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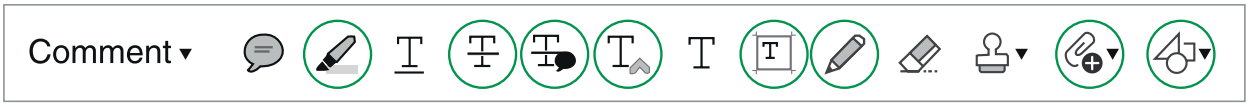


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# Borrowing from Adult Cardiac Surgeons—Bringing Congenital Heart Surgery Up to Speed in the Minimally Invasive Era

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## Abstract

The majority of congenital and adult cardiac surgery is performed through a median sternotomy. For surgeons, this incision provides excellent exposure; however, for patients, a median sternotomy confers a poorer cosmetic outcome and the possibility of postoperative respiratory dysfunction, chronic pain, and deep sternal wound infections. Despite the advances in adult cardiac surgery, the use of minimally invasive techniques in pediatric patients is largely limited to small case series and less complex repairs. In this article, we review the risks, benefits, and limitations of the minimally invasive congenital cardiac approaches being performed today. The interest in these approaches continues to grow as more data supporting reduced morbidity, decreased length of stay, and faster recovery are published. In the future, as the technology and surgical familiarity improve, these alternative approaches will become more common, and may someday become the standard of care.

## Keywords

minimally invasive cardiac surgery, pediatrics, congenital heart defects

### Central Message

Despite the advances in adult cardiac surgery, the use of minimally invasive techniques in pediatric patients is largely limited to small case series and less complex repairs. Herein we review the risks, benefits, and limitations of the minimally invasive congenital cardiac approaches being performed today. Interest in these approaches will continue to grow as more data supporting reduced morbidity, mortality, and length of stay are published.

## Introduction

[AQ2][AQ3]The majority of congenital and adult cardiac surgery is performed through a median sternotomy. For surgeons, this incision provides excellent exposure; however, for patients, a median sternotomy confers a poorer cosmetic outcome and the possibility of postoperative respiratory dysfunction, chronic pain, and deep sternal wound infections.[1,2] In an effort to address these complications, a variety of minimally invasive techniques were developed in adult cardiac surgery over the past 20 years. Despite these advances in adult patients, the use of minimally invasive techniques in pediatric patients continues to be limited to small case series and less complex cardiac defects.

Two of the main limitations in the advancement of minimally invasive congenital cardiac surgery have been patient size and technology. Minimally invasive cardiac surgery has a steep learning curve given the limitations on surgeons' working field and visual landmarks.[3] Needless to say, those hurdles become much larger with a neonate or small infant. Furthermore,

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pediatric patients present anatomic constraints with regard to the use of specific minimally invasive techniques, particularly those that are endovascular. Manufacturers are limited in their ability to simply miniaturize existing products to accommodate pediatric patients. For larger kids, endovascular options do exist, although surgeons are still faced with a growing patient, the need for dynamic repairs, and preserving vascular access for future reinterventions.

Herein we review the risk, benefits, and limitations of these minimally invasive congenital cardiac procedures in order to improve familiarity, accelerate adoption, and advance the standard of care.

## Minimally Invasive Approaches for Extracardiac Congenital Defects

### *Patent Ductus Arteriosus (PDA) Ligation*

Over the past 2 decades, video-assisted thoracoscopic surgical (VATS) ligation of PDA has become increasingly common. A 2017 study by Stankowski et al.[4] investigated the safety and efficacy of thoracoscopic closure of PDA. In total, 173 children were included in the study, which compared PDA closure using muscle-sparing posterolateral thoracotomy versus VATS. Patients who underwent VATS ligation experienced fewer postoperative complications, lower-volume chest drainage, and had more cosmetic outcomes than those patients undergoing conventional thoracotomy. Additional studies by Shelton et al.[5] and others continue to support that PDA ligation via VATS is not only safe and effective relative to thoracotomy, but also leads to faster recovery.

More recently, endovascular or percutaneous PDA repair has also been shown to be safe and efficacious for select patients. Knirsch and colleagues showed in their multicenter trial that percutaneous PDA closure in infants between 4 and 8 kg is both safe and effective. Of the 25 patients in their study, 17 received duct occluders and 8 received coils based on their anatomical constraints. No complications were reported and all patients demonstrated resolution of symptoms.[6] Furthermore, compared to surgical ligation, percutaneous treatment of PDA in infants weighing greater than 5 kg is associated with less intensive care unit time and faster recovery.[7]

Percutaneous PDA closure in low-weight neonates (those less than 4 kg) has been shown to be successful (46 out of 52 patients, or 88%), although the risks of arterial injury and thrombosis (20%) begin to outweigh the benefits of percutaneous closure for patients in this low-weight category.[8]

### *Vascular Ring Division*

Historically, a thoracotomy was the preferred approach for the treatment of vascular rings given its wide exposure, safety, and familiarity among surgeons. However, as VATS procedures have become more familiar, thoracoscopic has been proposed as the new standard of care for vascular ring division in adults.[9] The literature for VATS vascular ring division in neonates and children remains limited.

