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Value of the New Doppler-Derived Myocardial Performance Index for the Evaluation of Right and Left Ventricular Function Following Repair of Tetralogy of Fallot

M.Y. Abd El Rahman,[1] H. Abdul-Khaliq,[1] M. Vogel, V. Alexi-Meskischvili,[2] M. Gutberlet,[3] R. Hetzer,[2] P.E. Lange[1]

[1]Department of Congenital Heart Disease, Deutsches Herzzentrum, Augustenburger Platz 1, D-13353 Berlin, Germany
[2]Department of Cardiac Surgery, Deutsches Herzzentrum, Augustenburger Platz 1, 13353 Berlin, Germany
[3]Department of Radiology, Charité Berlin, Austenburger Platz 1, D-13353 Berlin, Germany

Abstract. The systolic and diastolic function in both ventricles may be altered even after successful corrective surgery of tetralogy of Fallot. The aim of this study was to assess the combined diastolic and systolic function of both ventricles using the Doppler-derived myocardial performance index (MPI) in patients with operated tetralogy of Fallot (TOF). We performed a prospective analysis of 51 patients following corrective surgery of TOF: 21 had a subannular patch, 20 had a homograft implantation at initial operation, and 10 were reoperated with secondary homograft implantation. Patients were examined with Doppler echocardiography, and the MPI, which incorporates ejection and isovolumetric relaxation and contraction times and is an index of global ventricular function, was calculated 10.2 ± 8.0 (0.89–36) years after surgery. In 86.4% of the examined patients the right ventricular isovolumetric relaxation time was shortened compared to the normal published range or even did not exist (negative value) ($p < 0.01$). The right ventricular MPI was paradoxically below the normal published range in 76.5% of the examined patients. The left ventricle global function was impaired in 23.5% of the examined patients, mainly due to altered systolic function with a prolonged left ventricular isovolumetric contraction time. The z score of the comparison between patients' left ventricular isovolumetric contraction time and the normal published values was 3.03. Patients with severe pulmonary regurgitation also had a prolongation of the isovolumetric relaxation time compared to patients with mild to moderate pulmonary regurgitation. The noncompliant right ventricle may shorten the right ventricular isovolumetric relaxation time, resulting in a paradoxically low right MPI. This may reduce the sensitivity of the index in recognizing patients with right ventricular dysfunction following corrective surgery of TOF. Additional diastolic impairment occurs in patients with right ventricular volume overload.

Key words: Myocardial Performance Index — Tetralogy of Fallot — Right ventricular function — Left ventricular function

Cardiac performance is of increasing importance for adolescents with surgically corrected tetralogy of Fallot because life expectancy has been prolonged [12]. Currently used techniques have limitations when applied in the assessment of ventricular function, particularly in patients with an abnormally shaped ventricle [2, 3]. Recently, an easily measured Doppler-derived index [myocardial performance index (MPI)] combining systolic and diastolic time intervals as a parameter for global ventricular function has been proposed [15, 17]. It is defined as the sum of isovolumetric contraction and isovolumetric relaxation time divided by the ejection time. Because it is a ratio of time intervals, the MPI is not dependent on geometric assumptions for the assessment of global ventricular function [3]. The purpose of this study was to assess the combined systolic and diastolic function of both ventricles using the MPI with special attention to the problems of right ventricular pressure and volume overload.

Materials and Methods

Patient Population

The studied population consisted of 51 patients (33 male and 18 female) following corrective surgery of tetralogy of Fallot selected

Correspondence to: H. Abdul-Khaliq

among 181 patients regularly followed in our outpatient department. These 51 patients were selected because they lived in the vicinity of Berlin, came to regular outpatient visits at least once a year, and had no obvious cardiac symptons. Their age at operation was 5.02 ± 6.87 (range, 0.25–43) years. The age at examination was 15.30 ± 10.27 (1.8–46) years, whereas the follow-up was done after a mean duration of 10.2 ± 7.28 (0.89–36) years. The right vertricular outflow tract was primarily reconstructed by a valved homograft in 20 patients (39.2%) and primarily by a right ventricular patch in 21 patients (41.2%). Among the latter group, 8 patients had a transannular patch. In 10 patients (19.6%) a second repair was needed because of severe right ventricular outflow tract obstruction or pulmonary regurgitation and in all of these a valved homograft was implanted.

