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Expert Consensus on Right Axillary Incision Approach for Open-Heart Surgery in Congenital Heart Disease

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Received: 21 December 2025; Accepted: 28 February 2026; Published: 31 March 2026

ABSTRACT: Congenital heart disease (CHD) is a common birth defect in children, and surgical intervention is the primary treatment. The traditional standard median sternotomy (MS) has drawbacks such as significant trauma and obvious scarring. The right axillary incision (RAI) has gradually become a conventional approach due to its advantages of preserving thoracic cage integrity, small incision size, rapid recovery, and hidden scarring. However, there is currently a lack of relevant guidelines and consensus for its application. This consensus adopts the international Delphi process, systematically searching domestic and foreign literature on CHD from 1982 to 2024. It uses the GRADE system for evidence grading and, through multidisciplinary expert discussions, clarifies the applicable CHD types, surgical techniques, establishment of extracorporeal circulation, organ protection strategies, management of special disease types, and approaches to common complications of RAI. Results show that RAI is strongly recommended for most simple congenital heart diseases (CHDs) (e.g., simple ventricular septal defect, atrial septal defect), weakly recommended for some complex CHDs (e.g., mild tetralogy of Fallot), and not recommended for complex CHDs such as transposition of the great arteries or in children with severe right thoracic deformity. Additionally, it standardizes key operational parameters: weight (5–30 kg as optimal), age (6 months–6 years as preferred), incision location, extracorporeal circulation cannulation, and organ protection measures. This consensus provides an evidence-based basis for standardizing the clinical application of RAI in open-heart surgery for CHD, ensuring surgical safety and efficacy.

KEYWORDS: Congenital heart disease; right axillary incision; open-heart surgery; expert consensus; extracorporeal circulation; perioperative management; GRADE system

1 Introduction

Since the inception of cardiac surgery, median sternotomy (MS) has long been the standard approach for cardiac operations due to its advantages of clear surgical field exposure and direct operability [1–3]. However, this procedure requires longitudinal sternal splitting, leading to numerous significant drawbacks [4]: splitting the sternum disrupts the continuity of the sternum and the supporting structure of the thoracic cage, resulting in extensive trauma and the need for foreign materials such as bone wax and steel wires. This not only increases intraoperative blood loss but also predisposes to pleural effusion [5,6]. Additionally, it carries a risk of infection; studies by Lin et al. indicated that steel wires, surgical sutures, and excessive biological products are the main causes of infection in children [7,8], with higher infection risks in females, patients undergoing reoperation, and those receiving blood products [4]. Moreover, infection is associated with significantly increased mortality and medical costs [9]. More importantly, postoperative pain is severe, which can also affect respiratory function [10,11]. Furthermore, the prominent midline chest scar not only severely impacts aesthetics but also causes long-term psychological distress [12] and even psychological disorders in patients [11,13,14]. In young children, the surgery is also associated with risks of thoracic deformities such as “pigeon chest” [15–21] and scoliosis [22].

For simple congenital heart diseases (CHD) requiring open-heart surgical repair, the multiple shortcomings of MS have driven innovations in surgical approaches. The right axillary incision (RAI) has emerged as a promising alternative with significant advantages: it avoids sternal splitting [23], maximally preserves thoracic cage integrity, and features a small, hidden incision [15]. Not only does it cause less trauma and reduce intraoperative blood loss, but it also achieves better control of pleural effusion [5,6]. Additionally, it reduces the use of foreign materials such as steel wires, thereby lowering the infection risk. Studies by Liu and Wang et al. have also confirmed that RAI can effectively alleviate postoperative pain and protect respiratory function [10,11]. Meanwhile, the scar is hidden in the axilla [24], offering excellent cosmetic results [10,25,26], which is particularly favored by female patients and their families. For children, this approach can shorten the operation time, reduce postoperative inflammatory responses, and promote rapid recovery [2,27]. Currently, RAI has gradually become a reasonable choice for surgical treatment of CHD [15,23,27–34]. However, there is still a lack of guidelines or expert consensus regarding the use of RAI as a routine approach for cardiac surgery, and clinical practice urgently requires standardized recommendations to guide diagnosis and treatment.

Based on this, experts from the Cardiothoracic Surgery Group of the Pediatric Surgery Branch of the Chinese Medical Doctor Association, the Cardiac Surgery Group of the Pediatric Surgery Branch of the Chinese Medical Association, and the Asian Association for Pediatric and Congenital Heart Surgery jointly organized the development of this consensus statement.

This consensus has been registered with the International Practice Guidelines Registry and Transparency Platform (<http://www.guidelines-registry.cn/>), registration number: PREPARE-2025CN1436.

2 Methods

2.1 Literature Retrieval

Literature searches confirmed that no guidelines or expert consensus on RAI as a routine cardiac surgical approach have been published domestically or internationally. There is an urgent clinical need for expert consensus to standardize its application.

This consensus adopts the international Delphi process and systematically retrieves literature on surgical treatment of CHD from 1982 to 2024 in databases including CNKI, Wanfang, VIP, Chinese Biomedical

Literature Database, PubMed, Embase, and the Cochrane Central Database of Evidence-Based Medicine, incorporating high-level evidence.

Chinese search terms and English search terms: “Congenital heart disease”, “right axillary incision”, “lateral incision”, “minimally invasive surgery”, “extracorporeal circulation”, “surgical approach”, “perioperative treatment”, “complications”, “prognosis”.

2.2 Consensus Development and Evidence Grading

This consensus uses the Grade of Recommendations Assessment, Development and Evaluation (GRADE) system (Table 1) to grade the evidence-based medical evidence supporting various diagnostic and therapeutic methods, including the strength of recommendations and quality of evidence.

Table 1: GRADE system for evidence quality and recommendation strength.

Levels	Definition
Level of evidence	
High quality (A)	There is a high degree of confidence that the estimated effect value is close to the true effect value and that further research is unlikely to change the credibility of the estimated effect value
Medium quality (B)	Medium confidence in the estimated effect value, the estimate is likely to be close to the true value, but there is still a possibility that they are not the same and that further research could change the confidence in the estimated effect value
Low quality (C)	There is a limited degree of confidence in the estimated effect value: the estimated value may be quite different from the true value. Further research is very likely to change the confidence in the estimated effect value
Extremely low quality (D)	There is little confidence in the estimated effect value, and the estimate is likely to be quite different from the true value. Any estimate of the effect value is highly uncertain
Strength of recommendation	
Highly recommendation (grade 1)	Clearly show that the benefits of the intervention outweigh the harms or the harms outweigh the benefits
Weak recommendation (grade 2)	Uncertainty about the benefits and disadvantages or evidence of both high and low quality shows comparable advantages and disadvantages

3 CHD Types Suitable for RAI

RAI minimally invasive surgery is applicable to most simple CHDs, including isolated ventricular septal defect (VSD), atrial septal defect (ASD), partial atrioventricular septal defect, pulmonary valve stenosis (PS), right ventricular outflow tract obstruction (RVOTO), and cor triatriatum. Multiple studies have shown that the safety and efficacy of RAI during the perioperative period are not inferior to those of median sternotomy, with additional advantages in cosmetic outcomes and recovery speed [12,35–39]. RAI may also be considered for certain moderately complex CHDs, such as mild tetralogy of Fallot, partial anomalous pulmonary venous return, and unroofed coronary sinus syndrome. Even when these lesions are combined with patent ductus arteriosus (PDA) or persistent left superior vena cava, they are not surgical contraindications [32–34,40].

