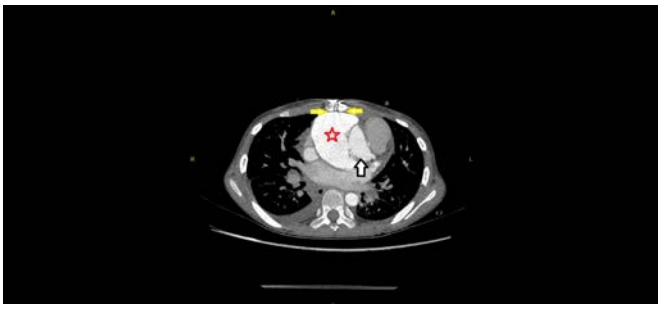


Figure 1. The patient with a giant pseudoaneurysm originating from the aortic root. Yellow arrows indicate the close proximity of the aortic sac wall to the sternum. The red star marks the pseudoaneurysm sac. The white arrow points to the aortic root.

For three high-risk RS patients, right carotid artery and IJV cannulation were used to manage the risk of major bleeding during RS (Table III). In these patients, previous catheterization procedures rendered the femoral artery and vein unsuitable for cannulation. The carotid and IJV were directly cannulated without the use of grafts, and CPB was initiated during RS, allowing full flow in all three cases. Access to the mediastinum was achieved without major bleeding. However, in two patients with pseudoaneurysms originating from the aortic arch, DHCA was required due to an inability to reach a healthy aortic segment for cross-clamping (Figures 2 and 3). In the remaining patient with a ruptured sinus of Valsalva, a suitable site on the ascending aorta allowed cross-clamping, and the procedure was completed under mild hypothermia. The rest of each surgery proceeded without complications. After decannulation, both neck vessels were primarily repaired.

Table III: Characteristics of high-risk patients who underwent carotid artery and IJV cannulation

	Patient No		
	1	2	3
Age(y)	2	1	1
Weight(kg)	10	8	6,5
High- Risk Resternotomy	Yes	Yes	Yes
Resternotomynumber	2	1	1
PrimaryPathology	TOF (operated)	HLHS (operated)	VSD Closure , PulmonaryDebanding
ReoperationIndication	SinusValsalvaRupture	AorticArcusPseudoaneurysm	AscendingAorticPseudoaneurysm
ImagingModality	CT,CardiacCatheterisation	CT	CT
MajorBleeding	No	No	No
IntraoperativeMortality	No	No	No
PostoperativeMorbidity	No	No	No
PerioperativeMortality	No	No	No

HLHS; Hypoplastic left heart syndrome , TOF ; tetralogy of Fallot , VSD;Ventricular septal defectCT;Computed tomography , IJV; Internal Jugular Vein

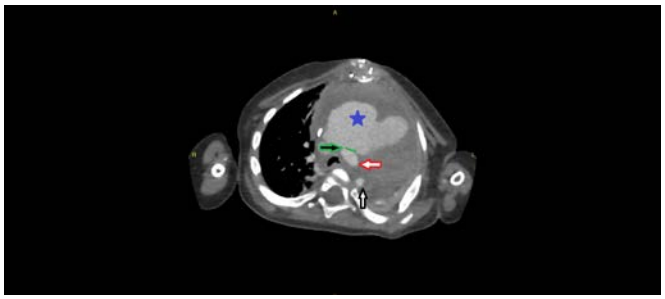


Figure 2. CT imaging of thepatient with an aortic pseudoaneurysm. The green line and arrow delineate the neck of the pseudoaneurysm. The blue star highlights the lumen of the pseudoaneurysm sac. The red arrow indicates the ascending aorta, while the black arrow denotes the descending aorta.

Figure 3. CT imaging of thepatient with an aortic pseudoaneurysm. The red arrows highlight the large pseudoaneurysm sac originating from the aortic arch and its close proximity to the sternum. The yellow line delineates the wide neck of the pseudoaneurysm. AA: Ascending Aorta.