Echocardiography and Doppler Studies

All patients were examined using a 3.5-MHz transducer interfaced with a Vingmed System V ultrasound system (GE-Vingmed, Horten, Norway). Transthoracic imaging was performed in the left lateral decubitus position. Initially, routine diagnostic imaging, including color-flow mapping and continuous-wave Doppler echocardiography, was performed. Pulsed Doppler flow across the tricuspid and pulmonary valve was assessed with simultaneous electrocardiograph (ECG) recordings in each patient but without respiratory gating. The usual size of the pulsed Doppler gate was 1.5 mm and the filter was adjusted at 100 Hz for optimal acquisition of the Doppler signals. All measurements were recorded on 3/4-in super-VHS videotape for subsequent offline data analysis. The mean value of each parameter was calculated in five consecutive heart cycles.

In an apical four-chamber view, the tricuspid and mitral valve inflow velocity profiles were recorded with the Doppler sample placed at the tip of the atriovertricular (AV) valves. The a "value," the time from closure to opening of the AV valve, and the "c value," the time interval from the peak R wave (first positive deflection after the P wave) of the simultaneously measured ECG to subsequent AV valve opening, were measured (Fig. 1).

Velocities across the right and left ventricular outflow were recorded in a parasternal short-axis view and apical five-chamber view, respectively, with the pulsed Doppler placed just below the semilunar valve. The ejection time ("b value") and the "d value," the time interval from the peak R wave (first positive deflection after the P wave) on the ECG to the end of the semilunar valve flow velocity signal, were also estimated while viewing the ventricular outflow tract. The MPI was calculated according to the following equation: MPI = (a − b)/b [17]. Data in patients were compared to the normal published range (mean ± 2 SD) [2]. The ventricular isovolumetric relaxation time, the time interval between the cessation of ventricular ejection and the onset of ventricular filling, was calculated by subtracting the d value from the c value [17]. Data were compared to the normal published range (mean ± 2 SD) [3]. The ventricular isovolumetric contraction time, the time interval between cessation of right ventricular filling and the onset of ventricular ejection, was calculated according to the following formula: isovolumetric contraction time = (a − b) - isovolumetric relaxation time (Fig. 1). Data were compared to the normal published range (mean ± 2 SD) [2].

The degree of pulmonary regurgitation (mild to moderate or severe) was judged by two experienced investigators with color Doppler echocardiography of the width and length of the regurgitant jet in the right ventricle and with pulsed Doppler echocardiography of the velocity and pattern of regurgitant flow in the right ventricular outflow tract and pulmonary artery [5]. Multiple subcostal or parasternal views were examined to determine the duration of pulmonary regurgitant jet. A duration of the regurgitant jet more than two-thirds of the diastole was considered to represent mild to moderate pulmonary regurgitation. A duration of the regurgitant jet less than two-thirds of the diastole accompanied by flow reversal in the distal pulmonary artery was considered to represent severe pulmonary regurgitation [5, 7].

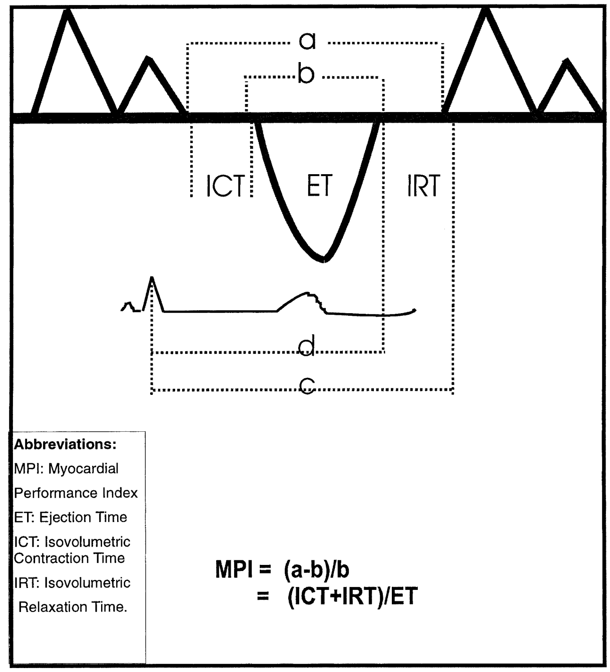

Fig 1. Illustration of the myocardial performance index (*MPI*).

The gradient across the right ventricular outflow was assessed by continuous Doppler echocardiography. Gatzoulis criterion for restriction (i.e., the occurrence of positive forward flow in late diastole concordant with atrial systole) was noted using pulsed Doppler echocardiography [4].