Currently, RAI is not recommended for most complex anomalies (e.g., transposition of the great arteries, interrupted aortic arch) or patients with significant right thoracic deformities; for patients with suspected/confirmed pulmonary infection, significant pulmonary congestion/edema, borderline pulmonary hypertension on cardiac catheterization, congenital right lung malformations, or a history of right lung

disease (e.g., pneumothorax, lung abscess), the use of RAI should be more cautious; for reoperative cases, the incision should be selected cautiously.

Recommendation 1:

- (1) RAI minimally invasive surgery is recommended as the optional approach for most simple CHDs, including isolated VSD, ASD, partial atrioventricular septal defect, PS, RVOTO, and cor triatriatum (Evidence level: B; Recommendation strength: I).
- (2) In experienced centers, RAI may be attempted for selected moderately complex CHDs, including mild tetralogy of Fallot, partial anomalous pulmonary venous drainage, and unroofed coronary sinus syndrome (Evidence level: B; Recommendation strength: II).
- (3) RAI is not recommended for most complex anomalies (e.g., transposition of the great arteries, interrupted aortic arch) or patients with significant right thoracic deformities; for patients with suspected/confirmed pulmonary infection, significant pulmonary congestion/edema, borderline pulmonary hypertension on cardiac catheterization, congenital right lung malformations, or a history of right lung disease (e.g., pneumothorax, lung abscess), the use of RAI should be more cautious; for reoperative cases, the incision should be selected cautiously (Evidence level: C; Recommendation strength: II).

4 RAI Minimally Invasive Surgical Technique

4.1 Body Weight Requirements

With continuous refinement of surgical techniques and improvements in perioperative monitoring, the suitable weight range for RAI procedures has gradually expanded. However, for centers in the early stages of adopting this approach, it is recommended to begin with children weighing 5–30 kg [12,41–43].

In patients with very low body weight (<5 kg), the narrow thoracic cavity and the relative obstruction caused by cannulation and surgical instruments may limit the operative field, thereby increasing the technical difficulty and operative risk [44,45]. Nonetheless, clinical studies have indicated that even in infants of low age and low body weight, RAI does not significantly increase procedure-related complications [1,46,47].

For children weighing >30 kg, the heart is positioned deeper along the right thoracic pathway, resulting in a more technically demanding exposure. In such cases, specialized instruments or thoracoscopic assistance may be required to complete the procedure [48].

Recommendation 2:

- (1) Children weighing 5–30 kg are preferred candidates for RAI surgery, as this range generally provides optimal operative exposure (Evidence level: B; Recommendation strength: I).
- (2) For children <5 kg, RAI may be performed only by experienced teams after thorough preoperative assessment of pulmonary development and cardiopulmonary bypass risks (Evidence level: B; Recommendation strength: II).
- (3) For children >30 kg, RAI should be used cautiously due to the depth of the operative field and challenges in exposure. Surgeons should possess advanced technical proficiency and consider using specialized instruments (Evidence level: C; Recommendation strength: II).

4.2 Age Requirements

The age range suitable for RAI is also expanding. For centers newly implementing this technique, the optimal candidates are children aged 6 months to 6 years, in whom thoracic shape, intercostal spacing, and operative exposure are most favorable.

Similar to concerns associated with low body weight, infants <6 months have smaller thoracic cavities and incisions, making intubation and exposure more challenging. However, in well-selected cases and in experienced centers, RAI can still achieve safety and clinical outcomes comparable to those of median sternotomy [49].

In older children, especially those >12 years, the heart lies deeper within the thorax, and limitations in exposure, suturing angles, and instrument maneuverability require careful evaluation of RAI suitability [12]. If exposure proves inadequate, alternative surgical approaches should be considered.

Recommendation 3:

- (1) Centers initiating RAI programs should prioritize children aged 6 months to 6 years, as this age group offers optimal thoracic and intercostal conditions for exposure (Evidence level: C; Recommendation strength: I).
- (2) Age <6 months is not an absolute contraindication; procedures may be performed by highly experienced teams under strict selection criteria (Evidence level: C; Recommendation strength: II).
- (3) For children >12 years, careful evaluation of RAI suitability is required. If exposure is insufficient, alternative approaches should be chosen (Evidence level: C; Recommendation strength: II).

4.3 Selection of Incision Location

The patient is placed in the left lateral decubitus position. A vertical or slightly curved small incision is made in the fourth intercostal space along the right midaxillary line. After incising the skin and subcutaneous tissues, the fascia of the serratus anterior muscle is opened. The muscle fibers should be preserved as much as possible while bluntly dissecting anteriorly and posteriorly to expose the intercostal space. The choice of intercostal space may be adjusted up or down by one level depending on the specific cardiac lesion.

Key considerations include: (1) An overly anterior incision may injure breast tissue and risks dislocation of the costochondral junction during retraction. (2) An excessively posterior incision results in a deeper operative field and inferior exposure due to cardiac displacement. (3) Overly extensive dissection between the chest wall muscles and ribs should be avoided to prevent adverse effects on muscle and breast development. (4) During serratus anterior dissection, care must be taken to protect the long thoracic nerve and associated vasculature to prevent winged scapula deformity [12,50,51].

Recommendation 4:

The standard RAI incision is made through the fourth intercostal space along the right midaxillary line, with adjustments to the third or fifth intercostal space as needed to optimize exposure. During thoracic entry and retraction, the long thoracic nerve and serratus anterior fibers should be protected, and anterior extension toward breast tissue should be avoided (Evidence level: C; Recommendation strength: I).

5 Establishment of Extracorporeal Circulation

The strategy for establishing cardiopulmonary bypass (CPB) in RAI procedures differs from that used in conventional open-chest surgery. Because the operative field through the axillary incision is relatively limited, the arrangement of cannulas and cross-clamping instruments, ensuring adequate venous drainage and arterial perfusion without obstructing the field of view, represents one of the key determinants of procedural success.

5.1 Cannulation Strategy

Two principal cannulation pathways may be used to establish CPB in RAI procedures: central cannulation and peripheral cannulation.

In infants and young children, the small caliber of peripheral vessels and the potential risks associated with retrograde perfusion make peripheral cannulation less suitable. Therefore, central cannulation through the operative incision remains the preferred approach in most cases. Selecting the appropriate cannulation strategy is crucial for ensuring both satisfactory exposure and reliable CPB support [46].