DISCUSSION

In recent decades, RS has been performed more frequently in congenital heart disease cases. The necessity for reoperations often arises due to various factors, such as completing the palliative stages of single-ventricle repairs, the requirement for valve re-repair or replacement and the outgrowth of aortic or pulmonary artery conduits as patients grow. However, with the increase in surgical experience and advancements in cannulation strategies, the incidence of major intraoperative complications has significantly decreased. Morales et al. reported major cardiac and vascular injury in only two (0.3%) of 602 RS procedures performed in 558 patients, with a need for femoral cannulation in fewer than four cases (0.6%)[5]. Kirshbom et al. reported major cardiac and vascular injury in only thirteen (1.3%) out of 1,000 RS procedures in 802 congenital heart disease patients[4]. In adult congenital heart patients, Holst et al. observed cardiac and major vascular injuries in fifty-five (6%) of 984 patients. In our study, major bleeding occurred in seven (4.5%) of 157 RS cases, a relatively high rate compared to these large series in the recent literature[6].

Although some studies report a very low risk of cardiac and vascular injury in RS, many centers still advocate for caution due to the procedure's inherent challenges[5,7]. There are few controlled studies in the literature specifically examining factors that increase the risk of major bleeding in RS. However, certain high-risk scenarios are widely acknowledged. Among the most recognized risk factors are the increased number of RS procedures and the presence of a right ventricle-to-pulmonary artery (RV-PA) conduit closely associated with the sternum[4,6,8]. Both factors have been reported to elevate the

risk of major injury during RS[4,5]. Particularly when the conduit is positioned directly behind the sternum without any intervening space, the risk of injury during RS significantly increases. In our sample, two out of the seven cases with major bleeding involved RV-PA conduit damage. Despite preoperative imaging to determine the precise conduit position and meticulous dissection during surgery, major bleeding still occurred in these cases.Although various surgical techniques have been described in the literature for managing conduits closely adhered to the sternum, severe adhesions and high right ventricular pressure on the graft wall often lead to unintended graft damage. For these high-risk cases, it is essential to be prepared for the rapid initiation of rescue perfusion techniques when necessary.

Similarly, aneurysmal enlargement of the ascending aorta or pulmonary artery can result in close adherence to the sternum, increasing the risks associated with RS. For instance, in conotruncal anomalies or aortopathies related to connective tissue diseases, the ascending aorta may become significantly aneurysmal. In repaired transposition of the great arteries (TGA) cases, severe enlargement of the main pulmonary artery proximal to a stenotic segment can lead to a close posterior relationship with the sternum. Additionally, aortic root aneurysms may develop as a long-term complication of the Ross procedure, further complicating RS[9]. Other high-risk scenarios include pseudoaneurysms originating from the aorta itself or from suture lines on its branches, both of which further increase the risk of bleeding during RS. In our study, three patients developed aortic pseudoaneurysms, with major bleeding occurring in one case (Figure 1), as well as in a patient who developed a main pulmonary artery aneurysm following a TGA repair. In both cases, the affected structures were closely adhered to the sternum. CPB support was promptly initiated upon bleeding, allowing the surgeries to proceed without additional complications.

Moreover, certain cardiac conditions can make RS particularly challenging. For instance, in cases of Ebstein's anomaly, atrial switch procedures, or high-grade tricuspid insufficiency due to endovascular pacemaker leads, severe right atrial and ventricular dilation may result in injuries that are difficult to repair during RS[10]. Additionally, patients with a history of mediastinitis or prior mediastinal radiotherapy present further challenges, as severe tissue adhesions can make separation during RS extremely difficult. These factors collectively render RS a high-risk procedure. The literature suggests that preoperative imaging and meticulous surgical planning can help mitigate the risk of major bleeding in such complex cases.

Assessing the severity of retrosternal adhesions from previous cardiac surgeries, as well as the proximity of major vessels, grafts, and cardiac chambers to the sternum, is crucial for surgical planning. Many centers worldwide routinely utilize contrast-enhanced CT and MRI before redo cardiac surgeries. Although both modalities are effective for evaluating retrosternal proximity, CT is generally preferred due to its superior image quality and faster acquisition time.In our clinic, while contrast-enhanced CT is not performed for every RS case, it is frequently used for preoperative assessment, particularly in patients with prior grafts, artificial vessels, or augmented vessels with prosthetic patches. This approach enables a comprehensive evaluation of both retrosternal anatomy and the current position of cardiac structures.

