Intraoperative Transesophageal Echocardiography in the Evaluation of Residual Gradients after Surgical Correction of Right and Left Ventricular Outflow Tract Obstructions

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Abstract

Background: Despite the large use of intraoperative Transesophageal Echocardiography (TEE) in congenital heart surgery, limited information is available regarding ventricular outflow tract obstruction.

Objective: The aim of this study was to assess the reliability of the post-bypass TEE to detect residual gradients in patients with ventricular outflow obstruction.

Patients and Methods: Post-bypass TEE peak systolic gradients of 127 patients (mean age of 7 years), being 79 with right ventricular outflow tract obstruction and 48 with left ventricular outflow tract obstruction, were compared with the postoperative TTE. Postoperative lesions were considered of hemodynamic significance when peak systolic gradient was higher than 40 mmHg.

Results: In patients with left ventricular outflow tract obstruction TEE showed mean peak systolic gradients higher than TTE (30 mmHg versus 24 mmHg; p= 0,014). In 75%, TEE gradients were lower than 40 mmHg and agreed with TTE in 97%. In the remaining patients, TEE gradients were higher than 40 mmHg and agree with TTE in 33%. In patients with right ventricular outflow tract obstruction TEE mean gradients agreed with TTE (28 mmHg versus 25 mmHg; p= 0.21). In 88%, TEE gradients were lower than 40 mmHg and agreed with TTE in 91.5%. In the remaining patients, TEE gradients were higher than 40 mmHg and agreed with TTE in 60%.

Conclusion: TEE showed to be a reliable technique to detect residual ventricular outflow tract obstructions in the majority of patients. However, when considered gradients higher than 40 mmHg, TEE suggested a greater severity of obstructions, particularly on the left side (Arq Bras Cardiol: Imagem cardiovasc. 2014;27(4):229-234).

Keywords: Echocardiography, Transesophageal; Ventricular Outflow Obstruction/surgery; Intraoperative Care.

Introduction

Transesophageal Echocardiography (TEE) has been an indispensable procedure in intraoperative monitoring of congenital and acquired heart diseases. Introduced in operating rooms in the mid-1980s, its usefulness and safety have been documented in a wide variety of congenital lesions[1-4]. TEE provides anatomical and functional pre-operative detailing, contributing to a better approach and strategy for correction, and after cardiopulmonary bypass, it allows evaluating surgical outcome and its complications, and its major impact related to the detection of significant residual defects that could compromise the prognosis of patients in the early or late postoperative period, leading to surgical revision in these cases[5-8].

Intraoperative TEE has been recommended in the evaluation of ventricular outflow obstruction, since residual gradients are important causes of morbidity and mortality in these cardiac defects. However, the medical literature presents few studies, mostly with a limited number of patients, evaluating the effectiveness of TEE in detecting residual obstructions, and there is still controversy of whether gradients detected immediately after Cardiopulmonary Bypass (CPB) would be strong indicators for recommending surgical revision to the patient.

The aim of this study was to evaluate the reliability of intraoperative TEE in detecting residual lesions through the gradient immediately after CPB, comparing the gradient obtained by Transthoracic Echocardiography (TTE) performed before the patient's discharge.

Patients and Methods

Patient Selection

Patients who underwent correction of right and/or left ventricular outflow obstruction, who underwent TEE during surgery, were selected.

The residual gradients obtained in the ventricular outflow tracts on TTE were compared to those obtained on TEE after CPB. TTE performed 30 days after surgery were considered for comparison. Patients with ventricular dysfunction were excluded.

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Post-bypass TEE

The tests were performed with off-the-shelf ultrasound equipment. In children younger than 15 kg, biplane pediatric esophageal transducer was used, while in patients heavier than 15 kg, an adult multiplane transducer was used. The echocardiographic planes were obtained as recommended by the American Society of Echocardiography (ASE), with special attention to transgastric planes of ventricular outflow tracts, which provide better alignment of blood flow with Doppler ultrasound beam[9,10].

Post-surgery TTE

All patients were restudied with transthoracic echocardiography from 1 to 30 days after surgical correction. Off-the-shelf ultrasound equipment with transducers ranging from 2.5 MHz to 7.5 MHz, depending on the patient's weight, were used.

