Echocardiographic assessment of right ventricular functions in children after surgical repair of Tetralogy of Fallot

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Introduction Tetralogy of Fallot (TOF) is the most common form of cyanotic congenital heart disease. Between 3.5 and 10% of the patients with congenital heart disease have TOF, with males and females being affected equally.

Aim The aim of this study is to assess right ventricular (RV) functions in children after surgical repair of TOF and to detect echocardiographic indices of prognostic value in these cases.

Patients and methods This is a cross-sectional analytic study. It was conducted at Bab Elsharia Hospital of Al-Azhar University in Cairo over a period of 18 months from May 2017 till October 2018. It included 30 children who underwent surgical repair for TOF.

Results A study was conducted on 30 children, comprising 11 male and 19 female children, and their mean age was 54.30 ±24.30 months. RV function assessment has been employed by MRI in eight cases, and conventional two-dimensional and Doppler echocardiography and finally tissue Doppler imaging in all cases. Postoperative echocardiography showed that the mean value of tricuspid annular plane systolic excursion was 14.78±4.53 mm, Myocardial Performance Index was 0.45 ±0.07, and RV end-diastolic diameter/left ventricular end-diastolic diameter was 1.03±0.27.

Conclusions After surgical repair of TOF, the RV systolic and diastolic dysfunction can be detected in most patients by echocardiography in the form of prolonged Myocardial Performance Index, low value of tricuspid annular plane systolic excursion, and decreased myocardial velocities of RV. There is a significant relation between the use of transannular patch and RV dysfunction after complete surgical repair of TOF.

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Introduction

Tetralogy of Fallot (TOF) is the most common form of cyanotic congenital heart disease (CHD). CHD occurs in ~1% of live births [1]. A number of studies indicate that the prevalence of TOF ranges from 2.8 to 3.9 per 10 000 live births, with males and females being affected equally. Between 3.5 and 10% of the patients with CHD have TOF [2].

The main feature of TOF is a ventricular septum defect with anterior deviation of the outlet septal defect, leading to infundibular subpulmonary stenosis and placing the aorta in an overriding position with possible hypoplasia of the main pulmonary artery and its side branches can occur, together with hypertrophy of the right ventricle (RV) [3].

The complete surgical correction was first introduced in 1955, and it is now used all over the world [4].

Initial TOF repair was mostly performed with transannular RV outflow tract patch to relieve the obstruction. In most cases what we obtain after this surgical correction is far from a complete resolution of the disease, rather it is an excellent palliation that solves the problem of cyanosis but predisposes the patients to subsequent interventions to treat the surgical sequelae. Nowadays, the most diffused surgical strategy is based on the presumption that the pulmonary annulus may be preserved and that a mixed lesion of moderate pulmonary stenosis and associated insufficiency is superior to the complete relief of obstruction and free pulmonary regurgitation (PR) [5,6].

In the long term, the residual pulmonary stenosis that remains after this conservative surgical approach and the free PR caused by the transannular patch (TAP) graft used to enlarged the RV outflow tract lead to the development of two pathophysiological conditions of the RV very different one from each other: RV hypertrophy and RV dilation [7].

Echocardiography is a noninvasive and useful tool for diagnoses. Echocardiography derives morphological and functional RV variables, including RV fractional

area of change, tricuspid annular plane systolic excursion (TAPSE), and RV Tei index [8].

Aim

The aim of this study is to assess RV functions in children after surgical repair of TOF and to detect echocardiographic indices of prognostic value in these cases.

Patients and methods

This is a cross-sectional analytic study. It was conducted at Bab Elsharia Hospital of Al-Azhar University in Cairo over a period of 18 months from May 2017 till October 2018. The Hospital Research Ethical board (REB) granted an approval for this study and access to clinical data. The study included 30 children in the status of postoperative repair of TOF. Overall, 80% of the patients had transatrial approach and 20% had transventricular approach for surgical repair. TAP was done in 63.3% of patients, whereas 36.7% had valve-sparing surgery without using the patch.

