Archives of Cardiovascular Disease xxx (xxxx) xxx–xxx

Disponible en ligne sur
ScienceDirect
www.sciencedirect.com

Elsevier Masson France
EM|consulte
www.em-consulte.com

Clinical Research

Usefulness of perioperative transoesophageal echocardiography during paediatric cardiac surgery☆

Pierrick Pyra[a,*], Khaled Hadeed[a], Aitor Guitarte Vidaurre[a], Rémi Vincent[a], Yves Dulac[a], Gérald Chausseray[b], Davide Felice Calvaruso[c], Philippe Acar[a,1], Clément Karsenty[a,d]

[a] *Paediatric Cardiology Unit, Department of Paediatrics, Children's Hospital, Toulouse University Hospital, 31059 Toulouse, France*
[b] *Department of Paediatric Anaesthesiology, Children's Hospital, Toulouse University Hospital, 31059 Toulouse, France*
[c] *Department of Congenital Cardiac Surgery, Children's Hospital, Toulouse University Hospital, 31059 Toulouse, France*
[d] *Inserm U1048, Institut des Maladies Métaboliques et Cardiovasculaires (Institute of Metabolic and Cardiovascular Diseases; I2MC), University of Toulouse, 31432 Toulouse, France*

ARTICLE INFO

Article history:
Received 28 October 2023
Received in revised form 7 December 2023
Accepted 12 December 2023
Available online xxx

Keywords:
3D echocardiography
Transoesophageal echocardiography
Congenital heart disease
Paediatric cardiac surgery

ABSTRACT

Background: Paediatric transoesophageal echocardiography probes allow perioperative evaluation during paediatric congenital heart disease surgery.
Aim: To assess the usefulness of perioperative transoesophageal echocardiography in evaluating the severity of residual lesions, based on the type of congenital heart disease repaired in paediatric patients.
Methods: A retrospective analysis was conducted on paediatric patients who underwent open-heart surgery at our tertiary centre over a four-year period. Perioperative transoesophageal echocardiography studies were performed, and residual lesions were classified as mild, moderate or severe.
Results: Overall, 323 procedures involving 310 patients with a median age of 13.8 (0.07–214.4) months and a median weight of 8.2 (2–96) kg at intervention were enrolled in the study. Twenty-one (6.5%) residual lesions led to immediate reintervention: severe right ventricular outflow tract obstruction ($n = 12$); severe aortic regurgitation ($n = 3$); superior vena cava stenosis ($n = 2$); moderate residual ventricular septal defect ($n = 2$); severe mitral regurgitation ($n = 1$); and severe mitral stenosis ($n = 1$). Three (0.9%) neonates had ventilation difficulties caused by the transoesophageal echocardiography probe having to be removed, but experienced no sequelae.
Conclusion: Perioperative transoesophageal echocardiography is a safe procedure, providing information on severe residual lesions, leading to the immediate revision of several paediatric congenital heart disease cases.

1. Abbreviations

3D	three-dimensional
CHD	congenital heart disease
LAVV	left atrioventricular valve
LVOT	left ventricular outflow tract
RAVV	right atrioventricular valve
RVOT	right ventricular outflow tract
RVOTO	right ventricular outflow tract obstruction
TOE	transoesophageal echocardiography
TTE	transthoracic echocardiography
VSD	ventricular septal defect

2. Background

Transoesophageal echocardiography (TOE) is frequently used in adults for various purposes. However, in neonates and children, transthoracic echocardiography (TTE) is usually sufficient for the screening, follow-up and characterization of congenital heart disease (CHD), as their hearts produce better echogenicity [1,2].

TOE in children typically requires sedation, which makes it an invasive technique [3], and limits its use primarily to percutaneous guidance procedures [4]. TOE may also be used in the operating theatre, but this will vary depending on the medical centre in question.

☆ Tweet: A retrospective analysis highlights the role of advanced imaging in enhancing outcomes for young hearts. Detecting and addressing severe residual lesions in real-time, led to immediate intervention in 6.5% of cases. #Pediatrics #Cardiology #CHD.

* Corresponding author. Hôpital des Enfants, 330, avenue de Grande-Bretagne, TSA 70034, 31059 Toulouse cedex 9, France.
E-mail address: pierrick.pyra@icloud.com (P. Pyra).
[1] Twitter handle: @acar_philippe.

https://doi.org/10.1016/j.acvd.2023.12.006
1875-2136/

Please cite this article as: P. Pyra, K. Hadeed, A. Guitarte Vidaurre et al., Usefulness of perioperative transoesophageal echocardiography during paediatric cardiac surgery, Arch Cardiovasc Dis, https://doi.org/10.1016/j.acvd.2023.12.006

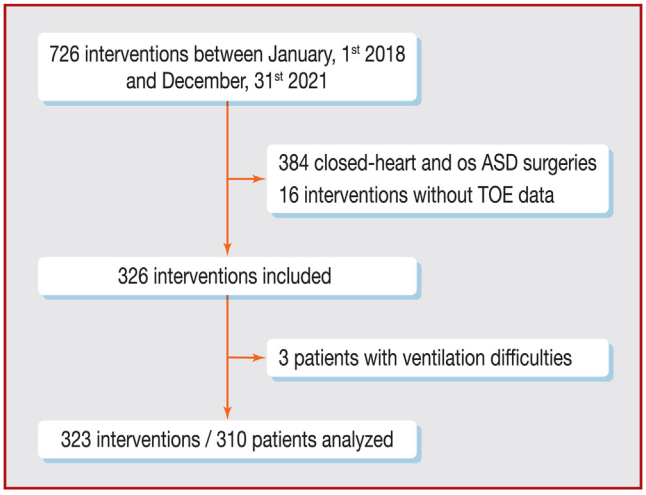


Fig. 1. Flowchart. os ASD: ostium secundum atrial septal defect; TOE: transoesophageal echocardiography.

Preoperative TOE is no longer beneficial for diagnosis, given the accuracy of TTE [5]. However, TOE is still useful in the immediate postoperative assessment of residual lesions before chest closure.

As a result of advancements in TOE technology, with good imaging quality, examination of low-weight neonates can now be conducted safely during surgery [6,7].

The purpose of our study was to evaluate the usefulness and safety of TOE in the paediatric cardiac operating theatre. We also refer to severe residual lesions that required further surgical intervention.

3. Methods

This research was registered in the establishment's records of processing activities in accordance with Article 30 of the General Data Protection Regulation (RnIPH 2022-95) pursuant to provision MR-004. The data were processed electronically in accordance with the General Data Protection Regulation.

This was a retrospective single-centre descriptive study conducted at Toulouse University Hospital between 01 January 2018 and 31 December 2021. All paediatric CHD procedures involving intraoperative TOE performed at Toulouse University Hospital during this period were included, covering all open-heart surgeries, except ostium secundum atrial septal defect closures. We do not perform TOE for closed-heart surgeries. A flowchart can be found in Fig. 1.

