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Ahmed A. Algebaly
National Heart Institute

Hanan Mohammed Hassan
National Heart Institute

Rania D. Eldin Abou Shokka
National Heart Institute, rania.abushokka@gmail.com

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Additive value of intraoperative hemodynamic monitoring to epicardial echocardiography during surgical repair of children with congenital heart disease

Rania D. Eldin Abou Shokka[a], Ahmed A. Algebaly[b], Hanan Mohammed Hassan[a]

Departments of [a]Congenital and Structural Heart Disease and [b]Pediatric Cardiothoracic, National Heart Institute, Cairo, Egypt

Abstract

Aim

The aim was to evaluate the additive value of intraoperative hemodynamic monitoring to epicardial echocardiography on the surgical outcome in children undergoing surgical correction of congenial heart disease.

Patients and methods

This study was conducted on 238 children with congenital heart disease who were enrolled for surgical correction. They were arranged in two groups: group A included 159 children in whom e-echo was used to detect intraoperative residual lesions while group B included 79 patients in whom e-echo and intraoperative hemodynamic monitoring using oxygen saturation step-up and intracardiac pressures after disconnection of cardiopulmonary bypass to detect residual shunt flow and outflow tract obstruction were used; revision of bypass was done when significant lesions were detected for repair. The follow-up echocardiography showed no significant residual lesions and complications in the subgroup of patients who had both epicardial monitoring and hemodynamic studies, in contrast to other groups of patients in whom19 patients had residual lesions and complications.

Conclusions

Routine use of intraoperative epicardial echocardiography allows detection of majority of residual defects after bypass; however, addition of other intraoperative monitoring tools like hemodynamic pressure measurement and oxygen saturation step-up can result in the detection of more residual lesions with revision of bypass, thus saving these patients from reoperation and postoperative complications.

Keywords: ICU intensive care unit, PA pulmonary artery, PG pressure gradient, PS pulmonary stenosis, RA right atrium, TGA transpostion of great vessels, VSD Ventricular septal defect

Introduction

Surgical repair of congenital heart disease has undergone a remarkable evolution especially in developing countries, as a significant proportion of cyanotic and acyanotic heart diseases are now often completely corrected in early life with improving survival rate. However, residual cardiovascular lesions in these patients whether anatomical or functional are a major cause of mortality and morbidity after repair [1–5].

The presence of various intraoperative monitoring (IOM) tools during surgical correction has made cardiac surgeons aware that intraoperative echocardiography can provide valuable information during all types of procedures [6].

Epicardial echocardiography (e-echo) has been used for assessment of small children undergoing surgical correction for congenital heart diseases especially those with contraindications to transesophageal echocardiography (TEE). The e-echo gives

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Correspondence to: Rania D. Eldin Abou Shokka, MD Cardiology, National Heart Institute, EBN Elnafes Square Agouza, 12654, Cairo, Egypt. E-mail: rania.abushokka@gmail.com

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additional advantages that include improved visualization of anterior and vascular structures and three-dimensional capability [7].

The role of intraoperative hemodynamic monitoring during surgical repair of congenital heart disease is well established in many institutes as it becomes routine to use a combination of left atrium, right atrium, and pulmonary artery catheter that showed an important role in the management of pediatric patients undergoing surgery [8–12].

Data from these monitoring catheters have greatly facilitated intraoperative and postoperative management [13–22].

Decisions regarding various determinants of overall cardiac function specifically preload, pulmonary vascular resistance, systemic vascular resistance, and contractility can be made with ease.

In the history, intraoperative assessment of surgical outcome in patients with congenital heart defects has been limited to oximetry or green dye curves to detect residual lesions such as shunts and pressure measurements to evaluate residual obstruction to the flow.

The first introduction of echocardiography during a surgical procedure was in 1972 when an epicardial probe was used to evaluate the results of a mitral commissurotomy [23]. Also, e-echo was used in the operating room after cardiopulmonary bypass (CPB) for the assessment of anatomic and surgical results, but its utilization has declined due to increased availability and improved technologic development of TEE probes [7].

Epicardial echocardiography is increasingly being used as an adjunct to TEE to visualize cardiovascular structures that are difficult to evaluate with TEE and are at risk of having residual abnormalities such as left pulmonary artery branch, aortic arch, left superior vena cava, and pulmonary vessel collaterals [24].