Inclusion criteria

The study included pediatric age group from 1 to 18 years, who were evaluated 6 months after surgical repair of TOF.

Exclusion criteria

Children with less than 6 months from the time of repair and children with diagnosis of TOF but did not undergo surgery yet were excluded.

Methods

All the included patients were subjected to the following: detailed history, clinical examination, and two-dimensional transthoracic echocardiography, with detailed assessment of RV functions. Moreover, cardiac MRI was done for eight patients.

M-mode echocardiography was done to evaluate the following:

(1) TAPSE: It has been proposed as a reliable objective index of RV systolic function. The values above 20 mm are considered normal. Decreases in TAPSE correlate with decrease in RV function [9].
(2) The left ventricular systolic function by fractional shortening (%) and ejection fraction (EF, %).
(3) Right ventricular end-diastolic dimension (RVEDD, mm).

Doppler echocardiography for measurement of the following:

(1) Residual right ventricular outflow tract obstruction (RVOT) gradient.
(2) E/A ratio for evaluation of RV diastolic function, where E is peak velocity of early diastolic wave of tricuspid inflow velocities and A is peak velocity of late diastolic wave of tricuspid inflow velocities.
(3) Pulmonary valve (PV) systolic velocity (m/s).

Color Doppler echocardiography was done for detection of the following:

(1) Residual ventricular septal defect (VSD) leak.
(2) Tricuspid regurgitation.
(3) Degree of pulmonary incompetence.
(4) Aortic regurgitation.
(5) RV Myocardial Performance Index (MPI) (Tei index):

It is a parameter that has been validated as a measure of both systolic and diastolic function of the RV and is free of errors generated by the geometry of the ventricle. Normal values for this index for children are 0.32±0.04 (Fig. 1).

It is unaffected by heart rate, loading conditions, or the presence and the severity of tricuspid regurgitation [13].

Collection of data

We reviewed our institutional database of patients' charts that prospectively captures clinical, laboratory, echocardiographic, and cardiac MRI data.

Statistical analysis

Data were presented, and suitable analysis was done according to the type of data obtained for each parameter.

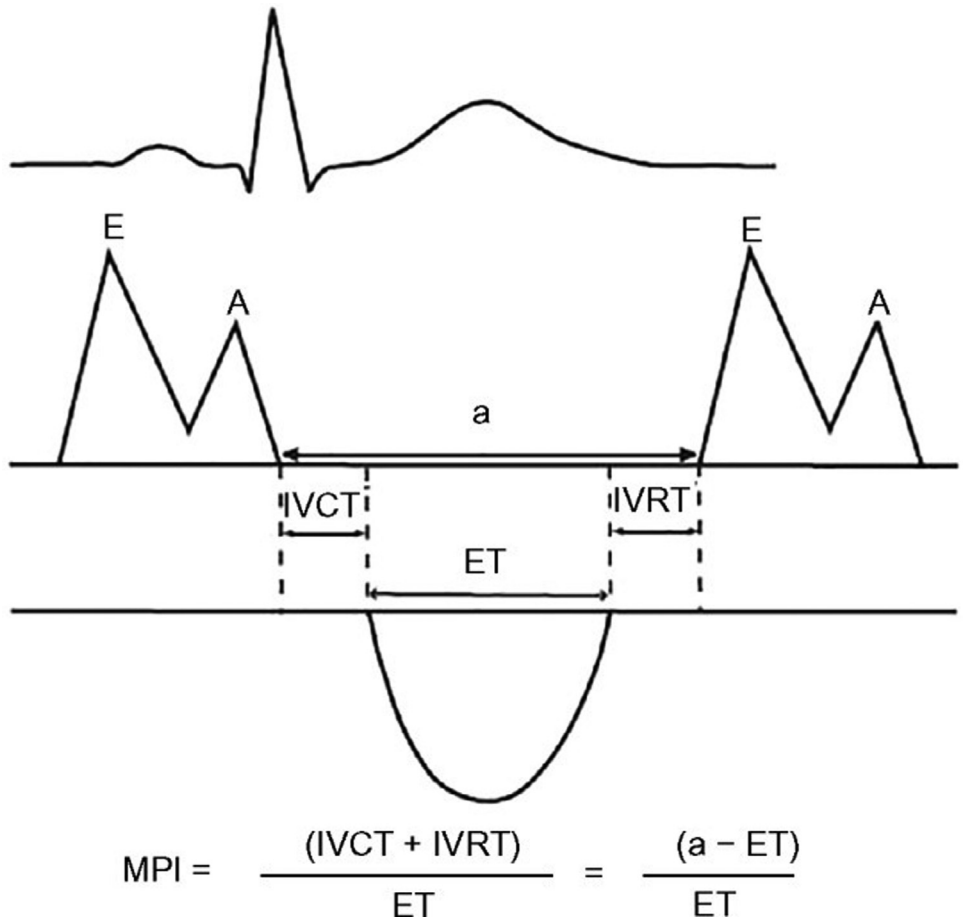
(1) For descriptive statistics: mean±SD, range, median, interquartile range, frequency, and percentage were used.
(2) For analytical statistics, dependent paired *t*-test, χ^2-test, and Pearson's correlation coefficient (*r*) were used.