Data were collected using computerized medical records from Toulouse University Hospital.

Cardiac surgery was categorized based on the specific procedures performed after analysing the surgical report. We identified six different groups of procedures: closure of ventricular septal defect (VSD); construction of right or left ventricular outflow tract (RVOT or LVOT); valvuloplasty of the left or right atrioventricular valve (LAVV or RAVV); and closure of pretricuspid shunt. For instance, tetralogy of Fallot surgery involves two procedures: VSD closure and RVOT surgery. Consequently, the total number of procedures performed exceeds the number of interventions analysed for residual lesions. The latter were classified using TOE reports and native images. Preoperative lesions, even without any accompanying surgical procedure, were still categorized as residual lesions for the purpose of analysis.

The severity of the residual lesions was analysed and classified. Residual ventricular shunts were classified as follows, according to the European Society of Cardiology 2020 recommendations for the management of adult CHD [8]: mild, when restrictive, without pulmonary arterial hypertension and without pulmonary hyperflow (Qp/Qs < 1.5); moderate, when Qp/Qs > 1.5 without pulmonary arterial hypertension; and severe, when non-restrictive (with pulmonary arterial hypertension).

The Qp/Qs was calculated perioperatively by using staged oximetry, except when the shunt was < 1 mm, when it was assumed to be mild. For the follow-up, Qp/Qs was estimated by the TTE velocity time integral method [9].

Residual right-sided stenosis was classified as follows: mild, when the systolic right ventricle pressure was estimated to be less than half of the aortic systolic pressure; moderate, when the systolic right ventricle pressure was estimated to be between one half and two-thirds of the aortic systolic pressure; and severe, when the systolic right ventricle pressure was ≥ two-thirds of the aortic systolic pressure.

Classification of other residual lesions followed the European Society of Cardiology 2021 recommendations for valve disease [10].

Echocardiography was performed to assess residual lesions on TOE, in accordance with the guidelines set by the American Society of Echocardiography (adult and paediatric recommendations [11–13]), as well as the International Society for Adult Congenital Heart Disease. TOE was conducted either before discontinuing cardiopulmonary bypass or before connecting to extracorporeal membrane oxygenation. We adopted the same classification for residual lesions observed through TTE shortly before the patient's discharge, following the practices recommended by the American Society of Echocardiography.

Repeat intervention was immediate when performed in the operating theatre, early when performed during hospitalization and late when performed after hospital discharge.

The following TOE probes were used, based on patient weight: the three-dimensional (3D) matrix probe X7-2t (> 30 kg), the paediatric probe S7-3t (5–30 kg) and the micro probe S8-3t (< 5 kg) on an Epic 7 echograph (Philips Healthcare, Andover, MA, USA). TTE probes used before hospital discharge comprised S8-3, S9-2, S12-4 and 3D matrix X5-1 probes on an Epic 7 echograph or 12S, 4VC and 6VC probes on a Vivid 9 echograph (GE Healthcare, Chicago, IL, USA).

Safety was defined as any alteration in vital variables or monitoring elements established during the procedure necessitating the removal of the probe at the discretion of the anaesthetist (e.g. changes in tidal volumes).

Statistical analyses were performed using SPSS Statistics software, version 26 (IBM, Armonk, NY, USA). Results are expressed in terms of numbers and percentages with binominal proportion confidence intervals (Clopper–Pearson with 95% confidence level) for qualitative variables or as median (minimum–maximum; interquartile range) for quantitative variables as a result of non-normal distribution, assessed using the Shapiro–Wilk test.

4. Results

Three hundred and ten patients with a median age of 13.8 (0.07–214.4; interquartile range: 44.2) months, a median weight of 8.2 (2–96; interquartile range: 9.4) kg and 323 procedures were included. Details of the study cohort are provided in Table 1. Of the 323 procedures, 664 surgical interventions were performed, and are described in Table 2.

Out of 323 procedures, TOE revealed 21 severe (6.5%, 95% CI: 4.1–9.8), 25 moderate (7.7%, 95% CI: 5.1–11.2%) and 208 mild residual lesions; these are shown by procedure families in Fig. 2. Examples of residual lesion TOEs are shown in Figs. 3–6.

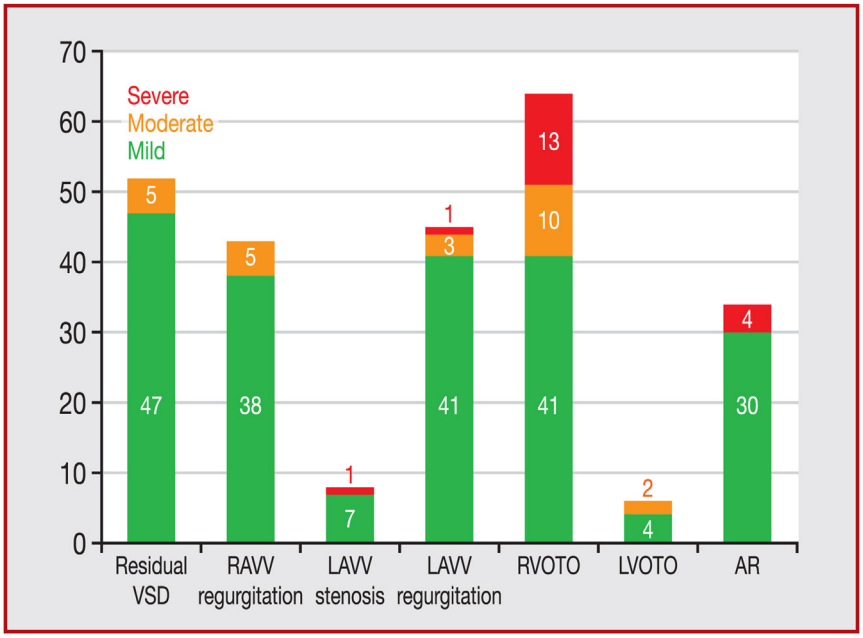


Fig. 2. Classification of residual lesions seen on perioperative transoesophageal echocardiography, and their severity. AR: aortic regurgitation; LAVV: left atrioventricular valve; LVOT: left ventricular outflow tract; LVOTO: left ventricular outflow tract obstruction; RAVV: right atrioventricular valve; RVOT: right ventricular outflow tract; RVOTO: right ventricular outflow tract obstruction; VSD: ventricular septal defect.