Degrees of residual lesions

The maximum instantaneous systolic gradient was calculated from the peak velocity on continuous wave Doppler, using Bernoulli's modified equation. Gradients higher than 40 mmHg were considered significant. The gradients found on post-bypass TEE were compared to TTE before hospital discharge.

Statistical Analysis

Pearson's correlation coefficient was used to evaluate the correlation between the gradients found on TEE and TTE; Bland-Altman test was used to evaluate the differences between the measurements and the Kappa index was used to evaluate consistency between the values ranked as higher than 40 mm Hg or lower than/equal to 40 mmHg. The results were expressed as mean and standard deviation and $p = 0.05$.

Results

This study included 128 patients who underwent correction of obstructive lesions of the right and/or left ventricular outflow tracts. Six patients were excluded from the study, as three of them failed to present TTE within 30 days from the surgery, two of them presented poor image resolution to obtain residual gradient, and one of them presented severe right ventricular dysfunction after correction of tetralogy of Fallot. The results of 122 patients, out of 127 corrections (five patients had obstruction of both ventricular outflow tracts) were analyzed. There were no complications related to the tests in the patients studied. The median age was seven years (ranging from one month to 37 years). The mean interval between TEE and TTE was seven days (1 to 30 days). There were 79 corrections of right obstructions and 48 of left obstructions (Table 1 and 2).

Obstructions of the Right Ventricular Outflow Tract

The gradients obtained on post-bypass TEE in 79 patients with obstruction of the right ventricular outflow tract ranged from 4 mmHg to 80 mmHg with a mean of 28 mmHg. In the TTE of these patients, gradients ranged from 4 mmHg to 80 mmHg with a mean of 25 mmHg, with no significant difference ($p = 0.21$). Pearson's correlation was $r = 0.7$. Bland-Altman test revealed a mean difference between the gradients of 2.3 mmHg with limits of agreement of -22 mmHg to 28 mmHg. Kappa concordance index was 0.47 for ranked values (gradients higher or lower than/equal to 40 mmHg).

Residual gradients on TEE lower than 40 mmHg were consistent with those obtained by TTE in 65 of 71 patients (91.5%). In six patients, the degree of ventricular outflow obstruction was higher on TTE. In four of these, the residual gradients were not found in the outflow, but in a supravalvular pulmonary region or in pulmonary branches (Table 3).

In the other eight patients, the gradients on TEE were higher than 40 mmHg suggesting residual lesion. These gradients were confirmed by TTE in only four (50%) patients, three of which after surgical correction of pulmonary atresia and one after correction of tetralogy of Fallot with pulmonary valvotomy. In four patients, the gradients were lower on TTE. In two of these, there was a hyperdynamic intraventricular component on post-bypass TEE (Table 4).

Table 1 – Patients with right ventricular outflow obstruction

N	Diagnoses	Additional diagnoses
47	Tetralogy of Fallot	Pulmonary atresia (N=7), Previous correction (N=11)
9	Valvular and pulmonary subvalvular stenosis	VSD (N=2), ASD (N=2), Supravalvular PS/Supravalvular AoS (N = 2), Severe TR (N=1)
7	Subvalvular PS/DORV with previous correction	LV Obstruction - Ao N = 1
6	RV Anomalous Bundle	Subvalvular AoS (N=1), major TR (N=1)
4	Truncus with RV obstruction — Postoperative PT	Severe MR (N=1)
2	Removal of pulmonary artery banding	DORV (N=1), VSD/AoS and operated CoA (N=1)
2	AVSD with pulmonary subvalvular stenosis	Intermediate Form (N=1)
2	Supravalvular PS after Jatene procedure (arterial switch).	Residual VSD (N=1)

Ao: aorta; ASD: atrial septal defect; VSD: ventricular septal defect; CoA: coarctation of the aorta; AVSD: atrioventricular septal defect; DORV: double outlet; RV; AoS: aortic stenosis; PS: pulmonary stenosis; N: number of patients; MR: mitral regurgitation; TR: tricuspid regurgitation; PT: pulmonary trunk; RV: right ventricle; LV: left ventricle.