Statistical significance was set as follows: *P* value more than 0.05 is nonsignificant, *P* value less than 0.05 is significant, and *P* value less than 0.01 is highly significant.

Results

In this study, the mean age at operation was 39.30 ±18.60 months, and mean postoperative follow-up on

Figure 1



Myocardial Performance Index (MPI). ET, ejection time; IVCT, isovolumic contraction time; IVCT, isovolumic contraction time; IVRT, isovolumic relaxation time.

study was 54.30±24.30 months. The mean weight at operation was 13.6±2.6 kg, and at the time of study was 17.08±4.00 kg. Male-to-female ratio was 1 : 1.58. The most common preoperative symptoms encountered were cyanosis, cyanotic spells, and exercise intolerance. It was found that 63.3% of those patients had cyanotic spells before operation. Their mean oxygen saturation was 77.83±5.77%. Preoperative β-blocker therapy was prescribed in 56.7% of the total patients with TOF. Overall, 30% of the patients had undergone modified Blalock–Taussig *shunt* as palliative shunts (Table 1).

Moreover, 30% of the patients had undergone preoperative cardiac catheterization. The mean PV annulus diameter was 9.20±1.67 mm. Moreover, the mean right pulmonary artery diameter was 9.52 ±2.10 mm, and the mean left pulmonary artery diameter was 9.11±1.84 mm. The calculated mean of the McGoon ratio was 2.18±0.34. Preoperative catheterization has shown that all patients had normal coronary anatomy with no additional VSD,

Table 1 Clinical characteristics of studied patients (*N*=30 cases)

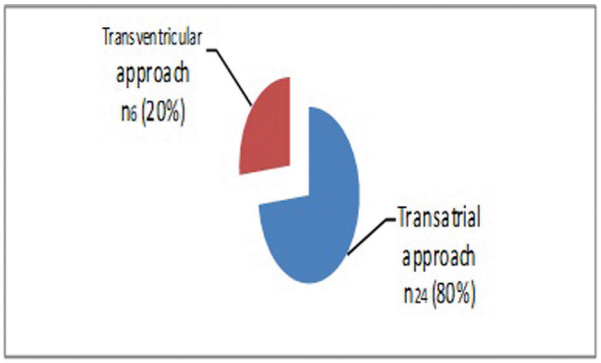
	n (%)
Sex	
Male	11 (36.7)
Female	19 (63.3)
Age at operation (months)	
Range	9.0–91.0
Mean±SD	39.30±18.60
Body weight at operation (kg)	
Range	8.0–22.0
Mean±SD	13.6±2.6
Cyanotic spells	
No	11 (36.7)
Yes	19 (63.3)
History of palliative operation (Blalock–Taussig shunt)	
No	21 (70.0)
Yes	9 (30.0)
History of drug therapy (β-blocker)	
No	13 (43.3)
Yes	17 (56.7)
McGoon ratio	
Mean±SD	2.18±0.34
Preoperative oxygen saturation (%)	
Mean±SD	77.83±5.77