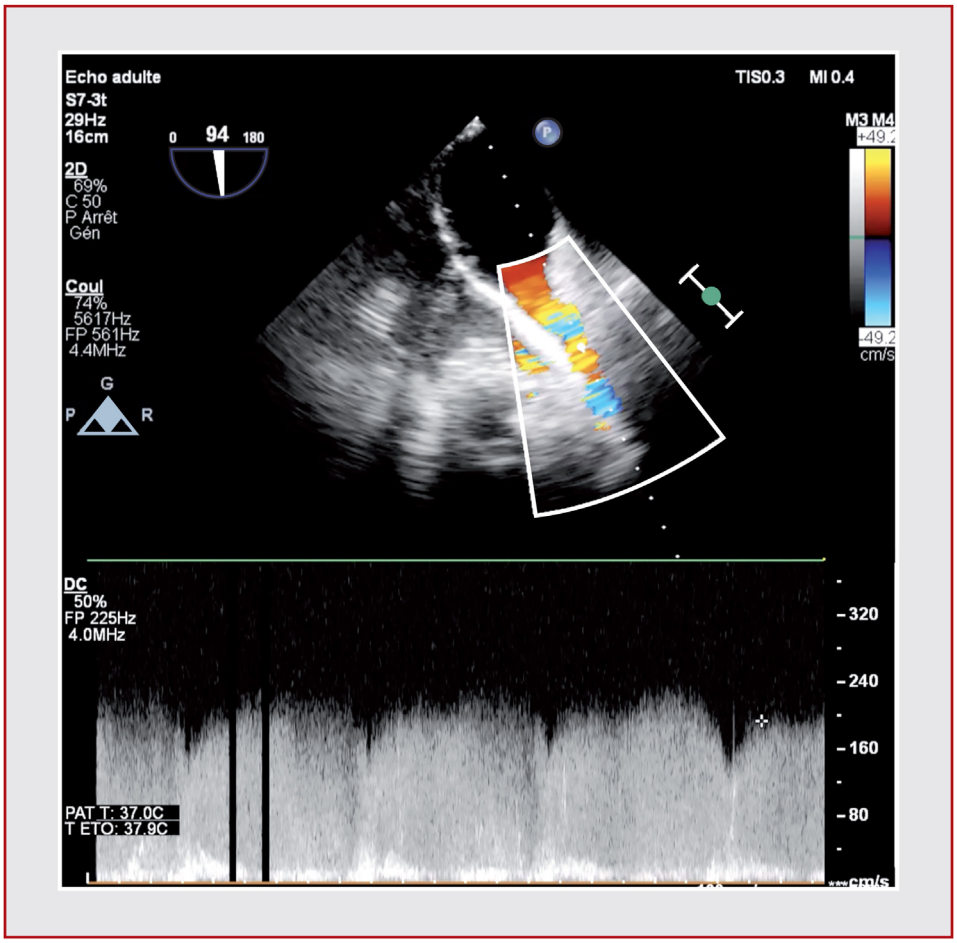


Fig. 3. Superior vena cava (SVC) acceleration following Warden surgery for partial anomalous pulmonary venous connection. Upper section: acceleration of SVC with colour-flow Doppler; deep transgastric modified view. Lower section: continuous Doppler scan of SVC acceleration.

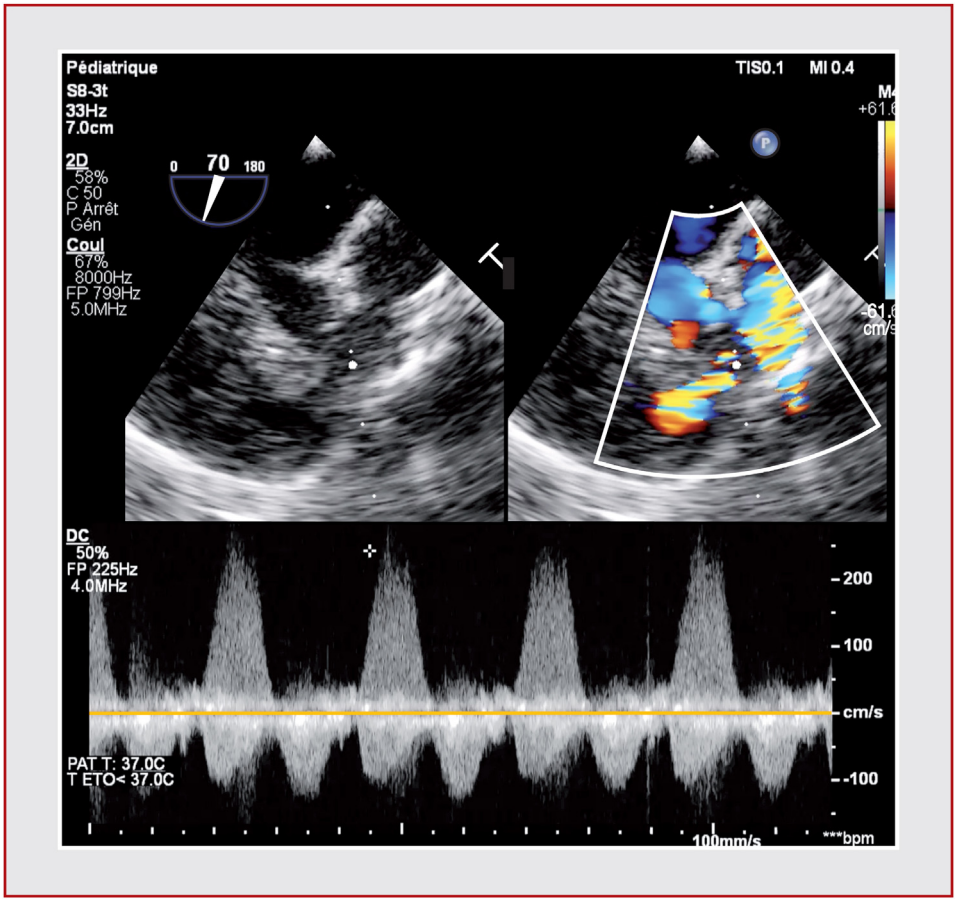


Fig. 4. Mild right ventricular outflow tract residual obstruction following tetralogy of Fallot surgery. Upper section: residual infundibular stenosis with colour-flow Doppler; midoesophageal right ventricle in-out view. Lower section: continuous Doppler showing residual acceleration.