Preoperative imaging of the carotid artery, internal jugular vein (IJV), and femoral vessels in patients undergoing resternotomy plays a crucial role in optimizing surgical planning and minimizing intraoperative complications. Given the potential for vascular anomalies,

thrombosis, or stenosis—particularly in patients with a history of catheterization, previous surgeries, or prolonged central venous access—systematic vascular assessment is recommended. Duplex ultrasonography (USG) is a widely used, non-invasive, and radiation-free modality that allows real-time evaluation of vessel patency, diameter, and flow dynamics. Computed tomography angiography (CTA) provides detailed anatomical visualization, particularly in cases where high-risk factors, such as mediastinal fibrosis or prior vessel manipulation, are present. Magnetic resonance angiography (MRA) may also be employed, especially for pediatric patients, to avoid radiation exposure while offering high-resolution imaging of vascular structures. Preoperative vascular imaging facilitates the selection of the most suitable cannulation strategy, thereby reducing the risk of failed access attempts and intraoperative hemodynamic instability. Given these benefits, incorporating routine or selective vascular imaging into preoperative assessment protocols could enhance the safety and efficacy of resternotomy procedures[4-9].

Various adjunct perfusion strategies may be employed in high-risk RS cases, depending on the surgeon's preference. In pediatric patients weighing over 15 kg, it is well established that full-flow perfusion can be readily achieved through femoral artery and vein cannulation when necessary[11]. During early adulthood, femoral and axillary artery cannulation can be performed using a graft with the chimney technique. In cases of extreme aortic dilation, where the aorta exerts posterior pressure on the sternum, the literature recommends axillary artery cannulation combined with suprasternal innominate artery control to mitigate neurological complications in the event of aortic injury during RS. This approach facilitates safe antegrade cerebral perfusion, ensuring neurological stability until the sternotomy is completed and aortic repair can be performed. The limitations of this technique include the anatomical suitability of the axillary artery for graft cannulation and the accessibility of the innominate artery for suprasternal control[12].

When femoral vessels are stenotic or occluded due to previous catheterizations, the inferior vena cava (IVC), abdominal aorta, or right main iliac artery can be cannulated via a right supra-iliac incision using a retroperitoneal approach.In a case series examining five high-risk RS cases with an average age of 4.6 ± 1.7 years, appropriately sized cannulas were successfully placed to achieve full-flow perfusion. No complications were observed during cannulation or in the postoperative follow-up after decannulation[13]. Additionally, Additigon et al. reported that in small children, where the femoral artery diameter is insufficient for standard arterial cannulas (8Fr), CPB support can be initiated using 10 to 14-gauge peripheral catheters in the femoral artery during complex RS procedures or in cases of cardiac injury. This approach helps maintain hemodynamic stability until the sternotomy is completed and standard cannulation can be performed[14].

Alternative cannulation methods are increasingly being utilized for high-risk RS in pediatric patients. Unlike in adults, where femoral and axillary artery cannulation is commonly feasible, patients with congenital heart disease often develop significant femoral artery stenosis due to repeated catheterizations. Additionally, prior cut-down procedures can further complicate secure femoral artery cannulation.In small children, cannulation-related irreversible damage to the femoral arteries may result in catastrophic complications, including limb loss. Consequently, carotid artery cannulation, either directly or via a graft, has gained popularity for high-risk RS in recent years[15]. The expanding use of veno-arterial (VA) ECMO in children

through a neck incision has further enhanced surgical expertise in cannulating vessels in this region.

Numerous studies have examined the risks associated with carotid artery cannulation in pediatric patients, particularly in relation to intracranial infarction and neurological sequelae, with mixed findings. Some studies suggest that distal ligation of the carotid artery during direct cannulation may lead to ipsilateral ischemia and neurological complications, especially in young children. However, other studies have reported no significant differences in neurological outcomes between cases involving arterial repair and those involving ligation. Some authors argue that sacrificing the carotid artery has no major clinical consequences in children due to the absence of atherosclerosis in cerebral vessels and the adequate collateral circulation provided by the circle of Willis. High-risk RS patients may undergo carotid artery cannulation either directly or via artificial grafts[16,17]. However, there is insufficient data comparing early and long-term outcomes between these two approaches.