Table 2 Distribution of studied patients according to preoperative catheter data (*N*=9 cases)

	n (%)
Pulmonary annulus (mm)	
Mean±SD	9.20±1.67
Right pulmonary artery diameter (mm)	
Mean±SD	9.52±2.10
Left pulmonary artery diameter (mm)	
Mean±SD	9.11±1.84
McGoon ratio	
Mean±SD	2.18±0.34
Additional VSD	
No	9 (100)
Yes	0 (0.0)
Coronary abnormalities	
NO	9 (100)
Yes	0 (0.0)
ASD	
No	8 (88.9)
Yes	1 (11.1)
PDA	
No	7 (77.8)
Yes	2 (22.2)

ASD, atrial septal defect; PDA, patent ductus artery; VSD, ventricular septal defect.

Figure 2



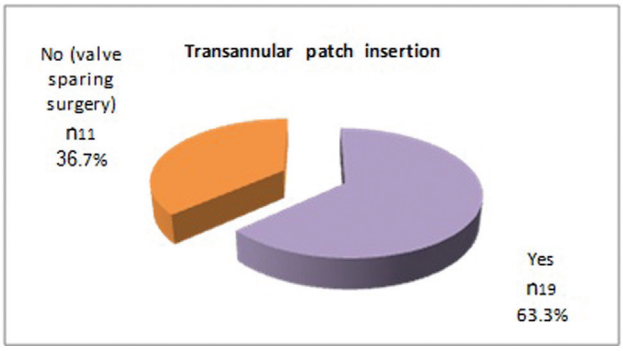
Surgical technique.

whereas 11.1% had atrial septal defect and 22.2% had patent ductus artery (Table 2).

Concerning the type of surgery, 80% of the patients had transatrial approach and 20% had transventricular approach for surgical repair (Fig. 2). TAP was done in 63.3% of patients, whereas 36.7% had valve-sparing surgery without the use of the patch (Fig. 3).

Follow-up by two-dimensional echocardiography showed that the mean tricuspid valve (TV) annulus diameter was 25.86±5.49 mm, mean mitral valve annulus diameter was 19.68±2.98 mm, and mean PV annulus diameter was 14.98±2.14 mm, and there were

Figure 3



Tranannular patch insertion.

Table 3 Distribution of studied patients according to postoperative two-dimensional echocardiographic data (*N*=30 cases)

Variables	
Tricuspid valve annulus (mm)	
Range	17.0–39.0
Mean±SD	25.86±5.49
Mitral valve annulus (mm)	
Range	16.0–27.0
Mean±SD	19.68±2.98
Pulmonary valve annulus (mm)	
Range	11.0–20.0
Mean±SD	14.98±2.14
Postoperative pulmonary branch stenosis [*n* (%)]	
No	28 (93.30)
Yes	2 (6.70)

only two cases that had postoperative pulmonary artery branch stenosis (Table 3).

The mean value of TAPSE measured by M-mode was 14.78±4.53 mm. It was found that 80% of the patients had TAPSE less than 20 mm. It was also found that there was a significant relationship between frequency of cyanotic spells preoperatively and TAPSE measured postoperatively (*P*=0.022) (Fig. 4).

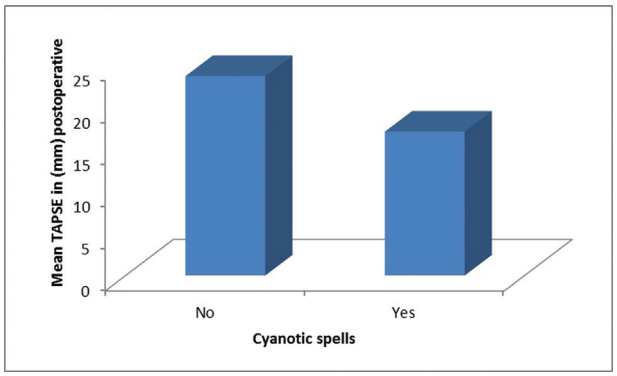
The mean value of E/A ratio was 0.88±0.2.

