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Original Article

Assessment of Pulmonary Regurgitation Severity in Tetralogy of Fallot Total Correction: Comparison Between Doppler Echocardiography and Cardiac MRI

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ABSTRACT

Background: Pulmonary regurgitation is a common finding in patients after tetralogy of Fallot total correction (TFTC). Right ventricular enlargement and dysfunction have been ascribed to pulmonary insufficiency (PI), which is an important issue in the follow-up of patients with TFTC. We sought to compare PI measured by echocardiography with data provided by cardiac magnetic resonance imaging (CMR).

Methods: We studied 155 selected patients (91 male; median age = 25.65 y, range = 15–55 y) after TFTC. To quantify the pulmonary regurgitant fraction (PRF) by CMR, we performed flow velocity mapping. On Doppler echocardiography, the length, width, and localization of the regurgitant flow, no-flow time, and pressure half-time were measured. The severity of PI on echocardiography was categorized as nonsignificant and significant and was thereafter compared to the data obtained by CMR.

***Results*:** In all 155 patients, the measurement of the flow and volume was possible by CMR, and the measurement of PI was possible by Doppler echocardiography. The mean PRF, as determined by CMR, was 33% ± 16.4%. Pulmonary regurgitation has been reported to be a causative factor in right ventricular volume enlargement. A PRF > 20% was considered significant and was compared with echocardiographic parameters and also right ventricular size and function and other indices resulted from CMR. The regression analysis showed a significant correlation between PI severity on CMR and right ventricular enlargement on MRI at end diastole ($r = 0.746$; $P < 0.001$) and also at end systole ($r = 0.71$; $P < 0.05$).

Conclusions: There was no significant correlation between right ventricular ejection fraction and PI severity on CMR (r=0.553; P=0.45). On echocardiography, the semiquantitative estimation of pulmonary regurgitation showed that there were 26 patients with mild-to-moderate PI and 99 patients with severe PI. A right ventricular end-diastolic volume index (RVEDVI) of 121 mL/m² was 87% sensitive and 54% specific for severe PI, and an RVEDVI of 180 mL/m² was 90% specific for severe PI. ***(Iranian Heart Journal 2016; 17(2): 6-11)***

Keywords: Pulmonary regurgitation ■ Cardiac MRI ■ Echocardiography.

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Tetralogy of Fallot (TOF) is the most common cyanotic cardiac lesion, but it is successfully manageable with surgery. The surgical modality confers successful intracardiac repair. In 1954, Lillehei and Varco performed the first repair of TOF by using parental cross-circulation at the University of Minnesota. They closed a ventricular septal defect and relieved right ventricular outflow tract (RVOT) obstruction under direct vision, but the procedure was associated with a high mortality rate (200%). In 1955, Kirklin performed the first successful repair of TOF with a pump oxygenator at the Mayo Clinic. Nowadays, the cardiopulmonary bypass machine is drawn upon to accomplish the complete repair of TOF. The aim of the surgical repair of TOF is to create a near-physiological hemodynamic situation, which is achieved by the closure of the ventricular septal defect and by the relief of RVOT obstruction. Currently, the mortality of tetralogy of Fallot total correction (TFTC) is low, the long-term results are good, and most of the patients reach adulthood.[1,2] The severity of pulmonary insufficiency (PI) has been quantified via different modalities, including the determination of regurgitant jet length and width; however, these parameters are highly dependent on the pressure gradient between the pulmonary artery and the RV and as such fail to constitute a very reliable index. The assessment of the vena contracta width in contrast with other valves is more difficult in the pulmonary valve and cannot be deemed very useful in the evaluation of PI severity. A further validated method—and the current gold standard—for the quantitative noninvasive assessment of the pulmonary regurgitant fraction (PRF) is cardiac magnetic resonance imaging (CMR) using flow velocity mapping (phase-encoded imaging). This method provides systolic and diastolic flow volumes through the pulmonary valve and is able to quantify the PRF without radiation exposure or contrast medium administration.[3-6]

The purpose of the present study was to compare the echocardiographic approach and the quantitative approach of CMR flow velocity mapping for the assessment of PI.