In our clinic, we have employed this technique in three patients considered at high risk for bleeding during RS (Table III). Using the direct cannulation technique, we cannulated the right carotid artery without ligating the distal portion, securing it with purse-string sutures. Following decannulation, the carotid artery was repaired using interrupted sutures. Intraoperative NIRS monitoring and postoperative neurological evaluations showed no signs of ischemia or infarction in these patients.Studies have reported that long-term VA ECMO treatments may lead to complications such as pseudoaneurysms, dissections, thromboembolisms, and carotid stenosis following carotid artery repairs. To mitigate these risks, carotid artery ligation is often recommended. However, in our clinic, we prefer arterial repair when the vessel walls are suitable for anastomosis and reconstruction.

In our study, unexpected bleeding occurred after the sternum was opened in two patients not initially deemed high-risk RS cases, specifically during BT shunt placement and right pulmonary artery retraction. In another patient, who sustained damage to the main pulmonary artery, bleeding resulted from an inadvertent posterior lamina incision made by an oscillating saw, constituting a technical error (Table II). While large-scale studies have suggested that RS in congenital heart disease patients is generally low-risk for major bleeding complications, some studies recommend preoperative risk stratification and corresponding precautionary measures, particularly for less-experienced surgeons in low-volume centers[16]. In our clinic, we also perform risk stratification for RS patients and adjust our surgical techniques accordingly Retraction devices that provide direct visual control during dissection are available on the market, though they are not yet widely used[18]. Additionally, various RS saws and osteotomes have been developed, with some studies reporting their safe use in re-entry procedures. However, controlled trials demonstrating the superiority of these instruments in preventing major bleeding are still lacking.

Adhesion severity within the mediastinum can significantly affect the risk of major bleeding during RS. Studies have shown that longer intervals between sternotomies may serve as a protective factor against injury, likely due to reduced vascularity and inflammation in the healing tissue during early postoperative periods[6]. Many authors suggest that more extensive adhesions are more likely to form within the first year following an initial RS, making tissue boundaries less distinct. To minimize adhesion formation during the initial surgery, measures such as minimizing serosal injury to the heart and ensuring postoperative

drainage of all blood in the pericardial space are recommended. Additionally, closing the native pericardium, when possible, or using synthetic materials like Dacron or PTFE to separate the sternum from the heart is advised[8].

There is also a growing trend to use pericardial sucts after the initial surgery in cases with planned staged procedures. Certain studies have demonstrated that polyethylene glycol-based products, when applied uniformly across cardiac structures before sternal closure, expand in the retrosternal area, creating an avascular, film-like adhesion that is easier to dissect[19]. When used appropriately, these products have been reported to reduce the risk of cardiac laceration during RS without causing complications such as pericardial tamponade or mediastinal infection. However, their high cost limits accessibility in some institutions.

Despite advancements in surgical experience and technology, minimizing the invasiveness of treatment whenever possible remains essential in reducing morbidity and mortality. Although RS is often unavoidable, alternative surgical approaches can sometimes be used in specific congenital heart defects to avoid RS. For instance, in patients with tetralogy of Fallot (TOF) who require pulmonary valve replacement (PVR) but cannot undergo valve-sparing surgery, left anterolateral thoracotomy has been proposed as an alternative to RS. Tatewaki et al. successfully performed PVR via left anterolateral thoracotomy in two patients following TOF repair[20]. Similarly, right anterolateral mini-thoracotomy approaches may enable valve surgery for aortic, mitral, or tricuspid valve issues without requiring RS.

CONCLUSION

With increasing surgical experience and advancing technology, the risk of major bleeding in resternotomy procedures today is lower compared to the past.However, it remains essential to be prepared for alternative perfusion strategies and surgical intervention techniques in all resternotomy patients in case of unexpected bleeding.

Ethics Committee Approval: This study was a retrospective observational study approved by the Ankara Bilkent City Hospital Ethics Committee with the decision number 608/2024 on 25.09.2024.

Conflict of Interest: The authors declared noconflicts of interest.

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