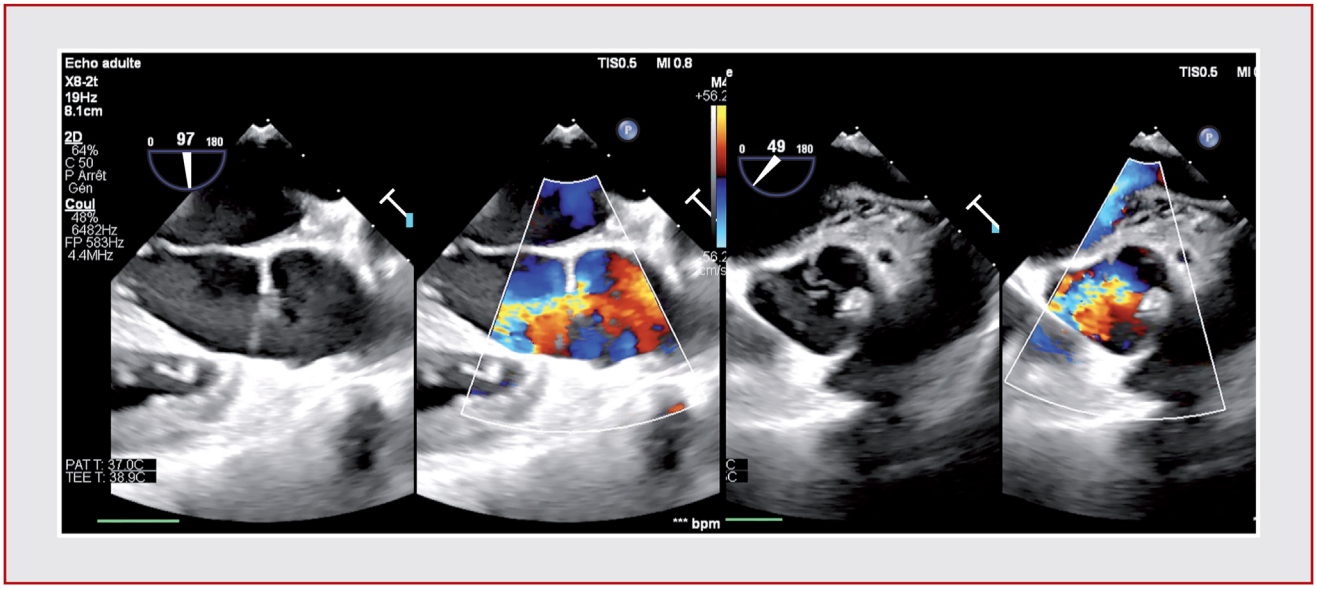


Fig. 5. Significant aortic regurgitation following primary plasty. Left section: midoesophageal aortic valve long-axis view with or without colour-flow Doppler. Right section: midoesophageal aortic valve short axis view with or without colour-flow Doppler.

Table 1
General population characteristics ($n = 323$).

Age at intervention (months)	13.8 (0.07–214.4; 44.2)
Weight (kg)	8.2 (2–96; 9.4)
Length (cm)	72 (39–193; 40.5)
Male sex	170 (52.6)
Female sex	153 (47.4)
Male:female ratio	1.11
Previous surgical procedures	–
None	262 (81.1)
One	50 (15.5)
Two	8 (2.5)
Three	3 (0.9)

Data are expressed as median (minimum–maximum; interquartile range) or number (%), unless otherwise indicated.

Table 2
Type of congenital heart disease, according to procedure performed ($n = 664$).

VSD surgery	202 (30.4)
Outlet VSD	103
Inlet VSD	26
Perimembranous VSD	71
Muscular VSD	2
RVOT surgery	167 (25.1)
Conotruncal CHD	69
RVOTO (with or without VSD; six with PAB)	42
Malposition of great arteries	48
TGA	33
DORV	14
PA from aorta	1
Univentricular (Damus–Kaye Stansel)	8
RAVV surgery	104 (15.7)
VSD (tricuspid plasty following closure)	64
AVSD	28
Conotruncal CHD	6
Malposition of great arteries	3
Ebstein	3
LVOT surgery	88 (13.3)
Malposition of great arteries	36
TGA	33
DORV	3
LVOTO (subvalvular, valvular or supravalvular)	27
Aortic regurgitation	8
Aortic dilatation	3
Univentricular (Damus–Kaye Stansel)	8
Truncus arteriosus	4
Other	2
Pretricuspid shunt surgery	60 (9.0)
Sinus venosus ASD	17
Other APVC (total or partial)	8
Ostium primum ASD	34
Coronary sinus ASD	1
LAVV surgery	43 (6.5)
AVSD	34
Mitral regurgitation	6
VSD with mitral anomalies	2
Malposition of great arteries (DORV with mitral cleft)	1

Data are expressed as number or number (%). APVC: anomalous pulmonary venous connection; ASD: atrial septal defect; AVSD: atrioventricular septal defect; CHD: congenital heart disease; DORV: double outlet right ventricle; LAVV: left atrioventricular valve; LVOT: left ventricular outflow tract; LVOTO: left ventricular outflow tract obstruction; PA: pulmonary artery; PAB: pulmonary artery banding; RAVV: right atrioventricular valve; RVOT: right ventricular outflow tract; RVOT: right ventricular outflow tract; TGA: transposition of great arteries; VSD: ventricular septal defect.

Out of the 21 severe residual lesions, 19 (90.4%, 95% CI: 69.6–98.8%) underwent immediate surgical reintervention, one had early reintervention and one had late reintervention.

Out of 167 RVOT procedures, TOE highlighted 64 cases (38.3%, 95% CI: 30.9–46.1%) of residual stenosis. Of the 13 cases (7.8%, 95% CI: 4.2–12.9%) of severe stenosis, 12 cases warranted immediate surgical revision; the last case underwent early reintervention.

Out of 202 VSD closures, TOE identified five cases (2.5%, 95% CI: 0.8–5.7%) with moderate residual VSD. Immediate surgical revision was performed in two cases (patients 18 and 19 in Table 3). In the other two cases, the residual VSDs were intentionally preserved during surgery, and were expected to be present postoperatively. The final case involved multiple residual muscular VSDs following coarctation syndrome surgery, where the main VSD closure was originally underestimated.

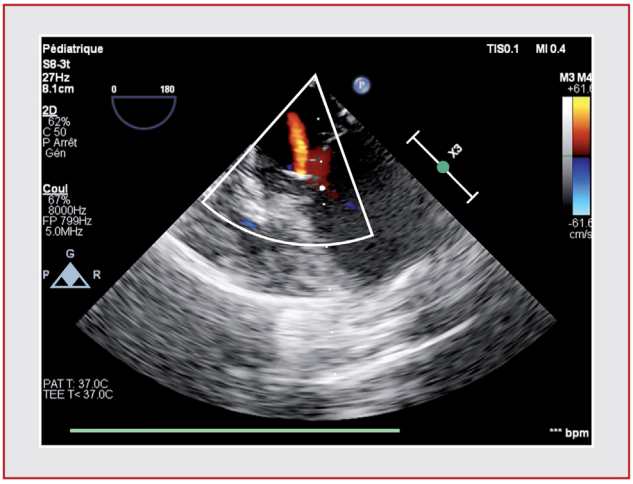


Fig. 6. Mild mitral regurgitation following left atrioventricular plasty (cleft) for complete atrioventricular septal defect surgery. Modified midoesophageal four-chamber view with colour-flow Doppler. Residual mitral regurgitation.