METHODS

Study Population

The study protocol was approved by the local ethics committee. We examined 155 selected patients, comprising 91 male and 59 female patients, who had undergone TFTC in childhood or years earlier and referred to us for routine follow-up visits. None of these patients had pacemakers or implantable cardioverter defibrillators. Claustrophobia and poor echocardiography window were also among the exclusion criteria. The median age of the patients at the time of CMR study was 25.65 years (range=15–55y). The echocardiographic assessment of pulmonary regurgitation was performed within a period of 14 days before CMR.

Cardiac Magnetic Resonance Imaging

All CMR examinations were performed using a 1.5-T Avanto (Siemens Medical Systems) with an 18-channel phased-array coil. For the assessment of regurgitation fraction phase shift velocity, mapping was performed with a flow-sensitive gradient-echo sequence.[8-11] This method allows the calculation of flow velocity and flow volume by the velocity-dependent phase shift of the moving spins. A perpendicular orientation (“through plane”) directly cranial to the pulmonary valve was used to quantify flow volumes (TE/TR6/22 msec, flip angle = 35°). The tolerated deviation of perpendicular orientation was 15° maximum.[12] Encoded velocity was 150 cm/s. In the event of aliasing, encoded velocity was increased in steps of 25 cm/s up to 350 cm/s. For the assessment of end-systolic and end-diastolic volumes of both ventricles, a cine-MR sequence in the short-axis view and the axial view without the navigator technique was employed (flip angle = 30°, matrix size = 128 × 256, and slice thickness = about 7 mm).

Cine-MR provides multiple slices that cover the entire volume of both ventricles. By manually tracing the endocardial contours of the end-diastolic and end-systolic phases of each slice, we found it possible to calculate the volume and function of both ventricles. The limits between RV blood pool from the right atrium were identified by marking the level of the atrioventricular valve in the RV 2-chamber long-axis view and transferring these marks to the short-axis views. RV infundibulum was also included in RV volume up to the pulmonary valve.[13-14]

Doppler Echocardiography

In all 155 patients, transthoracic echocardiography was performed by experienced echocardiologists within a period of 14 days before CMR using a Vivid GE system with a 3.5-MHz probe. Pulmonary regurgitation was classified into 2 categories (mild and moderate to severe), according to the length and width of the regurgitant flow in the color Doppler mode and pressure half-time and no-flow time (NFT) on continuous wave and pulsed-wave Doppler echocardiography.

Statistical Analysis

The values are expressed as medians (ranges) or means (±SDs). The correlations between the different variables were determined with ANOVA. The Pearson correlation was subsequently used to assess the different variables. The distribution of the PRF on CMR among the echocardiographic categories was depicted using box-plot diagrams. The Kruskal–Wallis test was utilized to determine the degree of correlation ($P < 0.01$ and $P < 0.05$). All groups were compared with one another pair-wise using the Mann–Whitney test. Calculations were performed using the SPSS-PC statistics software package.

RESULTS

In all 155 patients, the measurement of the flow and volume was possible by CMR, and the measurement of PI was possible by Doppler echocardiography. The mean PRF, as determined by CMR, was 33% ± 16.4%. Pulmonary regurgitation has been reported to be a causative factor in RV volume enlargement. A PRF > 20% was considered significant and was compared with the echocardiographic parameters and also RV size and function and the other indices resulted from CMR. The regression analysis exhibited a significant correlation between PI severity on CMR and RV enlargement on MRI at end diastole ($r = 0.746$; $P < 0.001$) and also at end systole ($r = 0.71$; $P < 0.05$) (Fig. 1).

