ORIGINAL ARTICLE

Determinants of left- and right-ventricular ejection fractions in patients with repaired tetralogy of Fallot: a cardiac magnetic resonance imaging study

Mateusz Śpiewak^{1,2}, Łukasz A. Małek^{2,3}, Joanna Petryka^{1,2}, Łukasz Mazurkiewicz^{2,4}, Magdalena Marczak^{2,5}, Elżbieta K. Biernacka⁶, Mirosław Kowalski⁶, Piotr Hoffman⁶, Marcin Demkow¹, Jolanta Miśko^{2,5}, Witold Rużyłło⁷

1 Department of Coronary Artery Disease and Structural Heart Diseases, Institute of Cardiology, Warszawa, Poland

2 Magnetic Resonance Unit, Institute of Cardiology, Warszawa, Poland

3 Department Interventional Cardiology and Angiology, Institute of Cardiology, Warszawa, Poland

- 4 Department of Cardiomyopathy, Institute of Cardiology, Warszawa, Poland
- 5 Department of Radiology, Institute of Cardiology, Warszawa, Poland
- 6 Department of Congenital Heart Diseases, Institute of Cardiology, Warszawa, Poland

7 Institute of Cardiology, Warszawa, Poland

KEY WORDS

ABSTRACT

left ventricular ejection fraction, right ventricular ejection fraction, systolic dysfunction, tetralogy of Fallot, ventricular interaction

Correspondence to:

Mateusz Śpiewak, MD, PhD, Klinika Choroby Wieńcowei i Strukturalnych Chorób Serca, Pracownia Rezonansu Magnetycznego, Instytut Kardiologii ul. Alpeiska 42, 04-628 Warszawa. Poland, phone: +48-22-343-43-42, fax: +48-22-343-45-16, e-mail: mspiewak@ikard.pl Received: June 8, 2013. Revision accepted: July 3, 2013. Published online: July 4, 2013. Conflict of interest: none declared. Pol Arch Med Wewn, 2013: 123 (10): 539-546 Copyright by Medycyna Praktyczna, Kraków 2013

INTRODUCTION There are inconsistent data regarding the factors affecting left ventricular ejection fraction (LVEF) and right ventricular ejection fraction (RVEF) in patients after tetralogy of Fallot (TOF) repair. **OBJECTIVES** The aim of the study was to assess the determinants of LVEF and RVEF in a large cohort of patients with repaired TOF.

PATIENTS AND METHODS The study comprised 122 patients with repaired TOF (median age, 24.2 years; interquartile range, 20.3–30.9; men, 60.6%) who had undergone cardiac magnetic resonance imaging study. Predictors of LVEF, RVEF, and RVEF corrected for shunting or regurgitations (cRVEF) were identified with the use of linear regression analyses.

RESULTS There was a weak correlation between RVEF and LVEF (r = 0.39, P < 0.0001). A multiple regression analysis revealed the following independent predictors of LVEF: positive predictor – RVEF (P = 0.0002); negative predictors – pulmonary regurgitation fraction (PRF, P = 0.01) and male sex (P = 0.001). RVEF was predicted independently by positive predictors such as LVEF (P < 0.0001) and LV end-diastolic volume (LVEDV, P = 0.04) and negative predictors such as right ventricular mass (P < 0.0001) and number of previous cardiothoracic surgery interventions (P = 0.005). In the model predicting cRVEF, only left ventricular mass was a positive predictor of cRVEF (P < 0.0001), while right ventricular mass (P < 0.0001), male sex (P < 0.0001), and RV late gadolinium enhancement score (P = 0.008) were negative predictors of cRVEF.

CONCLUSIONS Because PRF was inversely and independently correlated with LVEF, and LVEDV showed a positive and independent correlation with RVEF, left ventricular disease (low LVEF and LVEDV due to left ventricular compression) may be used as a marker of the severity of right ventricular disease (pulmonary regurgitation severity and its consequences). Further studies are needed to evaluate the role of LVEF and LVEDV in supporting patient selection for pulmonary valve replacement.

INTRODUCTION The advent of cardiac magnetic resonance (CMR) imaging revolutionized our understanding of the pathophysiology of the failing heart late after tetralogy of Fallot (TOF) repair.¹ A negative ventricular–ventricular interaction has been shown in this population of patients suggesting that the left heart disease may be a marker of the severity of the right heart disease.²⁻⁶ However, there have been sparse and inconsistent data regarding factors affecting left ventricular (LV) ejection fraction (LVEF) and right ventricular (RV) ejection fraction (RVEF) in this population. In particular, the impact of pulmonary regurgitation (PR) on LVEF and RVEF remains ambiguous.^{2,3,7,8} Accordingly, the aim of the study was to assess factors associated with LVEF and RVEF in a large cohort of patients after TOF repair.