These structures are better visualized by e-echo as during flexion of the TEE probe this can cause some distortion in the anatomy of pulmonary artery. Also, poor alignment may dismiss correct assessment of pressure gradients. In contrast, epicardial echo allows direct vessel visualization and adequate Doppler alignment.

There are certain limitations and disadvantages of epicardial approach compared with TEE such as limited access to view posterior and apical cardiac structures, interruption of the operative procedure during examination, and inability to perform continuous monitoring [25].

Patients and methods

In our center, TEE is not performed in neonates, infants, and small children undergoing surgical repair of congenital heart defects. Intraoperative hemodynamic monitoring during surgery were done using e-echo and hemodynamic monitoring of pressures to detect residual obstructions and oxygen saturations to detect residual shunt. Hence, our study was designed to determine the additive value of intraoperative hemodynamic oxygen and pressure monitoring in conjugation with epicardial echocardiography in detecting residual lesions and its impact on surgical outcome in comparison to e-echo as a sole monitor of residual lesions intraoperatively after cardiopulmonary bypass disconnection.

This study was conducted on 238 patients with congenital heart disease who were enrolled for surgical correction; these patients were arranged in two groups (Table 1): group A included 159 patients in whom e-echo was used intraoperatively after cardiopulmonary bypass disconnection, while group B included 79 patients in whom e-echo and intraoperative hemodynamic monitoring using oxygen saturation step-up and intracardiac pressures after cardiopulmonary bypass disconnection to detect residual shunt flow and outflow tract obstruction, revision of bypass when significant lesions were detected.

In patients where residual lesions were detected by e-echo after bypass disconnection, additional hemodynamic oxygen saturation step-up and pressures in various cardiac chambers (vena cava, right atrium, right ventricle, pulmonary artery, left atrium, left ventricle, aorta, and central venous pressure) were used to evaluate the significance of the lesion.

Nonsignificant residual ventricular septal defect (VSD) defects are defined as small if it has a color flow jet of 1–2 mm in width as measured on the left ventricular septal side, while moderate defect would be described as such when measured 3–5 mm in diameter of color flow jet width, whereas a large defect was any defect measuring equal to or more than 5 mm of color jet width or by the intraoperative estimate of pulmonary to systemic blood flow ratio by oximetry to be equal or more than 1.

Exclusion criteria

(1) Double outlet right ventricle with remote VSD.
(2) Patients with multiple VSD.
(3) Konno Aorta ventriculoplasty procedure.
(4) Interrupted aortic arch.
(5) Coarctation and vascular ring.

Intraoperative epicardial echocardiography

In all cases of e-echo and subsequent transthoracic echocardiographic examinations were performed using Phillips HD11XE ultrasound systems (Phillips, Andover, MA) and in the last year of the study a new machine was available (Phillips EPIQ7C) using higher frequency probes (5–12 MHz).

Epicardial images may only be obtained by an operator who is wearing a sterile gown and gloves within the operative field as described in the guidelines.

The guidelines describe seven e-echo imaging planes consistent with the American Society of Echocardiography recommendations for transthoracic echocardiography (TTE).

The probe was inserted in sterile gloves of adequate size and a small quantity of ultrasound gel was put in gloves in addition to applying on the probe head. It was ensured not to trap any air in between the probe and gloves.

Multiple epicardial views were performed for comprehensive analysis as parasternal long-axis view was useful for the assessment of VSD, left ventricular outflow tract, aortic valve, mitral valve, and pulmonary venous return to left atrium. With modification of long-axis view, it was possible to visualize the right ventricular inflow and outflow.

Short-axis view of great vessels was useful to assess flow across the pulmonary valve annulus, branch pulmonary artery, and residual patent ductus arteriosus. Short-axis view at the level of ventricle was used to assess muscular VSD, shape of the ventricle, and systolic ventricular function.

