

Review Article:

The Accuracy of Myocardial Performance Index in the Diagnosis of Right Ventricular Dysfunction After Surgical Correction of Tetralogy of Fallot: A Narrative Review



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ABSTRACT

Context: Tetralogy of Fallot (TOF) is one of the most important congenital heart diseases that its prognosis can be improved by surgery. However, Right Ventricular (RV) function may be disrupted because of pulmonary regurgitation and other preoperative and intraoperative factors. Access to a simple and reproducible diagnostic index of RV function is important. Echocardiographic index of Right Ventricular Myocardial Performance (RVMPI) has been used as a simple and noninvasive method for the assessment of RV function.

Evidence Acquisition: This article review was conducted utilizing PubMed, Web of Science, Scopus and Google Scholar databases with the keywords of "Right Ventricle (RV)", "Myocardial Performance Index (MPI)", and "Tetralogy of Fallot (TOF) repair or correction".

Results: RVMPI as a non-geometric echocardiographic index was compared with other echocardiographic indices, QRS duration in ECG, Cardiac Magnetic Resonance (CMR) findings, and exercise capacity in the pediatric and adult studies.

Conclusions: This narrative review suggested that RVMPI, especially the tissue Doppler-derived has been used as a useful index of RV function in the follow-up of the repaired TOF patients. However, more research, including systematic reviews are necessary to determine the potential implication of RVMPI in the assessment of RV dysfunction.

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1. Context

The evaluation of Right Ventricular (RV) myocardial function after the total correction of Tetralogy of Fallot (TOF) predicts early and late prognosis of the patients (1-3). Pulmonary Regurgitation (PR) is the most important prognostic factor that affects RV myocardial function and the late outcome after TOF correction (4). Progressive RV dysfunction is commonly associated with life-threatening arrhythmia and sudden death (2). Pulmonary Valve Replacement (PVR) is performed to avoid these complications at the right time (5).

Various diagnostic methods have been used in this regard, including electrocardiography, echocardiography, and magnetic resonance imaging. QRS duration in ECG has been investigated in several studies as a prognostic factor in the repaired TOF (rTOF) patients (6). The QRS duration of more than 180 ms was associated with life-threatening dysrhythmia and sudden death (7). Cardiac Magnetic Resonance (CMR) imaging is widely used in the assessment of cardiac function. It is the gold standard method in the assessment of RV function in rTOF patients (8, 9). However, it is expensive and time-consuming compared to the echocardiographic methods.

Conventional echocardiography is used for the serial assessment of RV function and pulmonary regurgitation after rTOF (10). First described by Chuwa Tei, Myocardial Performance Index (MPI) is a dimensionless echocardiographic parameter of systolic and diastolic function (11). Tei index is calculated by $IVCT+IVRT/ET$ or $a-b/b$ formula (a =closure opening time of AV valve; b =ejection time) in spectral Doppler echocardiography (12). Right Ventricle Myocardial Performance Index (RVMPI) as a global systolic and diastolic function is affected by pulmonary regurgitation and myocardial dysfunction (13, 14). The available data are controversial on the load dependency of the MPI (15-17).

MPI is affected by load and heart rate and disregards segmental function (18). However, several studies report that RVMPI could be used as a quantitative measure of RV performance (19, 20). As a simple non-geometric echocardiographic parameter, MPI was calculated in several studies to assess RV function after the surgical repair of TOF. Tei index is potentially a simple, reproducible, and readily available indicator of ventricular dysfunction. Nonetheless, the clinical applicability of RVMPI remains undiscovered (13).

We reviewed the application of MPI in rTOF patients compared to other modalities in addition to the impact of pulmonary regurgitation on this echocardiographic parameter.

2. Evidence Acquisition

The article review was performed utilizing PubMed, Web of Science, Scopus, and Google Scholar, with the following keywords: "myocardial Performance Index (MPI)", "Right Ventricle (RV)", "Tetralogy of Fallot (TOF) repair or correction". All studies in English from 1995 till the current time on TOF patients who had total correction with early or late postoperative echocardiographic evaluation were included, if they assessed RVMPI either by pulsed or tissue Doppler imaging (Table 1).

3. Results

3.1. Comparing RV MPI with other echocardiographic indices

RV MPI as a non-geometrical index can be used to assess right ventricular myocardial function (21-24). RVMPI is derived either by Pulsed Doppler (PD) or Tissue Doppler (TD) methods. Because of the special shape of RV, loading factors can affect some of the geometrical RV indices (25, 26). Although RVMPI is known as a non-geometrical index, PD-derived MPI might be affected by loading factors like the pulmonary regurgitation after TAP repair of TOF.