5.1.1 Central Cannulation

Direct central cannulation through the axillary incision via cannulation of the ascending aorta, superior vena cava, or right atrium, and inferior vena cava, is the mainstream method of establishing CPB for RAI procedures [52–54].

In pediatric patients, direct central cannulation is relatively straightforward and avoids the complications of peripheral retrograde perfusion, such as aortic dissection, cerebral embolism, and limb ischemia.

For superior vena cava cannulation, either an angled cannula or a straight cannula may be selected depending on the anatomy. A straight cannula offers the advantage of being inserted directly via the right atrial appendage into the superior vena cava, thereby reducing risks of post-repair local injury, thrombosis, or stenosis [55].

To minimize obstruction of the operative field by tubing from the primary incision, the inferior vena cava cannula may also be inserted through a separate small stab incision (typically in the sixth or seventh intercostal space), which can later serve as the thoracic drainage port [35,56].

5.1.2 Peripheral Cannulation

For patients weighing >35 kg or those with a femoral artery diameter >5 mm, the greater distance between the major vessels and the chest wall makes femoral arterial and venous cannulation feasible.

The primary advantage of peripheral cannulation is significantly improved exposure within the operative field.

If peripheral cannulation is planned, careful preoperative imaging is essential to assess vascular suitability, and the surgical team should prepare a contingency plan for conversion to central cannulation if required.

5.1.3 Other Cannulation Methods

In addition to purely central or purely peripheral cannulation, some studies have reported “hybrid cannulation” strategies. These typically involve central cannulation of the aorta and superior vena cava combined with percutaneous femoral venous cannulation, balancing the goals of safe perfusion and adequate exposure. However, this approach remains limited by the caliber of the patient’s femoral vein [10].

5.2 Aortic Cross-Clamping

In RAI procedures, the ascending aorta is typically cross-clamped either directly through the primary incision or via a small parasternal incision at the second or third intercostal space. The choice of cross-clamp depends on the patient’s body size and the depth of the operative field.

In older children, the Chitwood transthoracic aortic cross-clamp is often convenient. A fine-gauge cardioplegia needle should be used for cardioplegia infusion, and the needle may be temporarily removed after infusion to reduce obstruction in the operative field. It can then be repositioned during left-heart venting before releasing the aortic cross-clamp.

5.3 Vacuum-Assisted Venous Drainage (VAVD)

In RAI surgery, the position and size of venous cannulas are inherently limited; therefore, gravity drainage alone is often insufficient. In most cases, VAVD significantly improves venous return and allows the use of shorter and smaller tubing [57,58]. Evidence indicates that, when used correctly and safely, VAVD provides more benefits than risks in pediatric congenital heart surgeries requiring CPB [50,59].

Recommendation 5:

- (1) Perfusionists and surgeons should reach an agreement preoperatively regarding the size and type of venous and arterial cannulas (Evidence level: C; Recommendation strength: I).
- (2) Direct central cannulation through the axillary incision, cannulating the aorta and both venae cavae, is recommended as the first-line strategy for establishing CPB during RAI procedures, ensuring adequate and reliable bypass support (Evidence level: B; Recommendation strength: I).
- (3) When smaller venous cannulas cause inadequate gravitational drainage, VAVD may be used to augment venous return (Evidence level: C; Recommendation strength: II).

6 Organ Protection

6.1 Myocardial Protection

Myocardial protection is one of the most critical components of cardiac surgery, as its effectiveness directly influences surgical outcomes and postoperative prognosis. The myocardial protection strategies used in minimally invasive cardiac procedures via RAI are the same as those used in MS. These include antegrade delivery of cardioplegia, induction of myocardial arrest, and hypothermic myocardial protection. To date, no evidence suggests that myocardial protection protocols require modification specifically for RAI procedures.

6.2 Cerebral Protection

Cerebral injury is among the most serious complications following CPB. The placement of the aortic cannula is crucial in RAI procedures; improper depth or direction of cannulation may result in inadequate or excessive cerebral perfusion. If cerebral injury or suspicion of such injury occurs, cerebral protection protocols should be initiated immediately. The strategies used for cerebral protection during RAI are identical to those used in MS. Insufflation of carbon dioxide into the operative field can reduce the incidence of intracardiac air embolism by approximately 85%, and has become routine practice in many cardiac centers. A recent study indicated that, during RAI procedures, carbon dioxide insufflation at a flow rate of 5 L/min may help reduce the risk of cardiac and neurological injury in children undergoing congenital heart surgery [60]. Additionally, when VAVD is used to enhance venous return, the principle of minimal effective negative pressure should be followed, and bubble monitoring should be performed concurrently to reduce the risk of micro-gaseous emboli [61].

6.3 Pulmonary Protection

Because the RAI approach involves retraction and compression of the lung tissue, it can lead to mechanical lung injury, resulting in postoperative hypoxemia, blood-tinged sputum, pneumothorax, atelectasis, and delayed pulmonary recovery [39,62].

Pulmonary protection strategies during surgery include: (1) During thoracic entry, the anesthesiologist should temporarily stop ventilation and open the endotracheal tube to allow lung collapse, reducing the risk of instrument-related injury. Protective ventilation strategies should be maintained throughout the

procedure. (2) Operative manipulation must be gentle to avoid excessive traction and minimize mechanical injury to the lung. (3) During CPB, ensure unobstructed pulmonary venous drainage to prevent pulmonary congestion and edema. (4) Before releasing the aortic cross-clamp, perform adequate suctioning to clear secretions and ensure bronchial patency. (5) Avoid direct contact between suction instruments and lung tissue to prevent contusion. (6) Before closing the ribs, perform lung recruitment maneuvers to re-expand collapsed lung segments and reduce postoperative atelectasis [35].

Recommendation 6:

- (1) Myocardial and cerebral protection strategies during RAI should follow the same protocols used for MS (Evidence level: C; Recommendation strength: I).
- (2) Pulmonary protection strategies: (1) Open the endotracheal tube to collapse the lungs when entering the chest, avoiding instrument injury; (2) Ensure gentle manipulation to avoid excessive lung traction/compression; (3) Prioritize left heart drainage for unobstructed flow; (4) Fully suction sputum before opening the ascending aorta to ensure unobstructed bronchi; (5) Avoid direct lung contact with suction devices to prevent contusion; (6) Perform lung recruitment before chest closure to re-expand collapsed tissue (Evidence level: C; Recommendation strength: I).

7 Considerations for Special Diseases

7.1 Intracardiac Malformations Combined with PDA

The treatment of PDA through RAI surgery is relatively challenging, but feasible [63,64], especially in cardiac centers with large surgical volumes. During the surgery, it is necessary to clarify the anatomical position of the left pulmonary artery and aortic arch to avoid accidental ligation; When dissecting PDA, attention must be paid to protecting the recurrent laryngeal nerve. If dissection is difficult, it is recommended to establish extracorporeal circulation (CPB) with partial support to complete the separation, ligation, or suturing of PDA. For PDA that is still particularly difficult to expose during surgery, the PDA problem can be solved by opening the main pulmonary artery, extending the incision to within 3–4 mm from the starting point of PDA, reducing flow, and suturing the PDA opening after starting extracorporeal circulation.