Residual VSD was detected by color Doppler echocardiography in 4 patients; the residual leak was small and did not require surgical closure.

The postoperative follow-up echocardiography result showed that only 3.3% of patients had trivial PR, 23.3% had mild degree of PR, 63.4% had moderate-to-severe PR, and 10.0% had severe PR (Table 4).

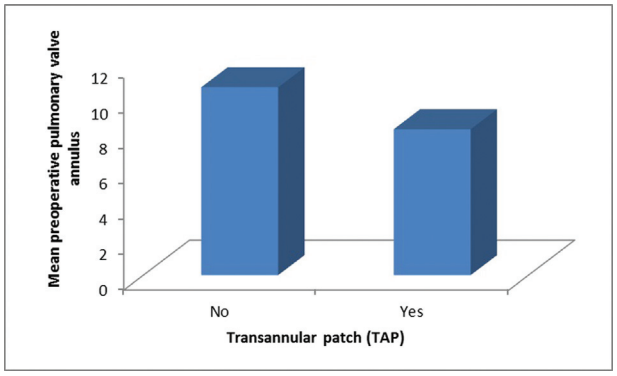
There was a highly significant relation between preoperative PV annulus diameter and the need

Figure 4



Simple bar chart showing mean tricuspid annular plane systolic excursion (TAPSE) postoperative and preoperative cyanotic spells.

Figure 5



Simple bar chart showing the relation between transannular patch (TAP) with preoperative pulmonary annulus.

of its augmentation by TAP insertion ($P<0.001$) (Fig. 5). There was a significant relationship between use of TAP and the incidence of PR (Fig. 6).

Regarding tricuspid regurgitation, 26.7% of patients had trivial TR, 40% had mild TR, 23.3% had moderate-to-severe TR, and 10% had severe TR. Concerning aortic regurgitation, only 4 patients (13.3%) had mild aortic regurgitation, which was detected by color Doppler echocardiography. The mean value of MPI was 0.45±07 (Table 4).

Preoperative and postoperative RVOT gradients were compared. Its mean preoperative value was 84.0 ±7.29 mm Hg and dramatically decreased postoperatively to 25.03±12.97 mmHg ($P<0.001$). Both left ventricular end-diastolic diameter (LVEDD) and left ventricular end-systolic diameter were significantly increased compared with preoperative data ($P<0.008$ and <0.001, respectively) (Table 5).

Table 4 Distribution of studied patients according to postoperative two-dimensional transthoracic echocardiography (*N*=30 cases)

	n (%)
Residual VSD	
No	26 (86.7)
Yes	4 (13.3)
Pulmonary regurgitation	
Trivial	1 (3.3)
Mild	7 (23.3)
Moderate-to-severe	19 (63.4)
Severe	3 (10.0)
Tricuspid regurgitation	
Trivial	8 (26.7)
Mild	12 (40.0)
Moderate-to-severe	7 (23.3)
Severe	3 (10)
Aortic regurgitation	
No	26 (86.7)
Mild	4 (13.3)
TAPSE (mm)	
Mean±SD	14.78±4.53
MPI	
Range	0.36–0.66
Mean±SD	0.45±07

MPI, Myocardial Performance Index; TAPSE, tricuspid annular plane systolic excursion; VSD, ventricular septal defect. No, the patch was not used. Yes; the patch was used.