Table 2 – Patients with obstruction of left ventricular outflow

N	Diagnoses	Additional diagnoses
23	Subvalvular AoS	Valvular AoS (N=4) other: MR, MS, anomalous RV, PO VSD, PO AVSD, RAo bundle
11	Valvular AoS	VSD/Operated CoA/PA bundle (N=1), CoA (N=1), AoS reoperation (N=1)
4	Supravalvular AoS	Supravalvular PS (N=2)
7	TGA with PS:	VSD + PA bundle (N=1) Subvalvular VSD + PS (N=4) PO Mustard/Senning + Subvalvular PS (N=2)
2	CTGA with PS	VSD (N=2)
1	DORV with LV stenosis - Ao after correction	Subvalvular PS (N=1)

Ao: aorta; PA: pulmonary artery; CoA: coarctation of the aorta; VSD: ventricular septal defect; AVSD: atrioventricular septal defect; DORV: double outlet right ventricle; AoS: aortic stenosis; MS: mitral stenosis; PS: pulmonary stenosis; N: number of patients; PO: Postoperative; AR: aortic regurgitation; MR: mitral regurgitation; CTGA: corrected transposition of the great arteries; TGA: transposition of the great arteries; RV: right ventricle; LV: left ventricle.

Table 3 – Patients with residual gradients ≤ 40 mmHg on TEE and > 40 mmHg on TTE on the right ventricular outflow

Diagnoses	Gradients on post-bypass TEE	Gradients on TTE
T4F	30 mmHg	Supravalvular 50 mmHg
T4F + PV agenesis	20 mmHg	Supravalvular 50 mmHg
ASD + IPVS	25 mmHg	Supravalvular 45 mmHg
Anomalous bundle + ASD	40 mmHg	45 mmHg
DORV/TB/PA banding	80/40 mmHg(*)	47 mmHg
T4F+ AVSD	40 mmHg	70 mmHg

AVSD: atrioventricular septal defect; DORV: double outlet right ventricle; IPVS: infundibular-pulmonary valve stenosis; PA: pulmonary artery; PV: pulmonary valva; T4F: tetralogy of Fallot; TB: Taussig Bing; (*) After initial evaluation with a gradient of 80 mmHg a new surgical approach was conducted and the gradient decreased to 40 mmHg on TEE.

Table 4 – Patients with residual gradients > 40 mmHg on TEE and ≤ 40 mmHg on TTE in the right ventricular outflow

Diagnoses	AO post-bypass	Gradients on TTE
T4F	57 mmHg	12 mmHg
T4F	50 mmHg	30 mmHg
T4F	80/80 mmHg (*)	40 mmHg
DORV/PA bundle	45 mmHg (Infund.: 25 mmHg)	36 mmHg

PA: pulmonary artery; DORV: double outlet right ventricle; Infund: infundibular; T4F: tetralogy of Fallot; (*) after initial evaluation with a gradient of 80 mmHg a new surgical approach was conducted and the gradient remained 80 mmHg.

Obstruction of the Left Ventricular Outflow

The gradients obtained on post-bypass TEE in 48 patients with obstruction of the left ventricular outflow ranged from 4 mmHg to 70 mmHg with a mean of 30 mmHg. The gradients on TTE, in these patients, ranged from 4 mmHg to 67 mmHg, with a mean of 24 mmHg. TTE showed higher residual gradients than TTE ($p = 0.014$). Pearson's correlation was $r = 0.6$. The Bland-Altman test revealed a mean difference between the gradients of 4.9 mmHg, with concordance limits of -22 mmHg to 30 mmHg. The Kappa concordance index was 0.40 for gradients higher or lower than/equal to 40 mmHg. We observed that the residual gradients on TEE and on TTE was equal or lower than 40 mmHg in 97% (35 of 36 patients). In the other twelve patients, residual gradients on TEE were higher than 40 mmHg, consistent with the TTE in four patients. Although TEE suggests residual obstruction in the other eight patients, this was not confirmed on TTE, which showed lower gradients (Figures 1 and 2). In three of these cases, there was a hyperdynamic intraventricular component on post-bypass TEE (Table 5).