There is still debate in the similarity of PD- and TD-derived MPI for the assessment of RV function. Saylan et al. found no difference between the rTOF and normal groups in PD-RVMPI (0.13 ± 0.03 and 0.15 ± 0.04 , $P=0.16$). However, TD-RVMPI was statistically higher in patients in respect of RV dysfunction after surgery (0.73 ± 0.059 and 0.51 ± 0.034 , $P<0.001$) (27). PD-MPI was partially influenced by changes in preload and heart rate, while TD-MPI was not affected (15).

Yasuoka et al. indicated that TD-RVMPI measurement is superior to the PD method to detect RV dysfunction in rTOF patients with PR (26). The RVMPI obtained by the PD method did not differ in rTOF and normal matched group (0.30 ± 0.12 vs. 0.32 ± 0.07 , the P value was not significant). In contrast, the TD-RVMPI was significantly greater in rTOF (0.48 ± 0.07 vs. 0.30 ± 0.07 , $P<0.0001$). The possibility of simultaneous measurement of the isovolumetric and ejection times in the same cardiac cycle by the method of TD is considered as the advantage of TD-RVMPI over PD-RVMPI. Physiologic changes of more

Table 1. Summary of reviewed articles

Author	Year of Publication	Country	Type of Study	Age, y (Mean±SD)	Technique of MPI	Sample Size
Abd El Rahman MY.	2002	Germany	Cross-sectional	15.3±10.3	PD	51 TOF
Yasuoka K.	2004	Japan	Cross-sectional	6.3±2.2	PD and TD	15 TOF vs. 24 age-matched controls
Norozi K.	2006	Germany	Cross-sectional	30±8	PD	59 TOF vs. 52 age-matched controls
Sachdev MS.	2006	India	Cross-sectional	5±4.6	PD	50 TOF
Pilla CB.	2007	Brazil	Cross-sectional	6.2±0.7	PD	35 TOF vs. 36 age-matched controls
Cetin I.	2009	Turkey	Cross-sectional	14.1±4.4	PD and TD	25 TOF vs. 29 age-matched controls
Erdem S.	2012	Turkey	Cross-sectional	7.9±4.4	PD and TD	57 TOF vs. 58 age-matched controls
Saylan B.	2012	Turkey	Cross-sectional	3.5±1.5	PD and TD	20 TOF vs. 30 age-matched
Tanasan A.	2012	Iran	Cross-sectional	6.4±4.1	PD	30 TOF vs. 32 age-matched controls
Lu JC.	2012	US	Cross-sectional	31±14.1	TD	38 TOF
Tanasan A.	2013	Iran	Case series	7.1±5.3	PD	57 TOF
Promphan W.	2014	Thailand	Cross-sectional	14±2	TD	20 TOF

PD: Pulsed Doppler; TD: Tissue Doppler; TOF: Tetralogy of Fallot; y: Year

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than 10% in the heart rate during PD examination will create less reliable results (28).

Both isovolumetric times were longer in rTOF, compared to the normal children (IVCT: 88±18 vs. 62±23 ms; IVRT: 46±11 vs. 21±12 ms; $P<0.0001$). Either intrinsic myocardial dysfunction or RV volume overload may contribute to prolonged IVRT and IVCT (29). Prolonged IVRT with decreased Ea revealed the delayed RV relaxation. Decreased Aa was in favor of restrictive RV filling. Prolonged IVCT (delayed systolic activation) in addition to decreased annular systolic descent suggested a systolic dysfunction.

All of the above-mentioned findings are in favor of diastolic/systolic dysfunction in TOF patients after the surgical repair. Moreover, the TD-RVMPI was not related to the PR degree and the residual RVOT obstruction. However, augmented PR may cause pseudonormalization of PD-RVMPI by prolonging the RV ejection time (26, 16). Higher RV filling pressures due to severe PR could cause pseudonormalization of this index. When the RV has a restrictive pattern in rTOF, there may be no correlation between RVMPI and RV ejection fraction (30, 31).

In a prospective study by Abd El Rahman et al. the measured PD-RVMPI in a group of rTOF at approximately 10 years post-surgery was paradoxically below

the normal range. They claimed that the noncompliant right ventricle may shorten the IVRT; thus, resulting in low RVMPI. However, they found that the patients with severe PR had a prolongation of the IVRT, compared to the patients with mild to moderate PR. In other words, those repaired by transannular patch had a higher index than those repaired by homograft ($P<0.05$) (32). It is difficult to interpret the RVMPI in cases with restrictive RV pattern.