Statistical methods

The assessment of differences in the means of the measured parameters of patient groups in question was generally done by applying the nonparametric Mann–Whitney U test for two unpaired samples. For the analysis of correlation the nonparametric Sperman–Rank correlation was performed. A z score was calculated to compare patients' values to published normal values in the literature according to the formula z = mean of the measured parameter - mean of the published normal value/standard deviation of the published normal value [l4]. Interobserver variability was measured in 10/55 randomly selected patients.

Results

Doppler Echocardiography of the Right Ventricle

Eight patients (14.5%) had severe pulmonary regurgitation (all of them were primarily corrected by a

Table 1. Clinical and Doppler-derived parameters of right and left ventricular function in relation to the severity of pulmonary regurgitation following surgical repair of tetralogy of Fallot

Variable	Mild to moderate pulmonary regurgitation(n = 47)	Severe pulmonary regurgitation (n = 8)	*P* value
Age (years)	12.5 ± 7.67	29.93 ± 10.51	<0.01
Duration of follow-up (years)	8.95 ± 5.3	17.09 ± 11.94	NS
RV ejection-(msec)	353.60 ± 52.94	364.29.93	NS
RV isovolumetric relaxation time (msec)	−5.02 ± 35.37	−14.29 ± 95.88	NS
RV isovolumetric contraction time (msec)	26.65 ± 40.65	103.49 ± 57.53	<0.01
RV myocardial performance index	0.2 ± 0.15 (median = 0.10)	0.27 ± 0.29	<0.05
Gradient across RVOT	30.82 ± 19	16.56 ± 9.4	NS
LV ejection time (msec)	295.52 ±33.05	296.08 ± 55.5	NS
LV isovolumetric relaxation time (msec)	6.61 ± 30.82	58.58 ± 59.51	<0.05
LV isovolumetric contraction time (msec)	70.84 ± 37.5	87.36 ± 47.64	NS
LV myocardial performance index	0.27 ±0.1 4	0.55 ± 0.43	<0.05

RV, right ventricle; LV, left ventricle; RVOT, right ventricular outflow tract; NS, not significant.

transannular patch), wereas 47 patients (85.5%) had mild to moderate pulmonary regurgitation. The mean gradient across the right ventricular outflow tract was 29.35 ± 18.6 (9–74) mmHg. There were no patients with severe pulmonary regurgitation and a gradient >50 mmHg across a residual right ventricular outflow tract obstruction. Gatzoulis criterion for restrictive physiology was only noted in 5 patients, with no interobserver interpretation difference.

Interobserver variability of the measurements of the Doppler-derived parameters (right ventricular isovolumetric relaxation time, right ventricular isovolumetric contraction time, and ventricular MPI) was 3.5% for a value, 2.1% for b value, 1.8% for c value, and 1.7% for d value.

The right ventricular isovolumetric relaxation time was −6.53 ± 48.94 (−115.44–147.73) msec. Forty-four patients (86.3%) were below the normal published range, 3 patients (5.9%) were above, and the remaining 4 patients (7.8%) were within the published normal range. It did not differ in patients with severe pulmonary regurgitation compared to patients with mild to moderate pulmonary regurgitation (Table 1).

The right ventricular isovolumetric contraction time was 39.20 ±51.80 (−72.22–207.3) msec. Eighteen patients (35.3%) had a right ventricular isovolumetric contraction time above the normal range, 14 patients (22.5%) were below, and the remaining 14 patients were within the normal published range. Patients with severe pulmonary regurgitation had significantly prolonged right vertricular isovolumetric contraction time compared to patients with mild to moderate pulmonary regurgitation (Table 1).

The mean right MPI, was 0.10 ± 0.19 (−0.22–0.87). Thirty-nine patients (76.5%) had an index below the published normal range (Fig. 2). The right ventricular MPI did not correlate to the heart rate, age of repair, and the time of follow-up. Patients repaired by a transannular patch had significant higher index compared to patients repaired by homograft, with *p* value less than 0.05. The right ventricular MPI was affected by residual defects since patients with significant pulmonary regurgitation had a higher right ventricular MPI compared to patients with mild to moderate pulmonary regurgitation (Table 1). Among patients with severe pulmonary regurgitation the right ventricular MPI correlates significantly with age ($r = 0.4$). Otherwise, the right ventricular MPI was not age dependent.