Out of 88 LVOT gestures, three of the four (4.5%, 95% CI: 1.2–11.2%) severe aortic regurgitations detected on TOE benefited from immediate surgical revision. The last case underwent reintervention at a later stage.

Out of 43 LAVV gestures, one case (2.3%, 95% CI: 0.1–12.3%) of severe mitral insufficiency and one case of residual severe mitral stenosis were detected on TOE, and required immediate revision.

Out of 60 pretricuspid shunt closure cases, two patients (3.3%, 95% CI: 0.4–11.5%) had significant superior vena cava stenosis on TOE after Warden surgery, and required immediate revision.

Details of all revision surgeries are provided in Table 3.

Fig. 7 summarizes the residual lesions observed upon hospital discharge. Of the two severe lesions reported at the time of discharge, mitral valve stenosis progressively worsened during the hospitalization and aortic insufficiency had been noted during TOE, but no further intervention was performed before discharge.

At the latest follow-up, 11 patients underwent a new reoperation or catheterization: three patients for residual lesions observed during the discharge TTE (two patients for the severe residual lesions depicted in Fig. 7; the patient with severe aortic insufficiency underwent a reoperation with a favourable outcome, and was doing well at the last follow-up; conversely, the patient with severe mitral stenosis in the context of a complex cardiac malformation progressed to pulmonary hypertension following detachment of the VSD patch after discharge and, unfortunately, succumbed after the subsequent surgical intervention; the last patient was treated with catheterization 3 months later for RVOT obstruction [RVOTO]); and eight patients for progressively deteriorating lesions, resulting in one cardiac transplantation, one surgery for pulmonary vein stenosis, two surgeries for progressive coronary artery stenosis, one surgery for progressive left pulmonary artery stenosis in a single ventricle, one surgery for prosthesis dislodgement, one surgery for progressive pulmonary artery stenosis and one surgery for mitral regurgitation without any previous intervention on the mitral valve.

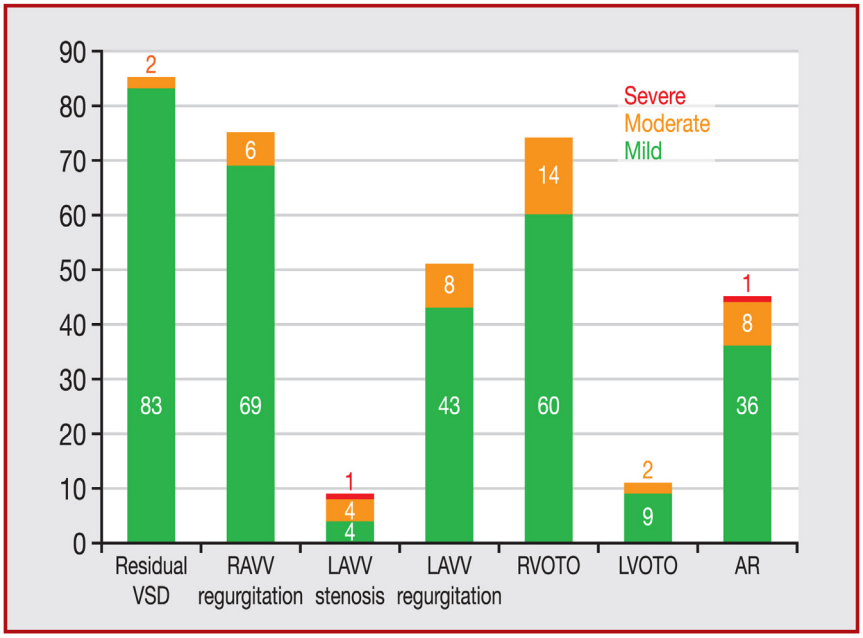


Fig. 7. Classification of residual lesions seen on exit transthoracic echocardiography, and their severity. AR: aortic regurgitation; LAVV: left atrioventricular valve; LVOT: left ventricular outflow tract; LVOTO: left ventricular outflow tract obstruction; RAVV: right atrioventricular valve; RVOT: right ventricular outflow tract; RVOTO: right ventricular outflow tract obstruction; VSD: ventricular septal defect.

4.1. Safety

Three (0.9%, 95% CI: 0.1–2.6%) neonates (2.4, 2.7 and 3 kg) had ventilation difficulties caused by the TOE probe having to be removed, but experienced no sequelae. If we consider neonatal patients, this accounts for 6.5% (95% CI: 1.4–17.9%) of newborns (S8-3t probe). We experienced no ventilation complication with the X7-2t probe (> 30 kg) or the paediatric probe S7-3t (5–30 kg).

No other complications were reported. We did not find any case of oto-rhino-laryngology complication related to TOE probe insertion with clinical consequence in this study.

5. Discussion

Our study adds some insights into the realm of paediatric heart surgery, especially regarding TOE. In adults, numerous large-scale studies are available on the utility of TOE in cardiac surgery, but this is less the case in paediatric congenital cardiac surgeries, and the few studies with a large cohort are a bit old, raising the question of the current necessity of this imaging technique, with the advancement of surgical techniques in paediatric congenital cardiology.

We noted that severe lesions, which accounted for 6.5% of interventions, were promptly revised during surgery in almost all cases (90.4%). These findings are consistent with published data, which highlight revision rates ranging from 3.9% [5] to 7.3% [14].

Most of the 664 procedures performed involved VSD closures (30.4%) and RVOT constructions (25%). Postsurgical residual lesions were, of course, mainly found in the form of VSD and RVOTO.

In RVOT surgery, we observed a reintervention rate of 7.8%, which is consistent with previous studies, reporting rates of 7.6% [15] to 9.4% [16] among patients with tetralogy of Fallot. Notably, our centre achieved a high pulmonary valve conservation rate of 89.5% versus 41.3% documented over 35 years in another study conducted by Blais et al. [17], thanks to a surgical technique known as "T-shaped infundibulotomy" [18]. Although this approach offers benefits, such as pulmonary valve preservation, it does increase the risk of residual RVOTO (38.3%).

The desire to preserve the pulmonary valve in tetralogy of Fallot surgery is corroborated by several studies. Kaushal et al. [19] found that residual stenosis tends to decrease over time. Boni et al. [20] did not report prolonged hospital stays, despite residual RVOTO. According to Blais et al. [17], valve-sparing surgery in tetralogy of Fallot resulted in improved survival rates and fewer reinterventions, even with residual RVOTO. But this idea has recently been debated by an article from Siddiqi et al. [21], which demonstrates a higher risk of reintervention in cases of moderate stenosis. Frigiola et al. [22] reported that patients with the best exercise capacity and no repeat valve replacement surgery had a mean residual RVOTO. Preservation of the pulmonary valve avoids significant pulmonary regurgitation, which is a risk factor for arrhythmia in adulthood, as evidenced by Gatzoulis et al. [23].