Discussion

The challenge of this study was to evaluate when the detection of residual gradients on post-bypass TEE at the

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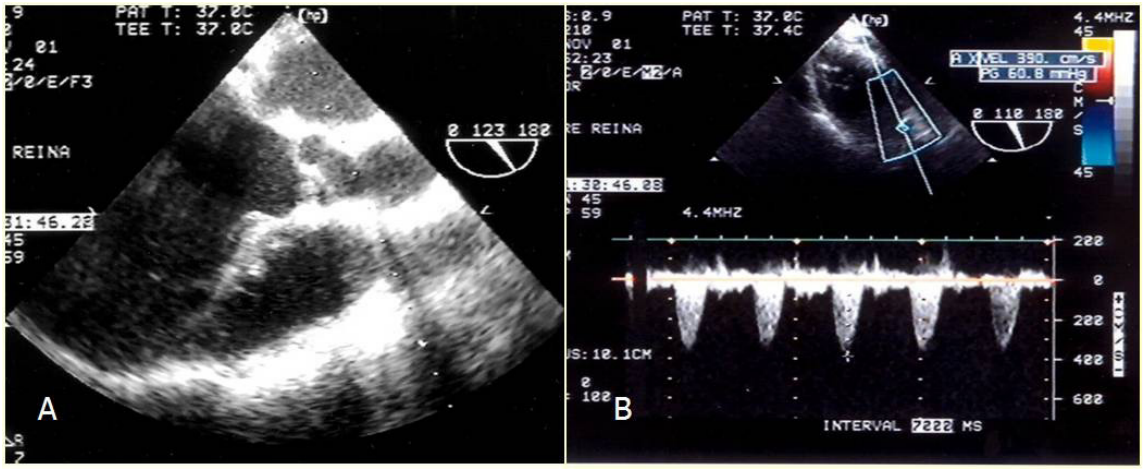

Figure 1 – *Post-bypass TEE on patient undergoing resection of subaortic membrane. A: Longitudinal plane showing no outflow obstruction. B: Residual gradient of 60 mmHg detected by continuous wave Doppler in transgastric view.*

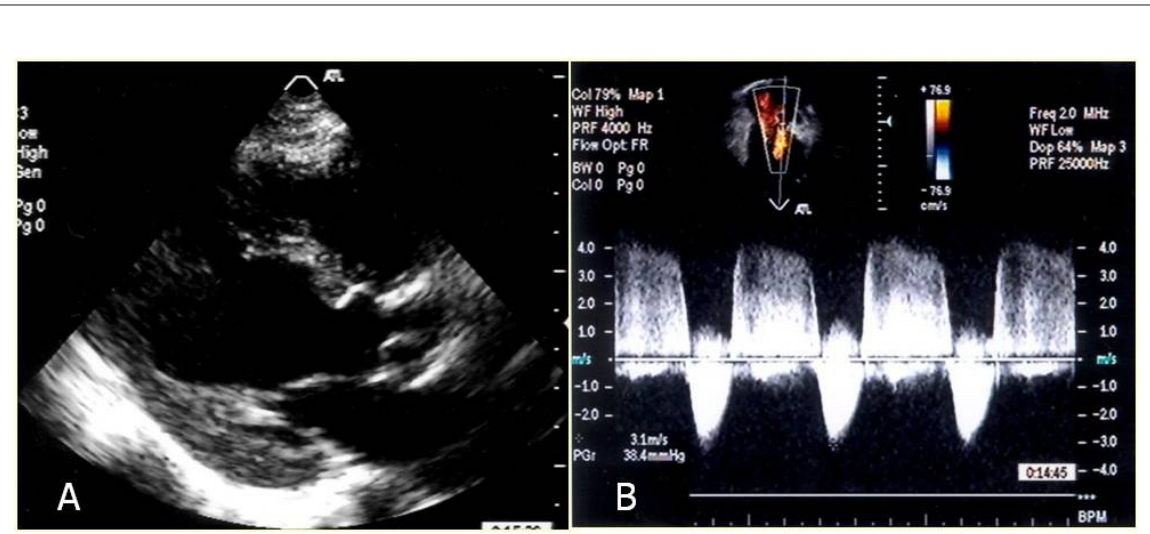

Figure 2 – *TTE of the same patient of Figure 1 performed seven days following surgery. A: parasternal longitudinal axis showing outflow free of obstruction. B: residual gradient of 38 mmHg detected by continuous Doppler in apical 5-chamber view.*

ventricular outflow predicts TTE gradients of discharge control and, consequently, when these gradients observed in surgery accurately demonstrate residual lesions. It is known that gradients higher than 40 mmHg would not be acceptable and a new CPB for reviewing surgical repair would be advisable[11]. Post-bypass TEE gradients were lower than 40 mmHg in most patients and consistent with those obtained on TTE (91.5% and 97%) in both ventricles, demonstrating good correlation with the correction of ventricular outflow obstruction. However, more distal stenoses were not diagnosed in five patients, probably due to the difficulties of alignment between the Doppler beam and blood flow and proximal view of the pulmonary branches and the ascending aorta on TEE.