Doppler Echocardiography of the Left Ventricle

Interobserver variability of the measurements of the Doppler-derived parameters (left ventricular isovolumetric relaxation time, left ventricular isovolumetric contraction time, and ventricular MPI was 2.9% for a value, 1.4% for b value, 1.6% for c value, and 1.5% for d value.

The mean left isovolumetric relaxation time was 14.76 ± 40.72 (−38.04–183.3) msec. Patients with severe pulmonary regurgitation had a significantly prolonged isovolumetric relaxation time compared to patients with mild to moderate pulmonary regurgitation (Table 1).

The left isovolumetric contraction time was 73.43 ± 39.19 (−23.75–l67.4) sec. The z score of the comparison between patients' left vertricular isovolumetric contraction time and the normal published values was 3.03.

The left vertricular MPI was 0.32 ± 0.23 (0.04–1.4). Twelve patients (23.5%) had an index above the published normal range. Patients with right ventricular volume overload had a significantly altered global function compared to patients with mild to moderate pulmonary regurgitation (Table 1; Fig. 3).

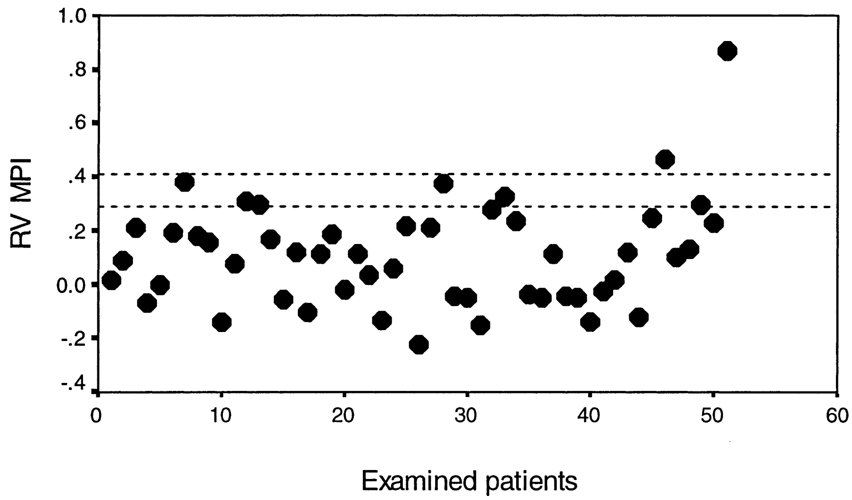

Fig 2. The majority of the examined patients had a myocardial performance index *MPI* below the published normal range. *RV*, right ventricle.

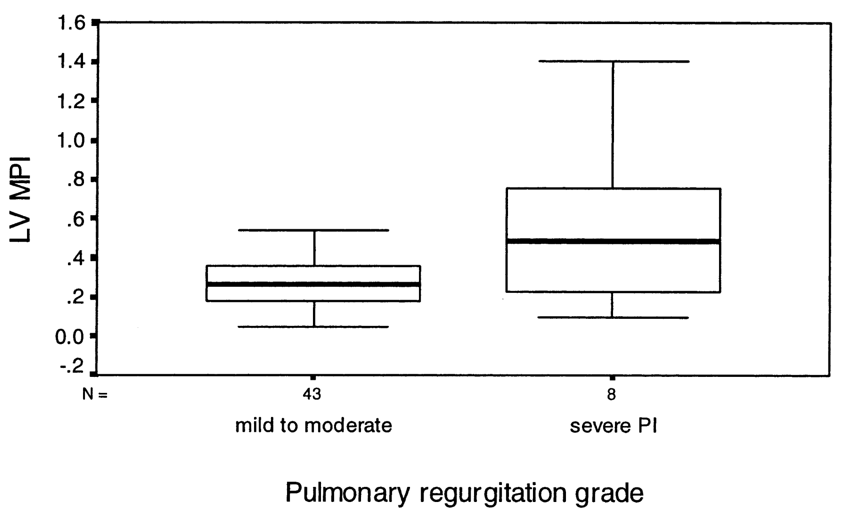

Fig 3. Right ventricular volume overload secondary to pulmonary regurgitation negatively influences the global left ventricular function assessed by the myocardial performance index (*MPI*). *LV*, left ventricle.

Discussion

Our study shows that diastolic and systolic time intervals can be routinely measured on both ventricles with a simple pulsed Doppler technique applied to the four valvular sites, Although surgical correction of tetralogy of Fallot may reconstruct the anatomy, morphological and functional myocardial problems seem to still be evident.