To investigate postoperative complications, operation duration, and total length of hospital stay following the use of the minimally invasive VATS technique in children for the division of vascular rings, Herrin et al. conducted a retrospective study of patients who underwent vascular ring division through conventional thoracotomy or minimally invasive VATS at their institution.[10] A total of 115 children (median age 2.7 years) underwent vascular ring division via VATS, while 85 patients underwent the conventional thoracotomy. VATS repairs were associated with significantly shorter operations and length of stay and improved cosmetic outcomes, as well as comparable incidence of major complications, including chylothorax and vocal cord paralysis, when compared to traditional thoracotomy. Herrin as well as others thereafter have demonstrated that VATS is a feasible and reproducible approach for the treatment of congenital vascular anomalies in select infants.[11]

The VATS approach for vascular ring division and other vascular anomalies is limited by its reduced working field. Due to such constraints, surgeons may be forced to convert to thoracotomy when atretic vessels are found to be patent, there is an inadequate exposure secondary to adhesions or anatomy, or bleeding is encountered. Most recently, this conversion rate was documented to be 9% to 12%.[12] Additionally, institutions vary in their decision to resect Kommerell diverticulum, if encountered, further influencing conversion rates and which patients are considered for a VATS approach.

### *Systemic–Pulmonary Shunts*

Tetralogy of Fallot (ToF), pulmonary atresia, and transposition of the great vessels require immediate surgical intervention in newborns due to the presence of a profound cyanosis particularly if the PDA begins to close. In the late 1940s, the first systemic–pulmonary shunt was completed through a thoracotomy. Although due to high shunt failure rates, surgeons transitioned to performing the now modified Blalock–Thomas–Taussig shunt (mBTTS) through median sternotomies.[13–15]

Although superior to the initial right thoracotomy, this approach is not without its postoperative complications and midline scar. Edwin et al.[16] described a minimally invasive technique for constructing mBTTS in neonates and children using a strictly posterior thoracotomy (SPOT) approach. In the left lateral decubitus position, the technique utilizes a 6 to 8 cm posterior incision between the scapular spine and posterior axillary line. Performed on 23 patients for palliation in a resource-poor country, this technique generated good outcomes with only 1 mortality and no shunt failures. Hospital length of stay was 7 to 10 days and only 3 patients required outpatient management for delayed wound healing with excellent cosmetic outcomes overall. Alternative approaches for mBTTS including right anterior mini-incisions seem technically feasible, although have not been described in the literature.

## Minimally Invasive Approach for Intracardiac Congenital Defects

### *Septal Defect Repair*

Intracardiac shunts such as atrial septal defects (ASDs) and ventricular septal defects (VSDs) are the most common congenital heart defects that affect newborns. Despite widespread adoption of the median sternotomy and its favorable surgical outcomes in both children and adults, patients continue to be concerned about the associated complications and cosmesis. In an effort to ease these concerns, numerous minimally invasive approaches have been introduced for isolated septal defects.

Right anterior minithoracotomy is a minimally invasive approach that has been introduced as an alternative to median sternotomy for isolated septal defects.[17,18] In contrast to median sternotomy, this approach is performed through a 5 to 6 cm incision at the second or third intercostal space starting from the sternal border. In 1 study, 75 pediatric patients (average age 9 years) successfully underwent intracardiac repairs, primarily septal defect repairs, through a right anterior minithoracotomy without conversion to median sternotomy. In the series, bicaval venous cannulation was achieved with 12F to 18F cannula placed in superior vena cava through right internal jugular vein by anesthesia team and 12F to 21F cannula placed in inferior vena cava via the right femoral vein by the surgeon. Femoral arterial cannulation was utilized. As expected, this approach resulted in longer cardiopulmonary bypass and aortic cross-clamp times compared to conventional surgical incisions. Despite the longer pump runs, patients had short hospital stays (mean 4 days), favorable cosmesis, and minimal pain. Two patients did require reoperation, but revisions were able to be performed through minimally invasive approach, and there were no residual shunts on predischarge echocardiography.[19]