7.2 Subarterial VSD

Subcapillary or intracapillary ventricular septal defect is located deep in the outflow tract. Traditionally, repair is performed through the main pulmonary artery or right atrium tricuspid valve pathway. In recent years, some centers have started using RAI to repair subarterial ventricular septal defect through tricuspid valve approach, achieving good results [65]. However, for young infants, the narrow surgical space can pose challenges for exposure and manipulation. Therefore, using a tricuspid valve approach to repair subarterial ventricular septal defect requires a high level of technical expertise. If the field of view through the tricuspid valve is poor, repair can be performed through an incision in the main pulmonary artery [23,39,66,67].

Recommendation 7:

- (1) For RAI surgery with PDA, if dissection is difficult, separation and ligation/suturing should be performed after establishing extracorporeal circulation with partial circulatory support. It is only recommended to use RAI for PDA surgical treatment in cardiac centers with high surgical volume (Evidence Level: B; Recommendation Strength: II).
- (2) For subarterial ventricular septal defect, it is recommended to use a tricuspid valve approach for repair during RAI. If the exposure is insufficient, the main pulmonary artery approach is an acceptable alternative (Evidence Level: B; Recommended Strength: I).

7.3 Reoperation via RAI

For children who have previously undergone cardiac surgery, the decision to use RAI for reoperation requires careful risk–benefit assessment. Compared with resternotomy, RAI reoperations avoid dense retrosternal adhesions and typically encounter only mild pericardial adhesions. However, the previous operation disrupts the pericardium and mediastinal pleura, potentially causing extensive adhesions between the lung, heart, and chest wall. Therefore, re-entering the thoracic cavity via RAI may require precise adhesiolysis.

When performing reoperations via RAI, the following key points must be noted to ensure safety and optimal recovery:

1. **Imaging evaluation:** Use cardiac CT/MRI or three-dimensional reconstruction to clarify changes in cardiac anatomy, adhesion extent, and the location of abnormal vessels or scar tissue.
2. **Individualized surgical planning:** Combine the initial surgical record to identify lesions requiring repair (e.g., residual shunt, valve issues) and plan the reoperation approach. Prepare alternative extracorporeal circulation plans (e.g., femoral arteriovenous cannulation) to address potential cannulation difficulties due to thoracic adhesions.
3. **Intraoperative considerations:** (1) **Incision/approach selection:** Prioritize the original incision (may require expansion or adjustment to avoid dense scarring); switch to MS if necessary. (2) **Avoid injury to vital structures:** RAI is adjacent to the phrenic nerve, which must be identified and protected throughout dissection. Avoid violent traction to prevent lung injury. Be alert to vessel displacement due to adhesions (e.g., innominate vein, superior vena cava).

Recommendation 8:

For patients who previously underwent RAI for CHD, reoperations may be performed either through the original axillary incision or via an MS. Compared with traditional resternotomy, patients who previously had RAI typically have less pericardial and retrosternal adhesion, although lung-to-heart and lung-to-chest wall adhesions may be significant. When re-entering through the original incision, careful dissection is required to avoid injury to vital structures (Evidence level: B; Recommendation strength: II).

7.4 RAI and ECMO Support

For patients undergoing RAI who require ECMO support: (1) **Cannulation can still be performed via the original axillary approach.** If left heart drainage is needed, the cannula may be inserted via the right upper pulmonary vein. Ensure the drainage tube is of sufficient length within the thoracic cavity and is securely fixed to the chest wall to avoid lung compression. (2) **With secure cannulation fixation:** The patient may be placed in a supine or slightly left lateral decubitus position to avoid skin pressure ulcers. Other management measures are identical to those for MS.

Recommendation 9:

When ECMO support is required in patients treated with RAI, cannulation can still be performed through the original axillary pathway. However, careful attention must be given to securing the drainage cannula and adjusting patient positioning (Evidence level: C; Recommendation strength: I).

8 Common Complications of RAI and Management Principles

8.1 Residual VSD Shunt

Residual shunts after VSD repair are among the most common postoperative complications. They most frequently occur at the anterosuperior and posteroinferior margins of the defect. Residual shunts

at the anterosuperior margin involve high-pressure areas and are prone to tearing, making spontaneous closure unlikely.

Clinically, residual shunts <3 mm without symptoms may be followed conservatively. Shunts <2 mm often close spontaneously. Shunts 2–3 mm require periodic evaluation of hemodynamic significance. Shunts >3 mm typically require intervention [68–70]. If intraoperative echocardiography reveals a residual shunt \geq 3 mm, immediate re-repair should be considered. If postoperative echocardiography identifies a residual shunt \geq 3 mm, treatment options include: Transthoracic echo-guided closure, catheter-based transcatheter closure, or reoperation with CPB through the original incision, each providing good clinical results [69,71–73].

8.2 Arrhythmias

Arrhythmias are common after open-heart surgery. Because the RAI incision is small, placement of internal defibrillation paddles may be challenging; therefore, preoperative placement of external defibrillation pads is essential.

For temporary pacing: A pacing lead can be sutured onto the right ventricular outflow tract, brought out through the fourth intercostal space, and connected to an external pacing device. The lead must remain sufficiently long to avoid tension or dislodgement during postoperative lung expansion or pericardial suspension.

Common arrhythmia types and management include: (1) Focal atrial tachycardia. (2) Intra-atrial reentrant tachycardia/Atrial fibrillation: Acute episodes may be terminated via cardioversion or medications. Unstable hemodynamics require immediate electrical cardioversion. (3) Complete atrioventricular block: If it occurs during surgery, it is usually recommended to perform another surgery immediately to rule out conduction block caused by suture or patch traction. If postoperative atrioventricular block persists for 7–10 days, permanent pacemaker implantation should be considered [74]. (4) Bundle branch block: Right bundle branch block typically requires no special treatment. Surgery-related left bundle branch block may partially recover. If left ventricular ejection fraction (LVEF) remains <35% after three months of optimized medical therapy, cardiac resynchronization therapy (CRT) should be considered.

8.3 Atelectasis

Mechanisms of atelectasis after RAI include: Factors similar to those in the MS (anesthesia effects and CPB) [75,76]. Surgical positioning, excessive intraoperative lung compression, postoperative edema, exudation, and fibrous scar formation.

Intraoperative and Postoperative Recommended Strategies include: (1) After releasing the aortic cross-clamp, perform intermittent lung recruitment to prevent postoperative atelectasis. (2) Because RAI requires posterior and lateral displacement of the right lung, care must be taken to minimize friction and mechanical injury to lung tissues from instruments. (3) In the ICU, timely suctioning and appropriate use of positive end-expiratory pressure (PEEP) are essential. (4) Routine and timely bronchoscopy with lavage helps prevent and treat atelectasis. Recent reports also suggest that single-lung ventilation during RAI may reduce the incidence of atelectasis, though further multicenter studies are necessary to confirm this [77].