In a similar study by Sachdev et al. the RVMPI in rTOF patients with restrictive RV physiology was paradoxically below the normal range (0.15±0.06 vs. 0.26±0.09, $P<0.001$) because of shortened isovolumetric relaxation time (19.4±17 vs. 39±30, $P<0.05$). The only independent determinant of restrictive RV pattern after surgical repair of TOF was the use of transannular patch (33, 34). In a cross-sectional observational analysis on 57 post-operative TOF patients, higher TD-RVMPI, higher RV dimensions, and volumes, and significantly lower RV Ejection Fraction (EF) were found, compared to a group of 58 aged-match controls ($P<0.001$ for all parameters).

They also found a positive correlation between RV MPI and LV MPI ($r=0.541$, $P<0.001$) (24). Focusing on the diastolic function of patients following the repair of TOF, there was a correlation between the lateral mitral E/E'

with tricuspid E/E' ($r=0.46$; $P=0.008$) and the right ventricular MPI ($r=0.42$; $P=0.01$) (35).

In another study on 25 patients with a Mean \pm SD age of 14.1 \pm 4.4 years who underwent primary repair of TOF, the TD-RVMPI (1.08 \pm 0.35 vs. 0.58 \pm 0.11, $P=0.0001$) was higher and the Isovolumetric Acceleration rate (IVA) (3.1 \pm 0.7 vs. 5.4 \pm 1.0 ms, $P=0.0001$) was lower than the matched control group. Moreover, the correlations between PR degree and TD-RVMPI ($r=0.7$, $P=0.0001$), and IVA ($r=-0.7$, $P=0.0001$) were statistically significant.

They found that IVCT and IVRT increased due to delayed systolic activation and delayed right ventricular relaxation, respectively. The authors also believed that the age at the time of assessment after the surgery has an impact on the results of MPI (36). In assessing the Tei index in adults with operated congenital heart disease, 59 patients with surgically corrected TOF had greater RVMPI than 52 patients with operated left-to-right shunt defects (RVMPI: 0.37 \pm 0.1 vs. 0.25 \pm 0.06; $P<0.0001$) (37).

3.2. Comparison of RV MPI with ECG findings and Cardiac Resynchronization Therapy (CRT)

Although the majority of studies reported that the QRS duration of more than 180 ms was correlated with severe RV dysfunction, other studies suggested that it might be affected by the RV size and the PR severity (6, 38-40). We failed to find any correlation between the RVMPI and QRS duration in a group of patients after the total correction of TOF ($r=0.242$, $P=0.084$). Our study limitations included the small sample size and the lack of tissue Doppler technique for MPI measurement.

We recognized that the QRS duration of greater than 160 ms was strongly correlated with severe PR (41). Moreover, the RVMPI did not differ in patients with and without right bundle branch block ($P>0.05$). However, the electromechanical delay does not affect the RVMPI (37). Systolic RV function and RV filling were improved by RV-CRT that was reflected by decreased RVMPI and increased RV maximum +dP/dt, pulmonary artery velocity time integral, and the RV filling time. RVMPI was 0.30 \pm 0.21 at baseline rhythm that declined to 0.20 \pm 0.16 after RV-CRT ($P=0.006$) (42).

3.3. Comparison of RVMPI with Cardiac MRI (CMR) findings

Several CMR guided studies were performed in children and adults with corrected TOF. In these studies, multiple CMR indices were quantified and compared

with the echocardiographic indices like RVMPI (9, 43-45). The measured CMR parameters were pulmonary regurgitant fraction, RV ejection fraction, RV end-diastolic volume, RV end-systolic volume and RV fractional area change (RV FAC). A few studies in the rTOF patients reveal that RVMPI is not correlated with the RV function and the severity of PR is measured by CMR (9, 43). However, other studies demonstrated that RVMPI values were inversely correlated with the CMR-derived RVEF. RVMPI >0.45 had a sensitivity of 70% and a specificity of 89% in terms of RV dysfunction (44).

PD-RVMPI and TD-RVMPI (DTI) could reliably diagnose RV dysfunction (confirmed by CMR), but surprisingly only the PD-RVMPI was diagnostic in the combined analysis ($P=0.0001$ vs. 0.18) (44). Koca et al. failed to find any significant correlation between TD-RVMPI and the parameters derived by cardiac MR for the assessment of RV function in 31 repaired TOF. They argued that although TD-RVMPI was significantly longer in rTOF patients than the controls (0.80 \pm 0.18 vs. 0.60 \pm 0.11, respectively, $P=0.0001$), it was not correlated with the right ventricle function source from CMR (43). However, they concluded that RVMPI could be used in the long-term follow-up of the patients operated for TOF.