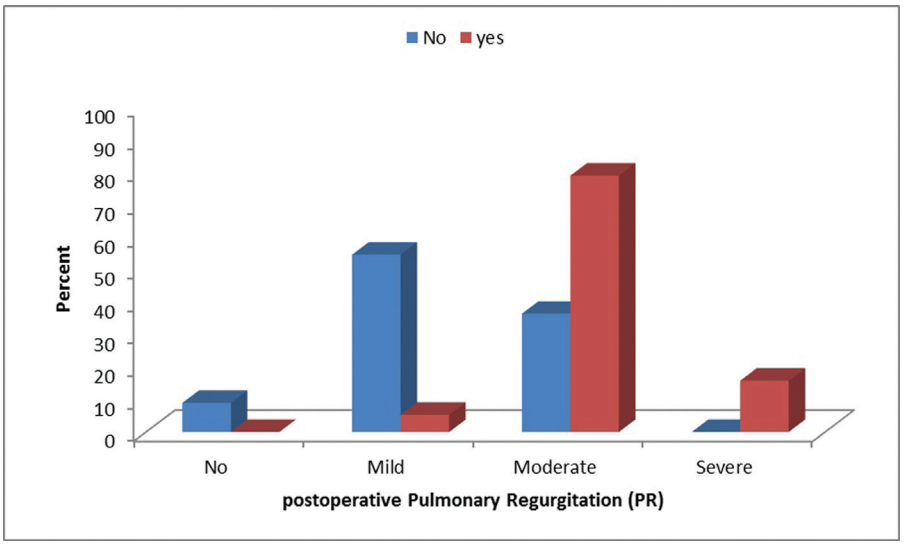
Decreased myocardial velocities were reported in patients after TOF repair, as the mean value of the peak myocardial velocity during systole (Sa) was 5.36 ±1.47 cm/s, early diastole (Ea) was 7.8±2.66 cm/s, and late diastole (Aa) was 3.56±0.58 cm/s, measured at the base of the free wall of the RV (Table 6).

A significant correlation between value of TAPSE and myocardial velocities by tissue Doppler echocardiography measured postoperative was reported (Fig. 7).

Comparison between TOF repair being performed at less than and more than 1 year of age showed that repair at less than 1 year of age had better results regarding TAPSE ($P<0.018$), RVEDD ($P<0.001$), LVEDD ($P<0.001$), and EF ($P<0.001$) (Table 7).

Cardiac MRI was done in eight patients who needed cardiac MRI, as they had moderate-to-severe PR on echocardiography. Left ventricular size and function were generally normal. Measurements of the RV dimensions showed dilated RV in all patients; the mean value of EDV is 186.0±72.13 ml, the mean value of ESV is 89.0±38.98 ml, and the mean value of EF is 53.5±9.96%. Two patients had mild RV dilatation, with indexed end-diastolic RV volume measuring 96 and 101 ml/m^2 correspondingly. The rest of the patients had severe RV dilatation with

Figure 6



Combined bar chart showing the relation between transannular patch and postoperative pulmonary regurgitation (PR).

Table 5 Preoperative and postoperative echocardiographic data (*N*=30 cases)

Mean±SD	Preoperative	Postoperative
RVOT gradient (mmHg)	84.0±7.29	25.03±12.97
RVEDD (mm)	35.24±7.32	32.01±4.9
LVEDD (mm)	28.76±6.79	34.13±8.39
RVEDD/LVEDD	1.28±0.33	1.03±0.27
LVESD (mm)	16.69±5.09	23.05±6.22
FS (%)	30.72±5.62	33.10±6.09
EF (%)	56.50±9.44	59.03±10.08

EF, ejection fraction; FS, fractional shortening; LVEDD, left ventricular end-diastolic diameter; LVESD, left ventricular end-systolic diameter; RVEDD, right ventricular end-diastolic diameter; RVOT, right ventricular outflow tract obstruction.

Table 6 Distribution of studied patients according to postoperative tissue Doppler echocardiographic data (*N*=30 cases)

	Range	Mean±SD
Tissue Doppler echocardiography		
Sa (cm/s)	3.2–7.80	5.36±1.47
Ea (cm/s)	2.90–11.30	7.8±2.66
Aa (cm/s)	2.30–4.30	3.56±0.58

Aa, late diastole; Ea, the mean value of early diastole; Sa, the peak myocardial velocity during systole. Decreased myocardial velocities were reported in patients after Tetralogy of Fallot repair.

indexed end-diastolic RV volume ranging from 166 to 259 ml/m^2 (Table 8).