Our study also found low reintervention rates in surgical procedures involving pretricuspid shunts (3.3%) and LAVV surgery (4.6%). This is consistent with a study conducted by Bettex et al. [15], which reported reoperation rates of 4.4% and 8.4% for atrial septal defects and LAVV, respectively, for residual lesions detected on TOE. Lin et al. [24] recorded a higher revision rate for superior vena cava stenosis, at 10.6%.

Residual shunts after closure of VSD are fairly common, occurring in approximately 30–25% of cases (28.6% in our study). However, these residual shunts are often mild, without significant haemodynamic effects [25]. Moderate VSDs have been reported in only 2.4% of population studies. A 2020 study conducted by Deng et al. [26] provides an additional insight into the spontaneous closure potential of these residual shunts. Shunts smaller than 2 mm are more likely to close independently, with a closure rate of 83% within 300 days. On the other hand, shunts larger than 2 mm have a lower spontaneous closure rate, occurring in only 33% of cases over a median period of 3 years.

Our study highlights the significant occurrence of RAVV valvuloplasties required to separate the valve for enhanced VSD visualization [27]. This approach has proved reliable, as evidenced by the absence of tricuspid valve stenosis reported in our study.

Table 3
Description of patients who underwent immediate perioperative reintervention.

Patients	Age (months)	Weight (kg)	Type of initial CHD	Type of residual lesion	Management
Patient 1	5.6	6.5	Pulmonary valve agenesis	Subvalvular pulmonary stenosis	Infundibular resection complement
Patient 2	8.4	8.2	Perimembranous VSD with initial PAB	Supravalvular pulmonary stenosis	MPA patch
Patient 3	159.2	40	Irregular TOF pulmonary valve preserved	Supravalvular pulmonary stenosis	MPA patch
Patient 4	22.2	8.5	VSD with PAB following primary coarctation surgery	Supravalvular pulmonary stenosis	MPA patch
Patient 5	9.4	5.6	Fallot-like DORV	Residual valvular pulmonary stenosis	Surgical commissurotomy
Patient 6	91	19	Irregular TOF (humanitarian chain); pulmonary valve preserved	Residual valvular pulmonary stenosis	Valve removal
Patient 7	5.7	5.8	Irregular TOF; pulmonary valve preserved	Residual valvular pulmonary stenosis	Valve removal
Patient 8	5.8	6.6	Irregular TOF; pulmonary valve preserved	Residual valvular pulmonary stenosis	Valve removal
Patient 9	19.7	10	Perimembranous VSD and valvular pulmonary stenosis	Residual valvular pulmonary stenosis	Valve removal
Patient 10	6.9	9.5	Irregular TOF; pulmonary valve preserved	Residual valvular pulmonary stenosis	Valve removal
Patient 11	8.6	7.3	DORV with subvalvular pulmonary stenosis and TGA	LPA stenosis following double-root translocation	LPA patch
Patient 12	21.2	8.7	TOF/PA surgery following palliation primary surgery	Severe residual RVOTO	Refection of RVOT
Patient 13	168	50	Aortic regurgitation	Severe aortic regurgitation	Mechanic valve implantation
Patient 14	32.2	12.6	TOF/PA: repeat RVOT	Severe aortic regurgitation	Aortic valvular plasty
Patient 15	208.5	66	Severe aortic regurgitation following AAOCA primary surgery	Severe aortic regurgitation	Aortic valvular plasty
Patient 16	180.2	40	Mitral regurgitation on Williams–Beuren syndrome	Severe mitral stenosis	Larger annuloplasty
Patient 17	32.8	8.6	Mitral regurgitation on Noonan syndrome with HCM	Severe residual mitral regurgitation	Novel mitral plasty
Patient 18	6.2	6.6	Fallot-like DORV	Hitherto unseen residual muscular VSD	Closure of VSD
Patient 19	38.5	9.5	Regular TOF (humanitarian chain)	Residual VSD around patch	Closure of VSD
Patient 20	214.5	51	Sinus venosus ASD	SVC stenosis after Warden procedure	Enlargement of SVC
Patient 21	143.9	65	Partial APVC	SVC stenosis after Warden procedure	Enlargement of SVC

AAOCA: anomalous aortic origin of coronary artery; APVC: anomalous pulmonary venous return; ASD: atrial septal defect; CHD: congenital heart disease; DORV: double outlet right ventricle; HCM: hypertrophic cardiomyopathy; LPA: left pulmonary artery: MPA: main pulmonary artery; PA: pulmonary atresia; PAB: pulmonary artery banding; RVOT: right ventricular outflow tract; RVOTO: right ventricular outflow tract obstruction; SVC: superior vena cava; TGA: transposition of great arteries; TOF: tetralogy of Fallot; VSD: ventricular septal defect.

TOE is an important tool in the surgical management of CHD; it detects residual lesions during surgery, and has been in use for several years. These residual lesions can have serious consequences, leading to longer hospital stays, prolonged periods in intensive care units, higher mortality rates and longer ventilation times for certain cardiac diseases [28].

TOE is easy and safe to use, with only 0.9% of non-severe complications being reported in our study. These complications resolved once the probe was removed, but were more significant (6.5%) in newborns and were not reported in the two other groups of patients (paediatric and adult probe). The use of TOE appears to be entirely safe in those weighing over 5 kg, using the appropriate probe; it should be introduced cautiously with monitoring of ventilatory variables for those under 5 kg, and more carefully for those under 3 kg. Additionally, handling and positioning with different probes require training, with a learning curve, as views slightly differs from that in adults. We therefore advocate the use of TOE in all types of congenital heart surgery, as all procedures pose the risk of residual lesions.

Without TOE-mediated intraoperative revision, we run the risk of postoperative revision, which can have significant cost repercussions. A study conducted in South Korea by Kim et al. [16] estimated that each patient would incur an additional cost of $1489 if postoperative revision were required. Furthermore, the psychological impact on parents should not be underestimated, as repeat surgery can be emotionally challenging.

In addition, TOE is presently the sole method known to accurately identify any remaining lesions. Alternative techniques, such as oximetry step-up and atrial and pulmonary lines do not provide precise information regarding the mechanism and anatomical characteristics of residual lesions. Pressure measurements provide valuable information regarding the presence or absence of residual lesions and their severity, particularly the right ventricular to pulmonary artery gradient or pulmonary pressure for VSDs. However, they do not provide information about the specific location of the residual VSD (supplementary VSD or residual VSD) or the location of right-sided stenosis (incomplete infundibular muscle resection, residual pulmonary valvular or supravalvular stenosis).

These factors are frequently intertwined in paediatric cardiac surgery as a result of the complexity of congenital heart conditions, in contrast to non-congenital adult cardiac surgery. Near-infrared spectroscopy or oesophageal Doppler scans can only provide an estimate of systemic flow and perfusion. The water test, routinely carried out by surgeons following valve surgery, has not undergone extensive examination in the literature, and no studies have evaluated its effectiveness in predicting residual leaks and assessing their severity.