Multiple epicardial views were performed for comprehensive analysis:
(1) Epicardial AoV short-axis view (TTE parasternal AV short-axis equivalent).
(2) Epicardial AoV long-axis view (TTE suprasternal AV long-axis equivalent).
(3) Epicardial LV basal SAX view (TTE modified parasternal mitral valve basal SAX equivalent).
(4) Epicardial LV mid-SAX view (TTE parasternal LV mid-SAX equivalent).
(5) Epicardial LV LAX view (TTE parasternal LAX equivalent).
(6) Epicardial 2-chamber view (TTE modified parasternal LAX equivalent).
(7) Epicardial RV outflow tract view (TTE parasternal SAX equivalent.

Postoperative transthoracic echocardiography

It was performed as a routine in all patients within 24 h of surgery, before extubation in the ICU. Subsequent transthoracic echocardiography studies were done according to the need of the patient. As a routine, predischarge echo was done in all the patients.

Results

Our study focuses on the additive role of using various intraoperative monitoring during surgical repair in children with congenital heart disease, using various monitoring tools to identify residual lesions intraoperatively and repair at the same surgical setting, where residual lesions whether residual shunts or obstructions represent a great burden especially in patients with congenital heart disease.

The study was conducted on 258 children undergoing surgical repair of congenital heart disease, these patients were arranged in two groups: group A included 159 patients where intraoperative epicardial echo was used to assess residual lesions after cardiopulmonary bypass disconnection, group B included 79 patients where intraoperative e-echo and hemodynamic monitoring was used to detect significance of residual obstructions and oxygen step-up saturation for significance of residual shunt after disconnection of bypass and revision when significant lesion was detected for repair.

Results of transthoracic echocardiography were done in the intensive care unit and subsequent echo studies before discharge to evaluate surgical outcome as regards residual shunt, residual pressure gradient, and any complication after surgery (Fig. 1).

Results of our study as regards residual outflow tract obstruction showed that there were 17 (10.7%) patients in group A with residual pressure gradient (nine patients post-Fallot repair, two patients post subaortic membrane resection, three patients post-septal myomectomy in HOCM, one patient with residual obstruction after repair of VSD, PS, and TGA, one patient after repair of VSD and PA) as shown in Fig. 2, while zero patient in group B with residual outflow obstruction with highly significant *P* value 0.003 as shown in Table 2. In the patient group additional intraoperative hemodynamic monitoring was used.

As regards residual shunt flow, in group A there were four (2.5%) patients from a total of 159 patients with residual significant shunt (two patients who had residual VSD; one of them had two

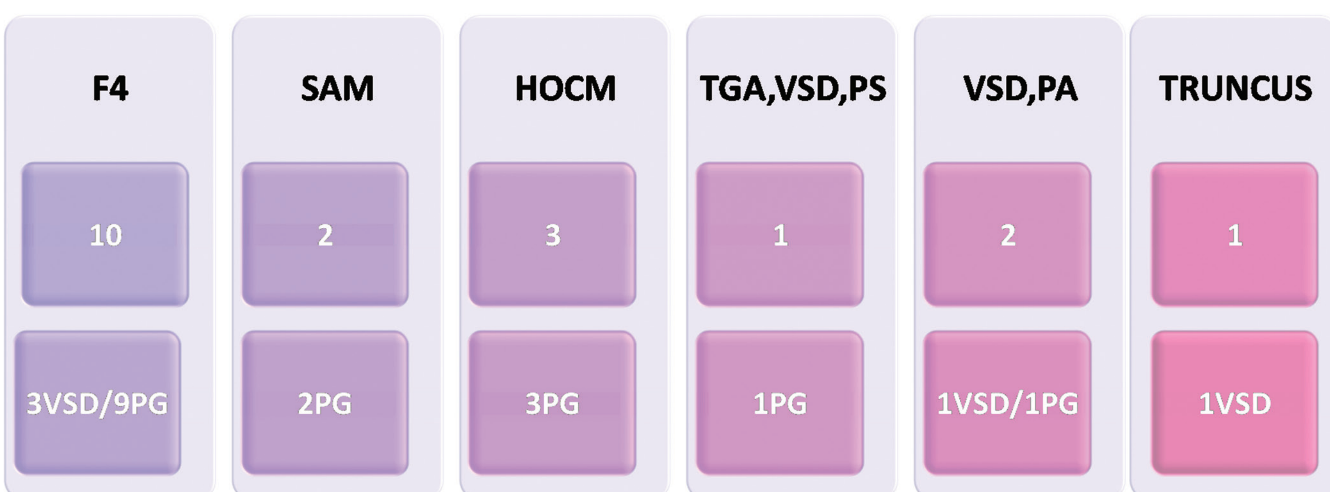

Figure 1: Residual lesions during transthoracic echocardiography follow-up.