Discussion

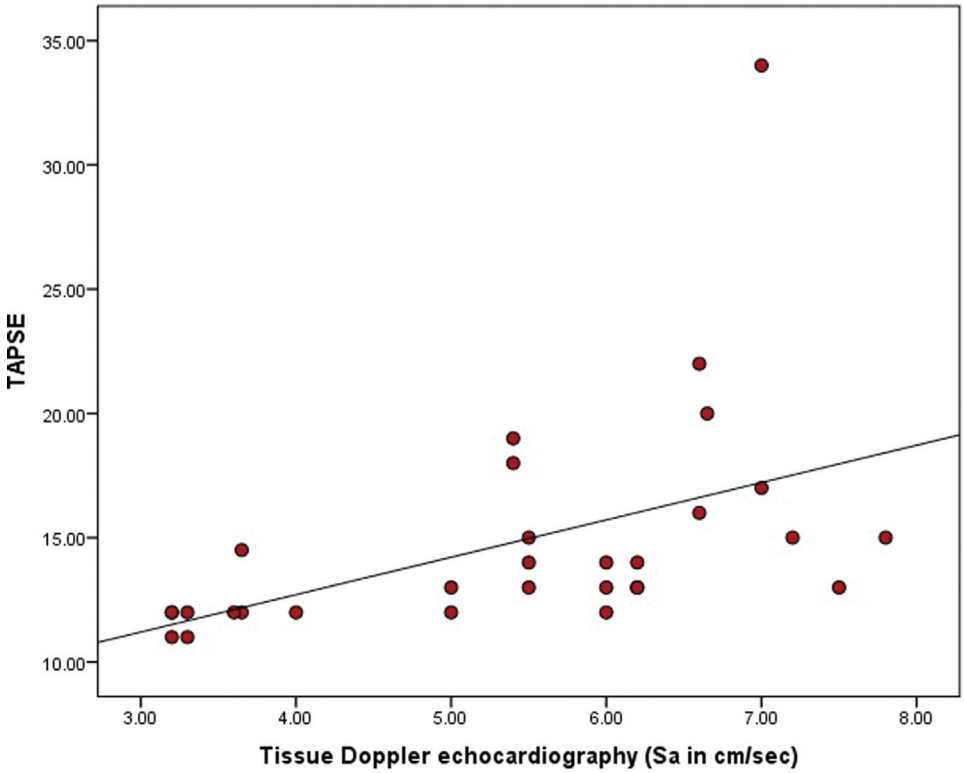
Transatrial approach was done on 80% of the studied patients. Alexiou *et al.* [10] found similar results in their study where more than two-third of the cases were performed through transatrial approach. This may be owing to the advantages of transatrial approach, which include the following: the long-term function of the RV is preserved when a ventriculostomy is avoided, the risk of injuring a major ventricular branch of the right coronary artery or an anomalous left coronary artery is minimized, and the ventriculostomy site can be the site of origin of serious life-threatening ventricular arrhythmias [11].

It was found that 80% of the patients had TAPSE less than 20, indicating an abnormal RV function. This can be attributed to the fact that PR results in volume overload of the RV and progressive dilatation over time, which leads to RV dysfunction and a lower value of TAPSE. Ho *et al.* [11] showed in their study that patients with severe PR had a mean TAPSE of 18.5±3.2 mm.

The significant relationship between frequency of cyanotic spells preoperatively and TAPSE measured postoperatively may be attributed to the degree of severity of TOF before corrective surgery, which leads to RV dysfunction that occurs before operation and continues postoperatively.

RV diastolic function abnormalities often occur in patients following repair of TOF. Those with a restrictive physiology had abnormal transtricuspid flow patterns, as shown by lower peak E velocity and lower E/A velocity ratio. There are various mechanisms that may lead to RV restriction, such as inadequate intraoperative protection and chronic hypoxemia. Sachdev *et al.* [12] had similar results to

Figure 7



Scatterdot graph showing correlation between tricuspid annular plane systolic excursion (TAPSE) with tissue Doppler echocardiography.