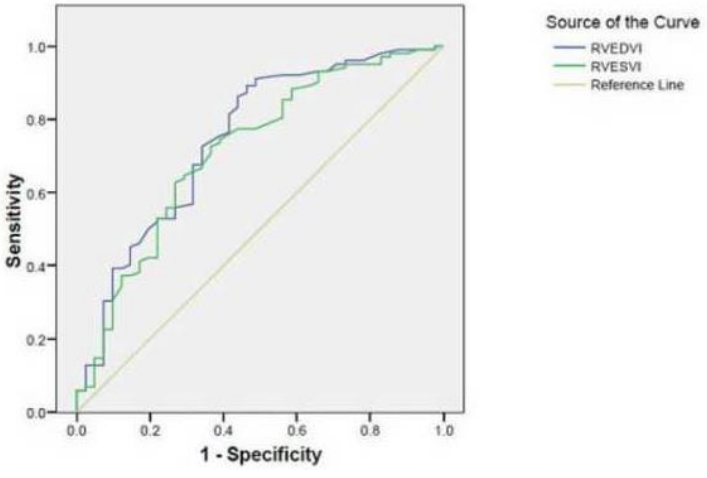
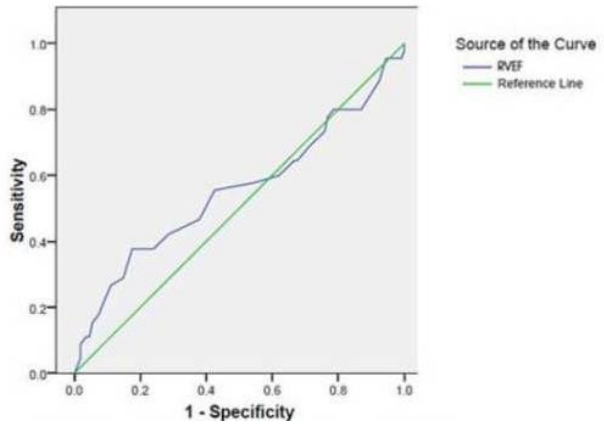


Figure 1. Relationship between right ventricular volumes and the pulmonary insufficiency severity ROC curve

A right ventricular end-diastolic volume index (RVEDVI) of 121 mL/m² was 87% sensitive and 54% specific for severe PI, and an RVEDVI of 180 mL/m² was 90% specific for severe PI. A right ventricular end-systolic volume index (RVESVI) of 66 mL/m² was 88% sensitive and 42% specific for severe PI. There was no significant correlation between right ventricular ejection fraction (RVEF) and PI severity on CMR (r = 0.553; P = 0.45).

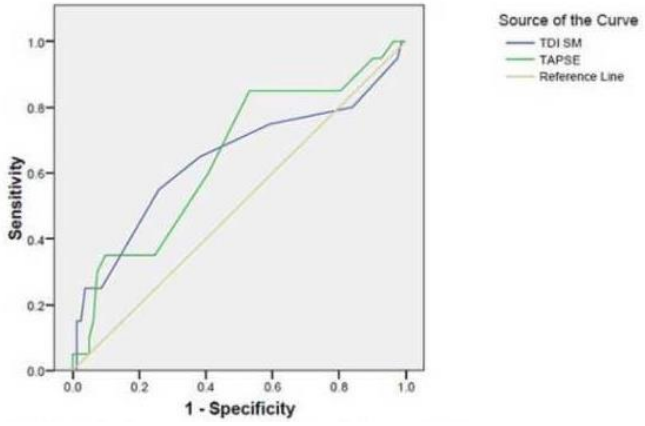
Figure 2. Relationship between right ventricular ejection fraction and the pulmonary insufficiency severity ROC curve



An RV outflow tract size (by MRI in the sagittal view) > 3.12 cm was 90% sensitive and 49% specific for severe PI. On echocardiography, the semiquantitative estimation of pulmonary regurgitation demonstrated that there were 26 patients with mild-to-moderate PI (group 1) and 99 patients with severe PI (group 2). An RVEDVI of 121 mL/m² was 87% sensitive and 54% specific for severe PI, and an RVEDVI of 180 mL/m² was 90% specific for severe PI. Additionally, an RVESVI of 66 mL/m² was 88% sensitive and 42% specific for severe PI. There was no significant correlation between RVEF and PI severity on CMR (r = 0.553; P = 0.45).