VSD after Fallot tetralogy repair, one patient who had VSD PA repair, and one patient after truncus repair), in group B where e-echo and intraoperative hemodynamic monitoring was used intraoperatively for evaluation of residual lesions. There were no patients with residual shunt from a total of 79 cases with a significant *P* value of 0.15 as shown in Table 3.

Detection of significant residual lesions in the operating room with revision of cardiopulmonary bypass for repair were performed in 11 patients in group A while in 13 patients in group B with repair of residual lesions in the same surgical setting with a significant *P* value of 0.021 (Fig. 2).

The sensitivity of using intraoperative hemodynamic monitoring and e-echo after disconnection of bypass and revision of cardiopulmonary bypass was 100%for detection of residual VSD and residual obstructions.

Mortality rate in both groups was the same as shown in Table 4, in group A there were four (2.5%) patients from total 159 patients and in group B there were two (2.5%) patients from a total of 79 patients with insignificant *P* value.

Discussion

Intraoperative imaging modalities have become more comprehensive, especially in patients with congenital heart disease surgery as residual lesions, whether anatomical or functional, represents a major cause of morbidity and mortality especially in these patients after repair [1–5].

Ungerleider *et al*. [7] concluded from their study that intraoperative echo-Doppler color flow imaging is useful in aiding the planning, conduct, and assessment of results in operations for congenital heart disease.

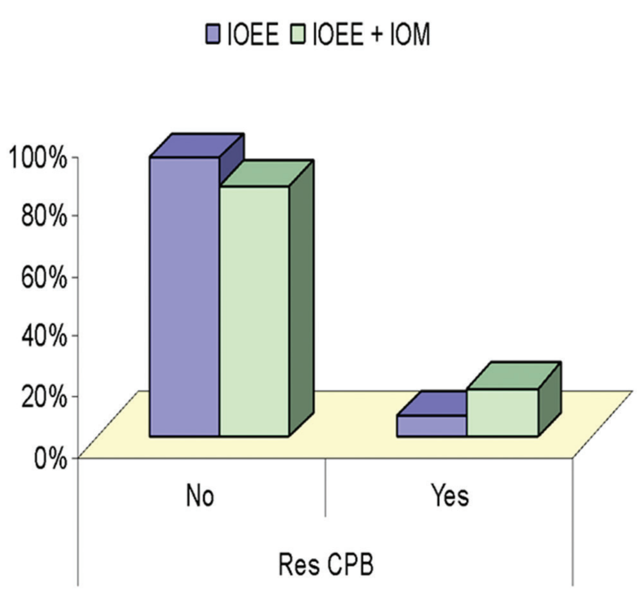

Figure 2: Comparison between IOEE and IOEE + IOM as regards reinstitution of Cardiopulmonary Bypass (CPB).

Our comparative study was done to detect additive value of using epicardial echo in conjugation with intraoperative hemodynamic monitoring on the surgical outcome in children undergoing surgical correction of congenial heart disease as regards residual significant shunt, residual obstructive outflow, revision of cardiopulmonary bypass, and mortality rate.

Results of this protocol were comparative to others in the literature regarding improvement in outcome after cardiac surgery, detection of residual significant shunt, and obstructive outflow tract, where e-echo and intraoperative hemodynamic

Table 1: Clinical and demographic data

	Group A with IOEE (159 patients)	Group B with IOEE + IOM (79 patients)
Fallot tetralogy	92	48
Subaortic membrane	24	14
HOCM	8	4
Truncus arteriosus	8	4
TGA + PS + VSD	15	2
VSD + PS	12	7

HOCM, hypertrophic obstructive cardiomyopathy; PS, pulmonary stenosis; SAM, subaortic membrane; TGA, transposition of great vessels; VSD, ventricular septal defect; IOEE, intraoperativeepicardial echocardiography; IOM, intraoperative monitoring.