Table 7 Comparison between tricuspid annular plane systolic excursion in groups performed repair less than and more than or equal to 1 year

	<1 year	≥1 year	Test of significance	*P*
TAPSE				
Range	14.50–34.0	11.0–18.0	2.918	0.018
Mean±SD	19.28±6.09	13.24±1.87		
Median	18.0	13.00		

There is significant difference between TAPSE in groups performed repair less than and more than or equal to 1 year. TAPSE, tricuspid annular plane systolic excursion. $P<0.05$, statistically significant difference.

our study as they had lower peak E velocity and lower E/A ratio (0.98±0.17).

PR has been shown to be related to the use of TAP during RVOT reconstruction and aggressive infundibulectomy involving the PV annulus.

Concerning TAP use, it appeared that the frequency of use of TAP is determined by the severity of hypoplasia of pulmonary annulus and not the age or the surgical approach. There is no consistency about when to place a TAP. Some surgeons use the size of annulus as compared with normal, but criteria are ill defined.

Tricuspid regurgitation is usually a consequence of progressive RV dilatation with subsequent annular dilatation of the TV, but it could be secondary to surgical injury.

A higher than normal MPI was indicative of reduced global RV function. The prolonged MPI is a reflection of reduced RV EF. Compared with normal children, operated patients with TOF had a longer isovolumetric contraction time (ICT), resulting in a higher MPI. Prolongation of the RV ICT may be explained by possible elevation of RV end-diastolic pressure secondary to PR, resulting in earlier closure of TV and thus earlier onset of the RV ICT. This means that MPI can be used as a helpful tool to assess RV function in cases of postoperative TOF.

Both LVEDD and left ventricular end-systolic diameter were significantly increased compared with preoperative data. This may be owing to the pathophysiology of TOF, which is characterized by reduced pulmonary blood flow, hence an untrained left ventricle. Advanced echocardiographic assessment of

Table 8 Postoperative cardiac MRI data of right ventricle (*N*=8 cases)

Right ventricle	Range	Mean±SD
EDV (mm)	96.0–256.0	186.0±72.13
ESV (mm)	33.0–135.0	89.0±38.98
SV (mm)	15.40–45.0	28.76±6.79
EF (%)	39.0–66.0	53.5±9.96
FS (%)	30.0–43.0	36.12±4.36
RVEDD (mm)	21.0–40.0	29.75±5.55
RVESD (mm)	18.0–30.0	21.62±4.03

EDV, end-diastolic volume; EF, ejection fraction; ESV, end-systolic volume; FS, fractional shortening; SV, stroke volume; RVEDD, right ventricular end-diastolic diameter; RVESD, right ventricular end-systolic diameter.

RV function including measurements of myocardial velocities may provide new insight into RV function under abnormal loading conditions. Decreased myocardial velocities were reported in patients after TOF repair compared with normal values. This observation suggests that patients after TOF repair may have decreased intrinsic myocardial contractility of the RV. Several causes can be postulated including chronic cyanosis before repair, intrinsic myocardial fibrosis, scars after open-heart surgery, and interventricular interactions.

The significant correlation between value of TAPSE and myocardial velocities indicates that TAPSE is a good method for RV functions assessment.

The RV dysfunction was present in patients following complete surgical repair of TOF with variable degrees. Serial monitoring of the RV MPI, TAPSE, and tissue Doppler of RV in the long-term follow-up of these patients particularly those patients with severe PR can be a useful adjunct tool in deciding timing of PV replacement to preserve their RV function and improve their exercise capacity.

Our study limitations include the following:

(1) Selection bias is a distortion in a measure of association owing to a sample selection that does not accurately reflect the target population.
(2) In the systemic review, the number of studies was small ranging from two to four studies for each outcome.
(3) Randomization and concealment were not clear.

Conclusion

After complete surgical repair of TOF, the RV systolic and diastolic dysfunction can be detected in most patients by echocardiography in the form of prolonged MPI and low values of TAPSE, E/A ratio, and RV myocardial velocities.

There is a significant relation between the use of TAP and RV dysfunction after complete surgical repair of TOF.

TOF repair in the first year of life had better results regarding TAPSE, RVEDD, LVEDD, and EF.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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