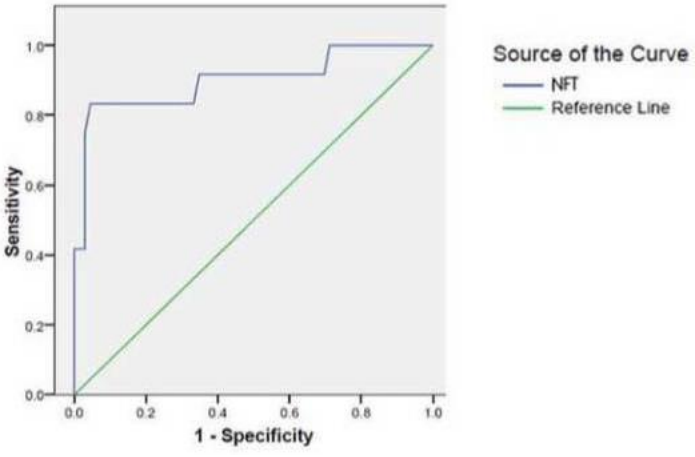
There was also a relatively significant correlation between the quantitative RV function parameters as assessed by echocardiography such as tricuspid annular plane systolic excursion (TAPSE) and tissue Doppler peak systolic velocity in systole (TDI SM) and PI severity according to the regression analysis (r=0.64 and 0.64; P=0.05). Additionally, a TDI SM of 8.5 cm/sec was 65% sensitive and 62% specific for severe PI, and a TAPSE of 15 cm was 85% sensitive and 47% specific for severe PI. Nonetheless, in the eyeball assessment of RV function by echocardiography, a relatively weak correlation was present with PI severity (r= 0.56).

Figure 3. Relationship between TDI SM and TAPSE and the PI severity ROC curve



TDI SM, Tissue Doppler peak systolic velocity in systole; TAPSE, Tricuspid annular plane systolic excursion; PI, Pulmonary insufficiency

Figure 4. Relationship between no-flow time (NFT) and the pulmonary insufficiency (PI) severity ROC curve



NFT, No-flow time; PI, Pulmonary insufficiency

DISCUSSION

A reliable estimation of PI is one of the central points in the follow-up of patients with TFTC. CMR phase-contrast flow measurement is the current gold standard for determining the PRF.[13-14] As much as the accuracy of this modality has been shown in several studies,[15–18] not only are there some relative and absolute contraindications to this modality but also it is very expensive and time-consuming. Therefore, a Doppler echocardiographic estimation of pulmonary regurgitation is a basic procedure in follow-up examinations. Although it is theoretically possible to quantify pulmonary regurgitation by echocardiography,[9] the estimation of PI is semiquantitative in routine clinical practice. The present study demonstrated the significance of Doppler echocardiography in the assessment of PI in patients after TFTC. Our results revealed that echocardiography according to a pressure half-time < 60 msec was able to predict significant PI depicted by CMR as a PRF > 20% and that there was a significant correlation between no-flow time (> 94 msec) on echocardiography and PI severity on MRI. In clinical practice, however, it is high-degree pulmonary regurgitation, its impairment of RV function, and its volume overload that should be recognized.[16] Doppler echocardiography is, therefore, considered a reliable diagnostic tool in the assessment of PI in follow-up examinations in patients after TFTC. There was a significant correlation between the echocardiographic assessment of RV function and MRI-derived RVEF.

CONCLUSIONS

Pulmonary regurgitation is an important prognostic parameter in patients after TFTC. In the present study, Doppler echocardiography was able to assess the severity of PI with reasonable agreement with CMR phase-contrast flow measurements. It is, therefore, a reliable, cost-effective, and readily available diagnostic tool for routine follow-up examinations in these patients.

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