TOE also enables the assessment of cardiac contractility and assists in anaesthetic management; it aids in detecting segmental dyskinesias, especially in surgeries involving coronary procedures to identify potential coronary involvement, but we did not observe any issues of this nature in our study.

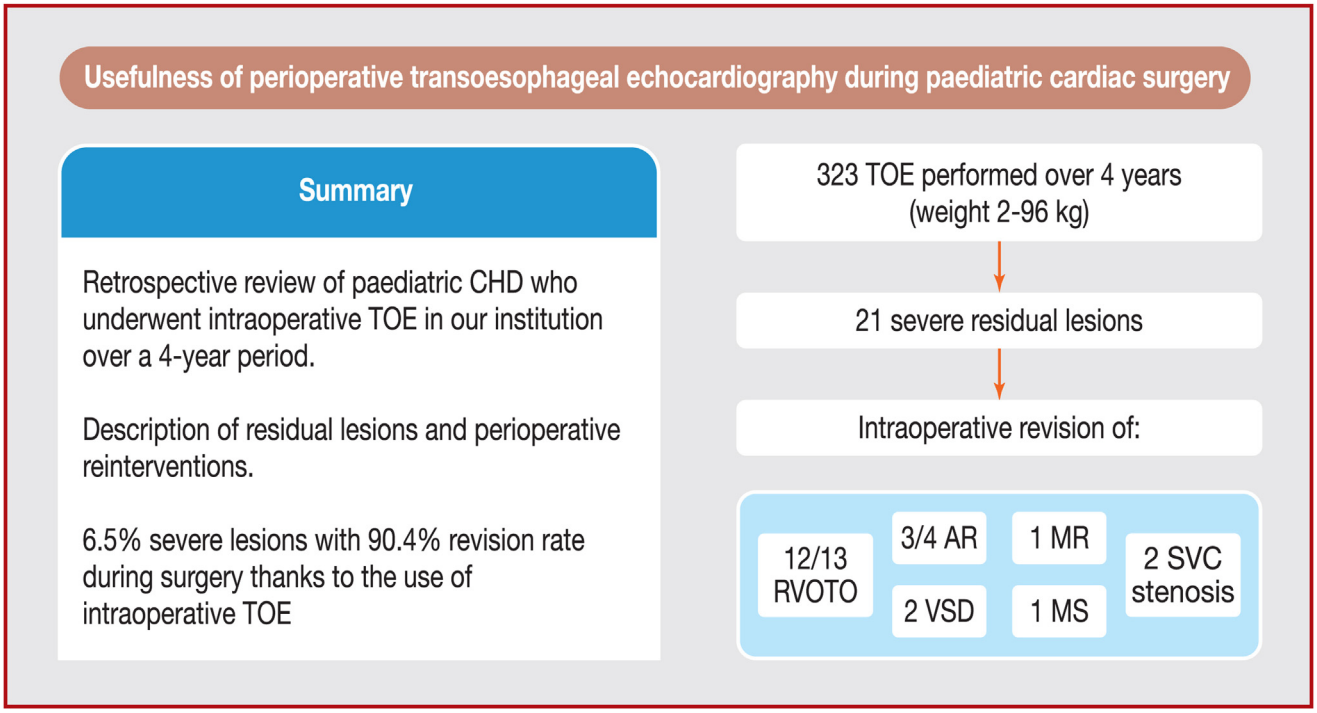
3D echocardiographic imaging is becoming increasingly popular and more widely used in adult cardiac surgery [29]. Our team has been working for many years to demonstrate the merits of this approach in routine paediatric and congenital cardiology applications. Paediatric 3D TTE probes provide more accurate estimates and assessments of paediatric CHD [30], including shunts and valvular lesions. Previously, there was only one 3D TOE probe reserved for patients weighing > 30 kg. However, the recent marketing of 3D paediatric TOE probes suitable for patients weighing ≥ 5 kg will certainly improve the surgical management of paediatric patients with CHD [31]. Simulation for echocardiographic training in the specific field of CHD is also promising [32].

5.1. Study limitations

Our study limitations include its retrospective design, with the potential for classification bias, and missing data. The impact of surgical techniques and experience of surgeons can also significantly impact the likelihood of residual lesions. Furthermore, the fact that our study was conducted at a single-centre limits its external validity. It is important to note that we classified residual lesions according to type of surgical procedure rather than the specific CHD, which further limits our ability to compare our findings with those of other studies. However, this approach showcases more routine residual lesion procedures across a wide range of CHDs. We did not use epicardial echocardiography because of the technical complexity of procedure (the need for the operator to wear additional sterile attire and for a second person to set up the ultrasound machine, in addition to the risk of surgical field contamination), but we used a neonatal TOE probe specifically designed for this purpose. We also do not use TOE for vascular anomaly surgeries, focusing on intracardiac lesions.

6. Conclusions

Our study emphasises the significance and impact of TOE in paediatric CHD surgery, and highlights key considerations in terms of lesion severity. The low-risk nature of this procedure makes it a safe and reliable option, even in low-weight patients; it also provides interesting insights that may have facilitated the prompt revision of severe residual lesions (Central Illustration).



Central Illustration. AR: aortic regurgitation; CHD: congenital heart disease; MR: mitral regurgitation; MS: mitral stenosis; RVOTO: right ventricular outflow tract obstruction; SVC: superior vena cava; TOE: transoesophageal echocardiography; VSD: ventricular septal defect.

Sources of funding

None.

Acknowledgements

The authors wish to thank Melanie Dean for editing.

Disclosure of interest

The authors declare that they have no competing interest.