8.4 Postoperative Diaphragmatic Elevation

Surgery-induced phrenic nerve injury may result in diaphragmatic paralysis. Studies have shown that RAI does not increase the incidence of diaphragmatic paralysis compared with the MS approach [41]. Most

cases of diaphragmatic elevation after cardiac surgery are associated with excessive phrenic nerve traction. Therefore, during RAI procedures, pericardiotomy and suspension should be performed 2 cm anterior to the phrenic nerve to avoid overstretching [78]. Using ice slush in the mediastinum for myocardial protection may increase the risk of diaphragmatic elevation. Thus, care should be taken to protect the phrenic nerve when using ice slush [79].

There is still controversy over the optimal timing for diaphragmatic folding surgery regarding postoperative management [80,81]. Follow up studies have shown that most postoperative diaphragmatic elevation can spontaneously alleviate over time [82,83]; However, for children who cannot escape mechanical ventilation due to diaphragmatic paralysis or have obvious respiratory distress, early surgical intervention often achieves good results [84].

Recommendation 10:

- (1) Residual VSD shunt: (1) Residual shunt ≤ 2 mm: Follow-up observation; (2) Intraoperative residual shunt ≥ 3 mm: Immediate re-repair; (3) Postoperative residual shunt ≥ 3 mm: closure via transthoracic echo guidance, catheter intervention, or reoperation via original incision (Evidence level: B; Recommendation strength: I).
- (2) Arrhythmias: (1) External defibrillation pads should be routinely applied. (2) Immediate reoperation for high-grade atrioventricular valve block detected intraoperatively. (3) For temporary pacing, right ventricle outflow tract leads should be placed via the 4th intercostal space with adequate length (Evidence level: B; Recommendation strength: I).
- (3) Atelectasis: (1) Perform intermittent lung inflation after aortic unclamping. (2) Avoid mechanical injury during lung retraction. (3) Timely suctioning and appropriate PEEP. (4) Routine bronchoscopy and lavage as needed (Evidence level: B; Recommendation strength: I).
- (4) Postoperative diaphragmatic elevation: (1) Pericardiotomy should be performed 2 cm anterior to the phrenic nerve. (2) Protect the phrenic nerve during ice-slush myocardial cooling. (3) Prefer observation unless the child cannot be extubated or has significant respiratory distress, in which case early surgery is advised (Evidence level: B; Recommendation strength: I).

9 Conclusion

RAI is strongly recommended for most simple congenital heart diseases (CHDs) (e.g., simple ventricular septal defect, atrial septal defect), weakly recommended for some complex CHDs (e.g., mild tetralogy of Fallot), and not recommended for complex CHDs such as transposition of the great arteries or in children with severe right thoracic deformity. Additionally, it standardizes key operational parameters: weight (5–30 kg as optimal), age (6 months–6 years as preferred), incision location, extracorporeal circulation cannulation, and organ protection measures. This consensus provides an evidence-based basis for standardizing the clinical application of RAI in open-heart surgery for CHD, ensuring surgical safety and efficacy.

Acknowledgement: We would like to thank all experts from the drafting guidance group and consensus members.

Funding Statement: This consensus was supported by the Jiangsu Provincial key research and development program (BE2023662), Noncommunicable Chronic Diseases-National Science and Technology Major Project (No. 2024ZD0527000 and No. 2024ZD0527005).

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Wang, Jirong Qi, Huiwen Chen, Shusheng Wen, Rui Chen, Ming Ye, Keming Yang, Minhua Fang, Caixia Liu, Ke Lin, Zhongshi Wu, Tianli Zhao, Xiangming Fan, Zhengxia Pan, Yiqun Ding, Ming'an Pi, Xin Li, Yong Zou, Shuguang Tao, Renwei Chen, Li Ma, Libing Zhang, Tao You, Dongshan Liao, Cheng Zhou, Hongxin Li, Gengxu Zhou, Chunhu Gu, Zhiqiang Li, Yonggang Li, Hui Zhang, Xiaomin He, Yanan Lu, Haifa Hong, Benqing Zhang, Li Gong, Jiafeng Qi, Song Bai, Yuhang Liu. All authors reviewed and approved the final version of the manuscript.

Availability of Data and Materials: All data is available via the corresponding author's email address attached.

Ethics Approval: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Abdel-Rahman U, Wimmer-Greinecker G, Matheis G, Klesius A, Seitz U, Hofstetter R, et al. Correction of simple congenital heart defects in infants and children through a minithoracotomy. *Ann Thorac Surg.* 2001;72(5):1645–9. [[CrossRef](#)].
2. Lei YQ, Liu JF, Xie WP, Hong ZN, Chen Q, Cao H. Anterolateral minithoracotomy versus median sternotomy for the surgical treatment of atrial septal defects: a meta-analysis and systematic review. *J Cardiothorac Surg.* 2021;16(1):266. [[CrossRef](#)].
3. Wu SY. Clinical effect of right subaxillary small incision approach in the treatment of children with congenital heart disease. *J Women Child Health Guide.* 2023;2(3):72–5. (In Chinese). [[CrossRef](#)].
4. Balachandran S, Lee A, Denehy L, Lin KY, Royse A, Royse C, et al. Risk factors for sternal complications after cardiac operations: a systematic review. *Ann Thorac Surg.* 2016;102(6):2109–17. [[CrossRef](#)].
5. Xiang F. Research progress on the causes and intervention strategies of pleural effusion after open heart surgery. *Cardiovasc Dis Electron J Integr Tradit Chin West Med.* 2017;5(08):19–20. (In Chinese).
6. Zhao K, Zhou YH, Gao H, Guo YP. Application of pericardial opening right thoracic drainage surgery in the surgical treatment of congenital heart disease in infants. *Int J Cardiovasc Dis.* 2023;50(05):333–5. (In Chinese).
7. Lin Y, Li SF. Clinical outcomes of vacuum-assisted closure for deep sternal wound infection after pediatric cardiac surgery. *J Clin Pediatr Surg.* 2020;19(09):806–9. (In Chinese).
8. Tan EM, Lyle M, Cawcutt K, Temesgen Z. Poststernotomy osteomyelitis presenting with severe sepsis and rhabdomyolysis. *Case Rep Med.* 2016;2016:4507012. [[CrossRef](#)].
9. Baillot R, Cloutier D, Montalin L, Côté L, Lellouche F, Houde C, et al. Impact of deep sternal wound infection management with vacuum-assisted closure therapy followed by sternal osteosynthesis: a 15-year review of 23, 499 sternotomies. *Eur J Cardiothorac Surg.* 2010;37(4):880–7. [[CrossRef](#)].
10. Heinisch PP, Bartkevics M, Beck MJ, Erdoes G, Glöckler M, Humpl T, et al. Right axillary thoracotomy in congenital cardiac surgery: analysis of percutaneous cannulation. *Ann Thorac Surg.* 2021;112(6):2047–53. [[CrossRef](#)].
11. Wang PG, Zhang Y, Chen ZJ, Cui YZ, Yu WB, Dong XY. Clinical effect of right subaxillary small incision approach on children with congenital heart disease. *Chin J Appl Clin Pediatr.* 2020;35(1):41–5. (In Chinese).
12. Yan L, Zhou ZC, Li HP, Lin M, Wang HT, Zhao ZW, et al. Right vertical infra-axillary mini-incision for repair of simple congenital heart defects: a matched-pair analysis. *Eur J Cardiothorac Surg.* 2013;43(1):136–41. [[CrossRef](#)].
13. Vittinghoff M, Lönnqvist PA, Mossetti V, Heschl S, Simic D, Colovic V, et al. Postoperative pain management in children: guidance from the pain committee of the European society for paediatric anaesthesiology (ESPA pain management ladder initiative) part II. *Anaesth Crit Care Pain Med.* 2024;43(6):101427. [[CrossRef](#)].
14. Clancy T, Jordan B, de Weerth C, Muscara F. Early emotional, behavioural and social development of infants and young children with congenital heart disease: a systematic review. *J Clin Psychol Med Settings.* 2020;27(4):686–703. [[CrossRef](#)].
15. Hong ZN, Chen Q, Lin ZW, Zhang GC, Chen LW, Zhang QL, et al. Surgical repair via submammary thoracotomy, right axillary thoracotomy and median sternotomy for ventricular septal defects. *J Cardiothorac Surg.* 2018;13(1):47. [[CrossRef](#)].