The Right Ventricular Global Function

The MPI has been validated as an index of global (i.e., combined systolic and diastolic right ventricular) function [2, 15, 16, 18]. It was initially proposed as a noninvasive method to assess this combined right ventricular function in patients with pulmonary hypertension (i.e., pressure overload) [15]. A higher than normal MPI in those patients was indicative of reduced global ventricular function [15]. In our study the right ventricular MPI was paradoxically below the normal range in the majority of the examined patients. This is explained mainly by significantly shortened isovolumetric relaxation time. This parameter is not only shortened but also it may result in negative calculated value. This can be explained by early opening of the pulmonary valve in late or even in middiastole before actual closure of the tricuspid valve occurs. Such phenomena have been previously noted in conditions of altered global right ventricular function secondary to myocardial hypertrophy or fibrosis, which allow the ventricular pressure to exceed the pulmonary artery pressure before atrial contraction [1]. A diastolic forward flow in the pulmonary artery was recognized in late diastole in only five patients, suggesting that such a flow may be too small to be detected with pulsed Doppler echocardiography or may be overlooked during pulmonary valve sampling.

A possible deleterious effect of pulmonary regurgitation on right ventricular function was suggested by previous studies [8, 11]. An elevated right ventricular MPI found among our patients with severe pulmonary regurgitation can be attributed to either the relatively old age or the prolonged isovolumetric contraction time since the ejection time and isovolumetric relaxation time did not alter with the severity of pulmonary regurgitation (Table 1). Prolongation of the right ventricular isovolumetric contraction time in this group of patients may be explained by possible elevation of the right ventricular end diastolic pressure secondary to severe pulmonary regurgitation, resulting in earlier crossover of right atrial and ventricular pressure curves (i.e., earlier closure of the tricuspid valve) and thus earlier onset of the right ventricular isovolumetric contraction time.

The Left Ventricular Global Function

The left MPI in the studied population was above the normal range in 23.5% of the studied population, which may reflect left ventricular global dysfunction. This is mainly due to prolongation of the left ventricular isovolumetric contraction time (i.e., altered systolic function) since the *z* score of the comparison between patient's left ventricular isovolumetric contraction time and the normal published value was 3.03. The altered systolic function observed in our study as well as by others [11, 19] can be contributed to possible paradoxical septal movements [9], myocardial fibrosis [10] or preoperative hypoxia [6]. In patients with right ventricular volume overload, the left ventricular global function is significantly impaired compared to that of patients with mild to moderate pulmonary regurgitation. This can only be attributed to prolonged left ventricular isovolumetric relaxation time since the left ventricular ejection time and left ventricular isovolumetric contraction time did not alter with the severity of pulmonary regurgitation (Table 1). Bulging of the interventricular septum toward the left ventricular cavity secondary to right ventricular volume overload may explain the altered left ventricular diastolic filling.

Limitations of the Study

One of the major limitations of this study is its cross-sectional and nonlongitudinal character. Applicability of all Doppler studies evaluating diastolic function is limited by the lack of information on atrial filling pressures, which can influence Doppler flow across the atrioventricular valves [l2]. The duration of systolic Doppler flow parameters can be altered by conduction delay observed frequently in tetralogy of Fallot following corrective surgery, but it is unlikely to influence the MPI. A major limitation to any novel quantitative assessment of right ventricular performance is the lack of an acceptable quantitative standard of comparison. The only methods of noninvasive measurement of ventricular function that can be successfully applied to ventricles with a distorted shape are magnetic resonance imaging [3] and three-dimensional echocardiography [20]. The first method requires expensive nonportable equipment, whereas three-dimensional echocardiography cannot be used transthoracically in all patients. Assessment of right ventricular mass, which is possible by these newer imaging tools, will aid in assessment of the degree of ventricular hypertrophy, which clearly influences the diastolic and systolic function [13].

Conclusion

From our data we conclude that the noncompliant right verticle may shorten the right ventricular isovolumetric relaxation time, resulting in a paradoxically low right MPI. This may reduce the sensitivity of the index in recognizing patients with right verticle dysfunction following corrective surgery of tetrology of Fallot. The left ventricular global function is impaired because of alteration of the left ventricular systolic function. In patients with severe pulmonary regurgitation the diastolic filling of the left ventricle is affected.

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