A negative linear correlation was found between MPI and MRI-derived RVEF by Schwerzmann et al. in a group of patients with rTOF ($r=0.73$). RVMPI values of >0.4 and <0.25 were predictive of RVEF $<35\%$, and $\geq 50\%$, respectively (44). In addition to RVMPI, myocardial tissue velocities (Sa, Ea, Aa, Ea/Aa, E/Ea), TAPSE (Tricuspid annular plane systolic excursion), and 3DE-RV findings were proportional to using CMR reference ranges (8, 23, 45, 46).

3.4. Comparison of RVMPI with exercise capacity

There are a few studies comparing RV MPI values to exercise capacity after TOF repair. These studies were conducted in children and adults and revealed that RV MPI values were inversely correlated with exercise capacity (13, 21, 24). Erdem et al. found a higher RVMPI and significantly lower exercise duration and lower maximum heart rate while exercising in patients with corrected TOF ($P<0.001$) (24). Cheung reported that RVMPI was inversely correlated with exercise duration ($r=-0.45$, $P=0.013$) and peak oxygen consumption ($r=-0.56$, $P=0.001$). Increased MPI was a reflection of reduced exercise capacity in the patients after TOF repair (13).

Pilla et al. investigated the Health-Related Quality of Life (HRQoL) in 35 successfully rTOF patients with 4.9 years of follow-up, and found a trend between RVMPI

and poorer results in physical domain; however, it was not statistically significant ($P=0.06$) (3). Lu et al. found no statistically significant relation between RVMPI and physical activity or the quality of life. However, RVMPI was trended with clinically important physical dysfunction (35).

3.5. RVMPI in pediatric and adult corrected TOF studies

Studies were available in both children and adults assessing RVMPI after the surgical correction of TOF. All of them stated in concordance that RVMPI value increases with RV dysfunction associated with PR. However, studies in the adult reported a rather weak trend of rising (21, 44). It was revealed that prolonged chest tube drainage and postoperative ventilation time were significantly correlated with increased RVMPI. Even the ICU stay and the need for inotrope assistance were correlated with this index, however, with less significance. Moreover, the serial measurement of RVMPI might be a useful adjunct to proceed with an intervention (23).

3.6. Correlation between RVMPI and PR in pediatric and adult corrected TOF studies

Although there are several studies on the pros and cons of correlation between the pulmonary regurgitation degree measured by PR index and RVMPI in rTOF, they are not similar in their method of RVMPI measurement (TD-RVMPI vs PD-RVMPI) and the degree of PR severity (mild vs. moderate and severe) (3, 21, 47-52). Moreover, all of them considered a small sample size. The pulmonary regurgitation after TOF repair is significant; thus, some studies have quantified it by non-geometrical indices, such as PR index (PI time to diastolic time), diastolic and systolic time velocities integral ratio, and the PR pressure half time (9). Although studies suggested that RVMPI was independent of chronic loading condition and the degree of PR (37), the opposite effect in acute loading changes had been reported by other studies (47-52).

These studies suggested that the RVMPI was probably affected by the PR, especially when the PR severity was high. Moreover, the PD-RVMPI was much more affected than the TD-RVMPI. Norozi et al. argued that the surgical type of right ventricular outflow tract reconstruction and nonhomogeneous contraction had no adverse effects on the myocardial performance index (37).

Ibrahim L found no relationship between the TD-RVMPI and the degree of regurgitation ($P=0.183$) (50). However, we found a strong correlation between the

conventional derived RVMPI and the degree of PR. The RVMPI in patients with $PR_i < 70\%$ was 0.42 ± 0.13 , compared to 0.24 ± 0.1 in the patients with $PR_i \geq 70\%$ ($P < 0.05$). Another limitation of the latter study was the inclusion of patients with valved transannular patch repair that significantly impacts the degree of pulmonary regurgitation (10).

4. Conclusions

Although the available data are controversial on the load dependency of MPI, it is a noninvasive, feasible and reproducible method for the serial assessment of RV function. There is also some limitation in its clinical and functional implication in rTOF patients because of RVMPI pseudonormalization in cases with severe PR and restrictive RV patterns. Further investigations with larger sample sizes and a systematic review method are necessary to evaluate the potential applicability of RVMPI in the assessment of RV function.

Ethical Considerations

Compliance with ethical guidelines

There is no ethical principle to be considered doing this research.

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Authors contributions

Writing-review and editing, visualization: Reza Shabnian; Conceptualization: Asadolah Tanasan; Writing-original draft: Minoos Dadkhah; Writing-original draft and software: Ehsan Mazloumi; and supervision: Reza Shabnian, Asadolah Tanasan.

Conflict of interest

The authors declared no conflict of interest.

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