16. İstar H, Sevuk U. Minimally invasive cardiac surgery in low-resource settings: right vertical infra-axillary mini-thoracotomy without peripheral cannulation—the first 100 cases. *Eur Rev Med Pharmacol Sci.* 2023;27(13):6247–55. [[CrossRef](#)].
17. Atalay A, Yilmaz M, Turkcan BS, Ecevit AN, Ozler B, Azak E, et al. Can right infra-axillary vertical thoracotomy make a big difference in surgical technique preference? *Heart Lung Circ.* 2022;31(10):1419–24. [[CrossRef](#)].
18. Dai XF, Chen Q, Zhang GC, Chen LW. A comparative study of minimal lower-sternal incision device closure, minimal right thoracic incision device closure, and midsternal open repair of isolated perimembranous VSD, a retrospective cohort study. *Int J Cardiol.* 2020;306:15–9. [[CrossRef](#)].
19. Jaroszewski DE, Gustin PJ, Haecker FM, Pilegaard H, Park HJ, Tang ST, et al. Pectus excavatum repair after sternotomy: the Chest Wall International Group experience with substernal Nuss bars. *Eur J Cardiothorac Surg.* 2017;52(4):710–7. [[CrossRef](#)].
20. Qiu ZH, Wu QS, Xiao J, Chai TC, Tang MR, Xie XB, et al. Mid-term outcomes of right subaxillary approach versus median sternotomy incision for ventricular septal defect with patent ductus arteriosus. *BMC Pediatr.* 2022;22(1):684. [[CrossRef](#)].
21. Zhang T, Ge JJ, Zhang HY, Wu HB, Jiao HM. Retrospective study on the efficacy comparison of right subaxillary small incision and median sternal incision approach in the treatment of simple congenital heart disease in children. *Prog Mod Biomed.* 2022;22(6):1056–9. (In Chinese).
22. Kaito T, Shimada M, Ichikawa H, Makino T, Takenaka S, Sakai Y, et al. Prevalence of and predictive factors for scoliosis after surgery for congenital heart disease in the first year of life. *JB JS Open Access.* 2018;3(1):e0045. [[CrossRef](#)].
23. Wang Q, Li Q, Zhang J, Wu Z, Zhou Q, Wang DJ. Ventricular septal defects closure using a minimal right vertical infraaxillary thoracotomy: seven-year experience in 274 patients. *Ann Thorac Surg.* 2010;89(2):552–5. [[CrossRef](#)].
24. An ZY, Zhai SF, Li JD, Cao QX, Sun YM. Clinical investigation of right vertical infra-axillary mini-incision on children with congenital heart disease. *J Cardiovasc Pulm Dis.* 2017;36(2):102–5. (In Chinese).
25. Gil-Jaurena JM, Pérez-Caballero R, Pita-Fernández A, González-López MT, Sánchez J, De Agustín JC. How to set-up a program of minimally-invasive surgery for congenital heart defects. *Transl Pediatr.* 2016;5(3):125–33. [[CrossRef](#)].
26. Lee T, Weiss AJ, Williams EE, Kiblawi F, Dong J, Nguyen KH. The right axillary incision: a potential new standard of care for selected congenital heart surgery. *Semin Thorac Cardiovasc Surg.* 2018;30(3):310–6. [[CrossRef](#)].
27. Zhao YL, Han L, Li YN, Mao Y, Liu DB, Gao BR. Right vertical infra-axillary thoracotomy surgery vs. standard median sternotomy in treating congenital heart diseases: a meta-analysis. *Chin J Hemorrhage.* 2017;27(4):419–25. (In Chinese).
28. Yaliniz H, Topcuoglu MS, Gocen U, Atalay A, Keklik V, Basturk Y, et al. Comparison between minimal right vertical infra-axillary thoracotomy and standard median sternotomy for repair of atrial septal defects. *Asian J Surg.* 2015;38(4):199–204. [[CrossRef](#)].
29. Hu CX, Tan J, Chen S, Ding H, Xu ZW. Comparison of clinical outcomes and postoperative recovery between two open heart surgeries: minimally invasive right subaxillary vertical thoracotomy and traditional median sternotomy. *Asian Pac J Trop Med.* 2014;7(8):625–9. [[CrossRef](#)].
30. Gao KZ, Li XB, Li QG, Jin J, Yu WD. Comparison of 4 operative methods to cure secundum atrial septal defect. *J Cardiovasc Pulm Dis.* 2019;38(4):399–402. (In Chinese).
31. Yang X, Wang D, Wu Q. Repair of partial atrioventricular septal defect through a minimal right vertical infra-axillary thoracotomy. *J Card Surg.* 2003;18(3):262–4. [[CrossRef](#)].
32. Rao RK, Varadaraju R, Basappa G, Nagaraja PS. Repair of sinus venosus defects with partial anomalous pulmonary venous connection in children by modified right vertical infra axillary thoracotomy. *Innovations.* 2019;14(6):553–7. [[CrossRef](#)].
33. Ito T, Maekawa A, Hoshino S, Hayashi Y. Right infra-axillary mini-thoracotomy for aortic valve replacement. *Ann Cardiothorac Surg.* 2015;4(1):78–80. [[CrossRef](#)].
34. Xu C, Pan J, Zhou Q, Wang Q, Cao H, Fan F, et al. Right vertical infra-axillary thoracotomy for double valve replacement. *J Card Surg.* 2015;30(5):427–30. [[CrossRef](#)].
35. An K, Li S, Yan J, Wang X, Hua Z. Minimal right vertical infra-axillary incision for repair of congenital heart defects. *Ann Thorac Surg.* 2022;113(3):896–902. [[CrossRef](#)].