Table 2: Comparison between e-echo and e-echo + IOM as regards residual pressure gradient

	Group A: IOEE [*n* (%)]	Group B: IOEE + IOM [*n* (%)]	χ^2-test	*P*
Residual PG				
No	142 (89.3)	79 (100.0)	9.096	0.003
Yes	17 (10.7)	0 (0.0)		

PG, Pressure gradient

Table 3: Comparison between e-echo and e-echo + IOM as regards residual ventricular septal defect

	Group A: e-echo [*n* (%)]	Group B: e-echo + IOM [*n* (%)]	χ^2-test	*P*
Residual VSD outpatient follow-up				
No	155 (97.5)	79 (100)	2.021	0.155
Yes	4 (2.5)	0 (0)		

VSD, ventricular septal defect.

Table 4: Comparison between IOEE and IOEE + IOM as regards mortality

	IOEE [*n* (%)]	IOEE + IOM [*n* (%)]	χ^2-test	*P*
Mortality				
Alive	155 (97.5)	77 (97.5)	0.000	0.994
Died	4 (2.5)	2 (2.5)		

monitoring detect residual significant VSD, residual obstructive outflow tract intraoperatively with revision of cardiopulmonary bypass in patients when significant lesion was detected.

As regards our results of the additional value of intraoperative hemodynamic monitoring, Vincent and colleagues has assessed the hemodynamic status immediately after closure of VSD by access to postoperative RA and PA oxygen saturation values. Also, the presence of a significant oxygen saturation step-up, that indicated, prompted immediate recatheterization and reoperation for closure of a residual or unrecognized additional VSDs [26].

Ungerleider and colleagues also have evaluated the exactness of surgical repair using epicardial echo in children with congenital heart disease, where they found that the rate of reoperation and early death were significantly higher in those with unrepaired residual lesion detected by e-echo; accordingly those subsets of patients in whom the residual lesion was corrected based on e-echocardiography had no postoperative events with good long-term results [3,27].

In our patients those who underwent intraoperative hemodynamic monitoring in addition to e-echo, there were no significant residual outflow obstruction that was detected by transthoracic echo in the intensive care unit in these patients' group monitored by e-echo and intraoperative hemodynamic study during surgical repair.

Results of our study showed the superiority of dual protocol of intraoperative monitoring for detection of residual lesions as regards residual significant shunt and obstruction than other groups in whom only e-echo monitor was used. Also, Lang *et al*. [19] had evaluated in their study the role of intraoperative hemodynamic monitoring particularly with pulmonary artery catheter for rapid detection of residual shunts and outflow tract pressure gradients in the operating room after bypass, especially in patients with Fallot tetralogy, as well as direct biatrial monitoring in the immediate postoperative period, as these patients with compromised right ventricular function are sensitive to even small residual flow or residual obstruction in the immediate postoperative period where invasive monitoring catheters, particularly the PA catheter, allow rapid detection of residual shunts and outflow tract pressure gradients in the operating room after bypass has been discontinued.

Mortality rate in both groups were the same (Fig. 2), as in group A there were four (2.5%) patients and in group B two (2.5%) patients. Also, Ungerleider and colleagues had evaluated the exactness of surgical repair using epicardial echo in children with congenital heart disease and it was found that the rate of reoperation and early death were significantly higher in those with unrepaired residual lesions detected by e-echo [28].

Limitations of the study

(1) Small numbers in the subgroups of clinical diagnosis.
(2) Some of the follow-up echo at the outpatient clinic were done by different personnel.

Conclusion and recommendation

Routine use of intraoperative epicardial echocardiography allows detection of majority of residual defects after disconnection of cardiopulmonary bypass; however, additional or other intraoperative monitoring tools like hemodynamic pressure measurement and oxygen saturation step-up can result in the detection of more residual lesions with revision of cardiopulmonary bypass in the same surgical setting, thus saving these patients from reoperation and postoperative complications.

We recommend conjugation of epicardial echocardiography and intraoperative hemodynamic monitoring during surgical correction of children with congenital heart disease for better outcome and total repair during the same surgical setting as residual lesions represent a great burden in these patients.

Use of this protocol is accurate, economical, and a safe modality of investigation; it should be used routinely in all patients with congenital heart disease undergoing surgical repair; thus avoiding TEE complications and limitations in neonates.

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Conflicts of interest

There are no conflicts of interest.

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