Inferior ministernotomy has also been well described as an option for repair of congenital heart defects, primarily VSD, as it provides excellent exposure of the right atrium and ventricle. The first series on this approach by Nicholson et al. in 2001 presented 104 patients who underwent VSD, ToF, atrioventricular canal, or mitral valve operations by division of the xiphoid and elevation of sternum only. This approach was impressively associated with comparable bypass and cross-clamp times, and shorter length of stay than traditional sternotomy.[20] Although traditionally described for ventricular defects, in another small case series of 5 patients, a 5-cm inferior ministernotomy allowed perventricular VSD as well as ASD closure with occluding devices under transesophageal echocardiographic guidance. More specifically, the ASDs in these cases were skillfully closed by placing a guidewire past the tricuspid valve, ASD, and into the left atrium before deploying the occluder. No complications including arrhythmias were reported at most recent follow-up.[21]

Axillary approaches provide a third minimally invasive solution for isolated ASDs. This incisions, which are commonly utilized in general thoracic surgery, not only confer superior cosmetic results with a small incision and hidden scar, but also produce less chest deformities and breast maldevelopment, particularly in young female patients.[22–24] With the patient in left lateral decubitus, the repair is completed through a 4-cm incision between the anterior and posterior axillary lines. Central aortic and bicaval cannulation is performed and aortic cross-clamp or electrical fibrillation utilized. When compared to another alternative minimally invasive approach, the ministernotomy, axillary technique yielded longer cardiopulmonary bypass and cross-clamp/fibrillation times, but otherwise no differences in major complications or hospital length of stay.[24]

When it comes to repairing isolated or combined septal defects, the right anterolateral minithoracotomy, right axillary incision, and inferior partial ministernotomy all have their advantages and disadvantages. The most noticeable disadvantage is the longer operative time secondary to a decreased operative field, prolonged bypass time, cross-clamp time, and lower target body temperatures requiring additional time to rewarm. Albeit, the longer operative time does not correlate with adverse events or prolonged hospitalization when compared to traditional median sternotomy for these patients in this setting.

### *Valvular Insufficiency*

Pulmonary insufficiency and the need for pulmonary valve replacement are expected in patients with ToF following primary repair. These patients have previously had one or more median sternotomies when they present with pulmonary insufficiency, and, given the natural deterioration of bioprosthetic valves, will require additional procedures in the future. Redo median sternotomies in this population are not without risks; therefore, minimally invasive and endovascular approaches have been developed.[25]

Percutaneous approaches exist, although this is not always feasible given the possibility of coronary compression or asymmetrical right ventricular outflow tract dilation following primary ToF repair.[26] Size is also an issue for these pediatric patients. To date, the smallest pediatric patient to be intervened on using a percutaneous valve was just over 2 kg although a majority of the literature reports reliable outcomes in patients >20 kg.[26–29] Following placement, patients continue to be at risk for stent fracture (up to 15% at 1 year) and infective endocarditis (1% to 5% per year based on the length of follow-up and valve manufacturer).[26,28,30,31]

Alternatively, Nellis et al. have described the use of a 5-cm left anterior mini-incision for pulmonary valve exposure during a fibroelastoma resection.[32] The approach provides direct visualization of the right ventricular outflow tract and main pulmonary artery, while allowing the surgeon to seamlessly convert to a median sternotomy if necessary. In unpublished data, the same group has successfully performed pulmonary valve replacement following primary ToF repair in 7 patients. Postoperative results suggest improved pain control, excellent cosmetic outcomes, and a similar length of stay relative to traditional median sternotomies.

### *Sew-on Epicardial Leads*

For patients who are in need of a permanent pacemaker yet do not qualify for transvenous lead placement, epicardial lead placement via a small sub-xiphoid incision can be employed. Screw-on epicardial lead placement through a small sub-xiphoid incision is limited to ventricular lead placement, whereas atrial lead placement often requires conversion to a median sternotomy for direct visualization.[33–35]

A recent case report by Nellis et al. describes the use of VATS for placement of a sew-on right atrial epicardial lead in a 9-year-old.[36] The team was able to place the lead using a titanium fastening device. Preliminary results at discharge and at 6-week follow-up appointment proved satisfactory with low impedance.

## Conclusions

Advances in the field of minimally invasive cardiac surgery continue to evolve and expand in the pediatric population. Growing evidence has been presented on the safety, efficacy, and reproducibility for the use of minimally invasive techniques in the repair of a wide range of intracardiac and extracardiac congenital defects. The interest in minimally invasive congenital cardiac surgery continues to grow as more data supporting comparable morbidity and mortality, decreased length of stay, and faster recovery are published. In the future, as technology and surgical familiarity improve, these alternative approaches will become more common, and, quite possibly, become the standard of care.

### Declaration of Conflicting Interests

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