36. Babliak O, Demianenko V, Babliak D, Marchenko A. Surgical maneuver for ventricular septal defect exposure during congenital heart surgery through the right axillary transverse minithoracotomy. *Innovations*. 2022;17(5):438–41. [[CrossRef](#)].
37. Butt W. Extubation after neonatal and pediatric cardiac surgery: where and when? *Pediatr Crit Care Med*. 2020;21(10):910–1. [[CrossRef](#)].
38. An G, Yang W, Zheng S, Wang W, Huang J, Zhang H, et al. Early and mid-term outcomes of total repair of tetralogy of Fallot through a right subaxillary thoracotomy. *Eur J Cardiothorac Surg*. 2020;58(5):969–74. [[CrossRef](#)].
39. An G, Zhang H, Zheng S, Wang W, Wu Q, Xing Q. Minimally invasive surgical closure for doubly committed subarterial ventricular septal defects through a right subaxillary thoracotomy. *Interact Cardiovasc Thorac Surg*. 2016;23(6):924–8. [[CrossRef](#)].
40. Meng F, Li J, Liang W, Dong H, Li B. Prognostic analysis of children with tetralogy of Fallot through a small incision in the right axilla. *Front Cardiovasc Med*. 2025;12:1457554. [[CrossRef](#)].
41. Shi BZ, He XM, Zheng JH, Luo K, Shi GC, Pan YJ, et al. Clinical efficacy of right midaxillary straight incision in the treatment of doubly committed subarterial ventricular septal defect: a retrospective cohort study. *Chin J Clin Thorac Cardiovasc Surg*. 2025;32(12):1702–7. (In Chinese).
42. Qiao YL, An GY, Zhang HY, Zheng SG, Chen GQ, Ni LC, et al. 270 cases of right axillary small incision extracorporeal circulation open heart surgery. *Chin J Clin Thorac Cardiovasc Surg*. 2012;19(5):565–6. (In Chinese).
43. Ren LL, Hao YJ, Chen XL, Xie YW, Gong J, Li XB, et al. Effect of right vertical infra-axillary thoracotomy on the repair of ventricular septal defect in children. *Chin J Clin Thorac Cardiovasc Surg*. 2020;27(08):870–3.
44. Li WW, Zhang JQ, Meng FM. Perioperative dynamic changes and interrelations of plasma cytokines of infants undergoing cardiopulmonary bypass. *J Chin Pract Diagn Ther*. 2017;31(6):577–9. (In Chinese).
45. Chen Y, Mo XM, Chen RS, Qi JR, Peng W, Wu KH, et al. A comparative study of right subaxillary small incision approach and traditional median sternal incision approach for ventricular septal defect. *J Clin Pediatr Surg*. 2023;22(5):419–24. (In Chinese).
46. Zhang YW, Wei ZP, Zheng JY, Liang WJ, Fan TB. Right axillary mini thoracotomy in cardiac surgery for congenital heart disease in low-age and low-birthweight infants. *Chin J Appl Clin Pediatr*. 2022;36(9):932–5. (In Chinese).
47. Li G, Su J, Fan X, Li Z, Zhang J, Zhu Y, et al. Safety and efficacy of ventricular septal defect repair using a cosmetic shorter right lateral thoracotomy on infants weighing less than 5 kg. *Heart Lung Circ*. 2015;24(9):898–904. [[CrossRef](#)].
48. Liu L, Wang C, Dong J, Lin J, Liu M, Li W, et al. Right vertical axillary incision vs. Median sternotomy for congenital ventricular septal defect repair in children: a propensity score-matched study. *Front Cardiovasc Med*. 2025;11:1527042. [[CrossRef](#)].
49. Jing X, Li L, Wu Y, Wang Z, Lv L, Wang Q. Right subaxillary small incision on low-age and low-weight infants with congenital heart disease. *Front Cardiovasc Med*. 2024;11:1468673. [[CrossRef](#)].
50. Dave HH, Comber M, Solinger T, Bettex D, Dodge-Khatami A, Prêtre R. Mid-term results of right axillary incision for the repair of a wide range of congenital cardiac defects. *Eur J Cardiothorac Surg*. 2009;35(5):864–9. [[CrossRef](#)].
51. Myers P, Sologashvili T, Prêtre R. Non-visible scar surgery: right axillary thoracotomy approach for partial atrioventricular canal repair. *Multimed Man Cardiothorac Surg*. 2019;2019. [[CrossRef](#)].
52. Li F, Cheng T, Yan M, Li T, Zhang T, Huang Y, et al. Analysis of the therapeutic effect of right mid-axillary approach in the surgical treatment of ASD and VSD in children. *J Cardiothorac Surg*. 2024;19(1):587. [[CrossRef](#)].
53. Dodge-Khatami J, Noor R, Riggs KW, Dodge-Khatami A. Mini right axillary thoracotomy for congenital heart defect repair can become a safe surgical routine. *Cardiol Young*. 2023;33(1):38–41. [[CrossRef](#)].
54. Yang X, Hu Y, Dong J, Huang P, Luo J, Yang G, et al. Rightvertical axillary incision for atrial septal defect: a propensity score matched study. *J Cardiothorac Surg*. 2022;17(1):256. [[CrossRef](#)].
55. Sharoni E, Erez E, Birk E, Katz J, Dagan O. Superior vena cava syndrome following neonatal cardiac surgery. *Pediatr Crit Care Med*. 2001;2(1):40–3. [[CrossRef](#)].
56. Heinisch PP, Wildbolz M, Beck MJ, Bartkevics M, Gahl B, Eberle B, et al. Vertical right axillary mini-thoracotomy for correction of ventricular septal defects and complete atrioventricular septal defects. *Ann Thorac Surg*. 2018;106(4):1220–7. [[CrossRef](#)].
57. Durandy Y. Vacuum-assisted venous drainage, angel or demon: PRO? *J Extra Corpor Technol*. 2013;45(2):122–7. [[CrossRef](#)].