References

[1] Alboliras ET, Seward JB, Hagler DJ, Danielson GK, Puga FJ, Tajik AJ. Impact of two-dimensional and Doppler echocardiography on care of children aged two years and younger. Am J Cardiol 1988;61:166–9.
[2] Alghamdi MH, Ismail MI, Yelbuz TM, Alhabshan F. Do we need more than a transthoracic echocardiography when evaluating children with congenital heart disease before cardiac surgery? Congenit Heart Dis 2016;11:262–9.
[3] Heard CM, Gunnarsson B, Heard AM, Watson E, Orie JD, Fletcher JE. Anaesthetic technique for transoesophageal echocardiography in children. Paediatr Anaesth 2001;11:181–4.
[4] Kamra K, Russell I, Miller-Hance WC. Role of transesophageal echocardiography in the management of pediatric patients with congenital heart disease. Paediatr Anaesth 2011;21:479–93.
[5] Jijeh AM, Omran AS, Najm HK, Abu-Sulaiman RM. Role of intraoperative transesophageal echocardiography in pediatric cardiac surgery. J Saudi Heart Assoc 2016;28:89–94.
[6] Hascoet S, Peyre M, Hadeed K, Alacoque X, Chausseray G, Fesseau R, et al. Safety and efficiency of the new micro-multiplane transoesophageal probe in paediatric cardiology. Arch Cardiovasc Dis 2014;107:361–70.
[7] Scohy TV, Gommers D, Jan ten Harkel AD, Deryck Y, McGhie J, Bogers AJ. Intraoperative evaluation of micromultiplane transesophageal echocardiographic probe in surgery for congenital heart disease. Eur J Echocardiogr 2007;8:241–6.
[8] Baumgartner H, De Backer J, Babu-Narayan SV, Budts W, Chessa M, Diller GP, et al. 2020 ESC Guidelines for the management of adult congenital heart disease. Eur Heart J 2021;42:563–645.
[9] Cloez JL, Schmidt KG, Birk E, Silverman NH. Determination of pulmonary to systemic blood flow ratio in children by a simplified Doppler echocardiographic method. J Am Coll Cardiol 1988;11:825–30.
[10] Vahanian A, Beyersdorf F, Praz F, Milojevic M, Baldus S, Bauersachs J, et al. 2021 ESC/EACTS Guidelines for the management of valvular heart disease. Eur Heart J 2022;43:561–632.
[11] Ayres NA, Miller-Hance W, Fyfe DA, Stevenson JG, Sahn DJ, Young LT, et al. Indications and guidelines for performance of transesophageal echocardiography in the patient with pediatric acquired or congenital heart disease: report from the task force of the Pediatric Council of the American Society of Echocardiography. J Am Soc Echocardiogr 2005;18:91–8.
[12] Mitchell C, Rahko PS, Blauwet LA, Canaday B, Finstuen JA, Foster MC, et al. Guidelines for Performing a Comprehensive Transthoracic Echocardiographic Examination in Adults: recommendations from the American Society of Echocardiography. J Am Soc Echocardiogr 2019;32:1–64.
[13] Puchalski MD, Lui GK, Miller-Hance WC, Brook MM, Young LT, Bhat A, et al. Guidelines for performing a comprehensive transesophageal echocardiographic: examination in children and all patients with congenital heart disease: recommendations from the American Society of Echocardiography. J Am Soc Echocardiogr 2019;32:173–215.
[14] Madriago EJ, Punn R, Geeter N, Silverman NH. Routine intra-operative transoesophageal echocardiography yields better outcomes in surgical repair of CHD. Cardiol Young 2016;26:263–8.
[15] Bettex DA, Schmidlin D, Bernath MA, Pretre R, Hurni M, Jenni R, et al. Intraoperative transesophageal echocardiography in pediatric congenital cardiac surgery: a two-center observational study. Anesth Analg 2003;97:1275–82.
[16] Kim SJ, Park SA, Song J, Shim WS, Choi EY, Lee SY. The role of transesophageal echocardiography during surgery for patients with tetralogy of Fallot. Pediatr Cardiol 2013;34:240–4.
[17] Blais S, Marelli A, Vanasse A, Dahdah N, Dancea A, Drolet C, et al. Comparison of long-term outcomes of valve-sparing and transannular patch procedures for correction of tetralogy of Fallot. JAMA Netw Open 2021;4:e2118141.
[18] Leobon B, Cousin G, Hadeed K, Breinig S, Alacoque X, Berthomieu L, et al. Tetralogy of Fallot: T-shaped infundibulotomy for pulmonary valve-sparing procedure. Interact Cardiovasc Thorac Surg 2022;34:488–91.
[19] Kaushal SK, Radhakrishanan S, Dagar KS, Iyer PU, Girotra S, Shrivastava S, et al. Significant intraoperative right ventricular outflow gradients after repair for tetralogy of Fallot: to revise or not to revise? Ann Thorac Surg 1999;68:1705–12 [discussion 12–3].
[20] Boni L, Garcia E, Galletti L, Perez A, Herrera D, Ramos V, et al. Current strategies in tetralogy of Fallot repair: pulmonary valve sparing and evolution of right ventricle/left ventricle pressures ratio. Eur J Cardiothorac Surg 2009;35:885–9 [discussion 9–90].
[21] Siddiqi U, Adewale A, Pena E, Schulz K, Ilbawi M, El-Zein C, et al. Preserving the pulmonary valve in Tetralogy of Fallot repair: reconsidering the indication for valve-sparing. J Card Surg 2022;37:5144–52.
[22] Frigiola A, Hughes M, Turner M, Taylor A, Marek J, Giardini A, et al. Physiological and phenotypic characteristics of late survivors of tetralogy of Fallot repair who are free from pulmonary valve replacement. Circulation 2013;128:1861–8.
[23] Gatzoulis MA, Balaji S, Webber SA, Siu SC, Hokanson JS, Poile C, et al. Risk factors for arrhythmia and sudden cardiac death late after repair of tetralogy of Fallot: a multicentre study. Lancet 2000;356:975–81.
[24] Lin H, Yan J, Wang Q, Li S, Sun H, Zhang Y, et al. Outcomes of the warden procedure for partial anomalous pulmonary venous drainage. Pediatr Cardiol 2020;41:134–40.
[25] Tee SD, Shiota T, Weintraub R, Teien DE, Deng YB, Sahn DJ, et al. Evaluation of ventricular septal defect by transesophageal echocardiography: intraoperative assessment. Am Heart J 1994;127:585–92.
[26] Deng X, Huang P, Luo J, Chen R, Yang G, Chen W, et al. Residual shunts following isolated surgical ventricular septal defect closure: risk factors and spontaneous closure. Pediatr Cardiol 2020;41:38–45.
[27] Lucchese G, Rossetti L, Faggian G, Luciani GB. Long-term follow-up study of temporary tricuspid valve detachment as approach to VSD repair without consequent tricuspid dysfunction. Tex Heart Inst J 2016;43:392–6.
[28] Nathan M, Levine JC, Van Rompay MI, Lambert LM, Trachtenberg FL, Colan SD, et al. Impact of major residual lesions on outcomes after surgery for congenital heart disease. J Am Coll Cardiol 2021;77:2382–94.
[29] Turton EW, Ender J. Role of 3D echocardiography in cardiac surgery: strengths and limitations. Curr Anesthesiol Rep 2017;7:291–8.
[30] Karsenty C, Hadeed K, Acar P. [Congenital heart disease: recent technical advances in three-dimensional echocardiography]. Presse Med 2017;46:482–9.
[31] Karsenty C, Hadeed K, Pyra P, Guitarte A, Djeddai C, Vincent R, et al. Advancing paediatric cardiac imaging: a comprehensive analysis of the feasibility and accuracy of a novel 3D paediatric transoesophageal probe. Front Cardiovasc Med 2023;10:1294109.
[32] Pezel T, Coisne A. What other than simulation for the future of echocardiography training? Arch Cardiovasc Dis 2023;116:298–9.