Post-bypass TEE gradient was higher than 40 mmHg in 11% of patients with obstruction of the right ventricular outflow tract, and in 25% of patients with obstruction of the left ventricular outflow tract, but was lower on TTE in 50% and 67%, respectively, even without further surgical intervention and preserved ventricular contractility. A hyperdynamic

Table 5 – Patients with residual gradients > 40 mmHg on TEE and ≤ 40 mmHg on TTE on the left ventricular outflow

Diagnoses	Gradients on TEE post-bypass	Gradients on TTE
Subvalvular AoS	60 mmHg (**)	12 mmHg
Valvular and subvalvular AoS	60 mmHg (**)	38 mmHg
Valvular and subvalvular AoS	80/60 mmHg (*)	34 mmHg
Valvular AoS	50 mmHg	20 mmHg
Subvalvular AoS	46mmHg (**)	16 mmHg
Valvular and subvalvular AoS	49 mmHg	30 mmHg
Valvular AoS/valvular replacement	49 mmHg	30 mmHg
Valvular AoS/valvular replacement	45 mmHg	40 mmHg

AoS: aortic stenosis; (*) after initial evaluation with a gradient of 80 mmHg, a new surgical approach was conducted and the gradient decreased to 60 mmHg; (**) intraventricular hyperdynamic component.

myocardial component of the ventricular outflow tract on post-bypass TEE in many of these patients can generate overestimated systolic gradients even after adequate relief of obstruction.

Such behavior appears to result from the effects of long-term myocardial hypertrophy, the level of inotropic support, peripheral vasodilation and higher level of catecholamines[12]. In these patients, if we took into account only the criterion of a high gradient, which would indicate the need for a new CPB for surgical revision of the residual lesion. In the case of a high residual gradient, an appropriate decision regarding a new CPB requires experience and careful evaluation of surgical data, such as the degree of obstructive lesion resection, ventricular hyperdynamic state, outflow tract diameters and hemodynamic stability.

TEE should seek to establish the outflow tract morphology, confirming the full resection of the obstruction and the mechanisms of residual obstruction, whether dynamic or fixed, looking for any insights to suspect that the patient would really benefit from a new surgical intervention. Moreover, many parameters are changed and the surgical team must await patient stabilization and should not be carried away by the anxiety for immediate operative outcomes.

Ideally, the hemodynamic conditions must be balanced and similar to what the patient had before the surgery. Despite the difficulties of interpreting the real meaning of a high post-bypass gradient, this data is an important alert to carefully evaluate the anatomy of ventricular outflow, indicating or not, in a more conscious and safer manner, a new CPB for surgical revision of the residual lesion, as in some cases the best possible has already been done.

Limitations

Although stable hemodynamic conditions have been reported during TEE, a direct correlation between blood pressure levels and medication doses was not made during the test due to the retrospective nature of the study.

The population of patients studied had a bias of post-bypass TEE due to the expected risk of residual lesions in the postoperative period, high complexity, associations of defects and reoperations, and no patients with simple defects were included.

Conclusions

Post-bypass TEE proved to be a useful and reliable technique in detecting residual lesions with a good correlation with TTE in the vast majority of patients. When we consider gradients above 40 mmHg, TEE may overestimate the severity of ventricular outflow obstruction, particularly on the left side, and a hyperdynamic ventricular component should be ruled out before recommending surgical revision of the residual lesion solely based on the gradient. Special attention should be given to the pulmonary trunk and branches, avoiding a failed diagnosis of distal residual obstructions.

Authors' Contribution

Research design: Pachon DQV, Morhy SS, Andrade JL; Data sourcing: Pachon DQV, Morhy SS, Andrade JL, Cassar RS, Coimbra VG, Tavares GMP, Jatene MB; Analysis and interpretation of data: Pachon CVD, Morhy SS, Andrade JL; Statistical analysis: Pachon DQV, Morhy SS, Andrade JL; Manuscript drafting: Pachon DQV; Critical revision of the manuscript as for important intellectual content: Pachon DQV, Morhy SS, Andrade JL, Miura N, Kalil-Filho R.

Potential Conflicts of Interest

No relevant potential conflicts of interest.

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Academic Association

This study is not associated with any graduate programs.

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