58. Willcox TW. Vacuum assist: angel or demon CON. *J Extra Corpor Technol.* 2013;45(2):128–32. [[CrossRef](#)].
59. Nakanishi K, Shichijo T, Shinkawa Y, Takeuchi S, Nakai M, Kato G, et al. Usefulness of vacuum-assisted cardiopulmonary bypass circuit for pediatric open-heart surgery in reducing homologous blood transfusion. *Eur J Cardiothorac Surg.* 2001;20(2):233–8. [[CrossRef](#)].
60. Guo Z, Li Z, Bai S, Tong F, Zheng J, Ding N, et al. CO₂ field-flooding devices offer potential value for cardiopulmonary bypass procedures for CHD performed via a right-side small incision approach. *J Cardiothorac Surg.* 2025;20(1):88. [[CrossRef](#)].
61. Wang S, Undar A. Vacuum-assisted venous drainage and gaseous microemboli in cardiopulmonary bypass. *J Extra Corpor Technol.* 2008;40(4):249–56. [[CrossRef](#)].
62. Koutsogiannaki S, Huang SX, Lukovits K, Kim S, Bernier R, Odegard KC, et al. The characterization of postoperative mechanical respiratory requirement in neonates and infants undergoing cardiac surgery on cardiopulmonary bypass in a single tertiary institution. *J Cardiothorac Vasc Anesth.* 2022;36(1):215–21. [[CrossRef](#)].
63. Wang Q, Ye JX, Ge M, Wang DJ. Early- and long-term outcomes of cardiovascular surgery via minimal right vertical infra-axillary thoracotomy: a 15-year study of 1, 126 patients. *Sci Rep.* 2018;8(1):4376. [[CrossRef](#)].
64. Zhang SC, Hua ZD. Right vertical infra-axillary thoracotomy in surgical repair for intra-cardiac congenital heart defects combined with patent ductus arteriosus. *Chin J Clin Thorac Cardiovasc Surg.* 2020;27(05):515–20. (In Chinese).
65. Liu R, Rui L, Zhang B, Lin Y, Li S, Hua Z. Through tricuspid closure for doubly committed subarterial ventricular septal defect with right vertical subaxillary mini-incision: a matched-pair analysis. *Pediatr Cardiol.* 2019;40(6):1247–52. [[CrossRef](#)].
66. Kaneda T, Nishino T, Saga T, Nakamoto S, Ogawa T, Satsu T. Small right vertical infra-axillary incision for minimally invasive port-access cardiac surgery: a moving window method. *Interact Cardiovasc Thorac Surg.* 2013;16(4):544–6. [[CrossRef](#)].
67. Gang L, Junwu S, Xiangming F, Zhiqiang L, Jing Z, Yinglong L. The application of minimally invasive open heart surgery through right subaxillary shorter incision for ventricular septal defects in infants weighted less than 5 kg. *J Cardiovasc Pulm Dis.* 2014;33(3):374–8. [[CrossRef](#)].
68. Dodge-Khatami A, Knirsch W, Tomaske M, Prêtre R, Bettex D, Rousson V, et al. Spontaneous closure of small residual ventricular septal defects after surgical repair. *Ann Thorac Surg.* 2007;83(3):902–5. [[CrossRef](#)].
69. Yang SG, Novello R, Nicolson S, Steven J, Gaynor JW, Spray TL, et al. Evaluation of ventricular septal defect repair using intraoperative transesophageal echocardiography: frequency and significance of residual defects in infants and children. *Echocardiography.* 2000;17(7):681–4. [[CrossRef](#)].
70. Nakayama Y, Horimoto Y, Suzuki K, Takiguchi M, Ishihara K, Umehara N, et al. Clinical course of residual ventricular septal defects after congenital heart disease repair. *Pediatr Cardiol.* 2025;46(5):1248–53. [[CrossRef](#)].
71. Cilsal E, Tanıdır İC, Yukcu B, Sahin M, Guzeltas A. Transcatheter closure of postoperative residual VSD and acquired left ventricle-to-right atrium shunt with using two different devices. *Acta Cardiol Sin.* 2022;38(2):201–3. [[CrossRef](#)].
72. Kouakou NYN, Song J, Huh J, Kang IS. The experience of transcatheter closure of postoperative ventricular septal defect after total correction. *J Cardiothorac Surg.* 2019;14(1):104. [[CrossRef](#)].
73. Mo XM, Qi JR, Peng W, Zhuang ZL, Wang ZQ, Yang YZ, et al. The feasibility of hybrid procedure of percutaneous puncture for residual shunt after ventricular septal defect repair. *Chin J Thorac Cardiovasc Surg.* 2017;33(9):539–41. (In Chinese).
74. Silka MJ, Shah MJ, Silva JNA, Balaji S, Beach CM, Benjamin MN, et al. 2021 PACES expert consensus statement on the indications and management of cardiovascular implantable electronic devices in pediatric patients: executive summary. *Ann Pediatr Cardiol.* 2022;15(3):323–46. [[CrossRef](#)].
75. Park S, Lee JH, Kim HJ, Choi H, Lee JR. Optimal positive end-expiratory pressure to prevent anaesthesia-induced atelectasis in infants: a prospective, randomised, double-blind trial. *Eur J Anaesthesiol.* 2021;38(10):1019–25. [[CrossRef](#)].
76. Singh S, Chauhan M, Jafra A. In response to-Effect of ultrasound-guided lung recruitment manoeuvre on perioperative atelectasis during laparoscopy in young infants: a randomised controlled trial. *J Clin Anesth.* 2023;88:111119. [[CrossRef](#)].

77. Chen H, Liu T, Dong W, Sun Y. Effect of one-lung ventilation in children undergoing lateral thoracotomy cardiac surgery with cardiopulmonary bypass on postoperative atelectasis and postoperative pulmonary complications. *BMC Pediatr.* 2025;25(1):268. [[CrossRef](#)].
78. Akbariasbagh P, Mirzaghayan MR, Akbariasbagh N, Shariat M, Ebrahim B. Risk factors for post-cardiac surgery diaphragmatic paralysis in children with congenital heart disease. *J Tehran Heart Cent.* 2015;10(3):134–9.
79. Diehl JL, Lofaso F, Deleuze P, Similowski T, Lemaire F, Brochard L. Clinically relevant diaphragmatic dysfunction after cardiac operations. *J Thorac Cardiovasc Surg.* 1994;107(2):487–98. [[CrossRef](#)].
80. Rizeq YK, Many BT, Vacek JC, Reiter AJ, Raval MV, Abdullah F, et al. Diaphragmatic paralysis after phrenic nerve injury in newborns. *J Pediatr Surg.* 2019;55(2):240–4. [[CrossRef](#)].
81. Denamur S, Chenouard A, Lefort B, Baron O, Neville P, Baruteau A, et al. Outcome analysis of a conservative approach to diaphragmatic paralysis following congenital cardiac surgery in neonates and infants: a bicentric retrospective study. *Interact Cardiovasc Thorac Surg.* 2021;33(4):597–604. [[CrossRef](#)].
82. Cao GQ, Tang ST, Aubdoollah TH, Yang L, Li S, Lei HY, et al. Laparoscopic diaphragmatic hemiplication in children with acquired diaphragmatic eventration after congenital heart surgery. *J Laparoendosc Adv Surg Tech A.* 2015;25(10):852–7. [[CrossRef](#)].
83. Tarmahomed A, Adan A, Thomas A, Sanghavi R, Amin K, Asif W, et al. Management of phrenic nerve injury post-cardiac surgery in the paediatric patient. *Cardiol Young.* 2021;31(9):1386–92. [[CrossRef](#)].
84. Simsek B, Ozyuksel A, Saygi M, Bilal MS. Plication for diaphragm paralysis after paediatric cardiac surgery: a single-centre experience. *Cardiol Young.* 2023;33(10):2087–93. [[CrossRef](#)].