PATIENTS AND METHODS Patients In our center, cardiac magnetic resonance (CMR) imaging study has become part of routine evaluation in patients with repaired TOF and all these patients without contraindications for CMR imaging are referred by treating physicians for the study. We screened consecutive patients after TOF repair who had undergone CMR imaging study from June 2008 through end-January 2012. Between June 2008 and mid-September 2011, we collected data retrospectively, and from mid-September 2011 on, we recruited patients prospectively. Patients with pulmonary atresia and ventricular septal defect (VSD) were excluded so that a homogeneous patient population could be achieved. Additional exclusion criteria were: artifacts precluding either a reliable assessment of ventricular size and function or pulmonary artery flow, incomplete CMR data set, incomplete echocardiographic study, known coronary artery disease, and age at TOF repair of 18 years and older. When more than 1 CMR imaging study was performed in a given patient, only the initial study was included in the analysis. The analysis was approved by the local ethics committee. Each patient or parents/guardians gave a written informed consent for a CMR imaging study. The investigation conformed with the principles outlined in the Declaration of Helsinki. Selected data on patients with repaired TOF undergoing CMR imaging study in our center were published previously.9-12 In particular, we previously analyzed factors associated with biventricular dysfunction in the same study population (31 patients with biventricular dysfunction and 65 patients with normal biventricular systolic functions were selected out of a group of 146 patient; unpublished data).

Cardiac magnetic resonance imaging All patients underwent a standard CMR imaging study with the use of a 1.5 Tesla scanner (Avanto, Siemens, Erlangen, Germany). A stack of shortaxis breath-hold steady-state free precession images (typical imaging parameters: repetition time, 2.2 to 3.6 ms; echo time, 1.2 ms; flip angle, 64° to 79°; slice thickness, 8 mm; gap, 1.6 mm) served for calculation of ventricular volumes and ejection fraction with the use of dedicated software (MASS 6.2.1, Medis, Leiden, The Netherlands). Manual delineation of endocardial and epicardial contours was performed in end-diastolic and end-systolic phases by 6 experienced observers. On the basis of these data, RV and LV end--diastolic volumes (RVEDV and LVEDV, respectively), RV and LV end-systolic volumes (RVESV and LVESV, respectively), RV and LV masses, (RVM and LVM, respectively), and RVEF and LVEF were calculated. RVEDV, LVEDV, RVESV, LVESV, RVM, and LVM were indexed for the body surface area and expressed either in ml/m² or g/m². Corrected RVEF (cRVEF) was defined as a percentage calculated by dividing the net pulmonary flow by absolute RVEDV.13 Trabeculations and papillary muscles were included in the blood pool and excluded from mass calculations.⁹ PR fraction (PRF) and aortic regurgitation (AR) fraction (ARF) were calculated on the basis of a flow sensitive gradient echo sequence (typical parameters: effective repetition time, 9.4 ms; echo time, 2 ms; flip angle, 30°; slice thickness, 5 mm) with the use of dedicated semi-automated software (Argus, Siemens, Erlangen, Germany). The imaging plane was prescribed perpendicularly to the vessel wall, and located in the mid-point of the main pulmonary artery or conduit (for PRF) or at the level of the sinotubular junction (for ARF). Significant PR was defined as PRF of 20% or higher.⁸ The presence of the RV outflow tract (RVOT) aneurysm or akinesia was assessed as described previously.²

Data on inter- and intraobserver variability of the measurements of ventricular volumes and PR were published previously 10,12 and were comparable to those from other centers. 14,15

The presence and extent of late gadolinium enhancement (LGE) was assessed with the use of the previously described highly reproducible methods.^{16,17} Briefly, LV-LGE was scored in each LV segment from 0 to 5 points depending on the percentage of the myocardium occupied by LGE. RV-LGE was scored in each of the 7 RV regions (anterior wall of RVOT, RV anterior wall, RV inferior wall, RV surface of septum, VSD patch region, trabecular bands, inferior and superior RV-LV hinge points) depending on the extent of LGE in each region.¹⁶ The summation of the RV-LGE and LV-LGE scores gave the total LGE score. LGE imaging was performed 10 to 15 min after intravenous administration of 0.2 mmol/kg gadobutrol (Gadovist, Bayer Pharma AG, Berlin, Germany).

Echocardiography All patients underwent standard echocardiography with the commercially available system. The maximal velocity across RVOT was measured with the continuous-wave Doppler, and peak instantaneous RVOT gradient was calculated using the Bernoulli equation.

Statistical analysis All continuous variables were expressed as mean ± standard deviation or as median and interquartile range and were tested for normal distribution with the use of the Kolmogorov–Smirnov test. A linear regression analysis was conducted to identify factors associated

TABLE 1 Baseline characteristics and findings of imaging studies

Parameter		Value	
median age at CMR i	24.2 (20.3–30.9)		
men, n (%)	74 (60.6)		
median age at TOF repair, y		3.6 (2.3–5.8)	
median time since initial correction, y		20.1 (16.4–25.0)	
prior palliative shunt, n (%)		31 (25.4)	
time from first palliative shunt to TOF repair, y		0–10.0	
	patch, n (%)	69 (56.6)	
type of TOF repair	conduit, n (%)	12 (9.8)	
	details unknown, n (%)	41 (33.6)	
median number of previous cardiothoracic surgeries		1 (1–2)	
RVOT aneurysm/akinesia, n (%)		55 (45.1)	
any VSD, n (%)		24 (19.7)	
significant VSD, n (%)		3 (2.5)	
RV-LGE, n (%)		82 (67.2)	
median RV-LGE score		3 (1–4)	
RVEDV, ml/m ²		159.8 ±48.3	
RVESV, ml/m ²		87.9 ±37.2	
RVEF, %		46.2 ±8.7	
RVM (g/m ²)		31.1 ±9.4	
LVEDV, ml/m ²		90.0 ±19.2	
LVESV, ml/m ²		38.9 ±12.4	
LVEF, %	56.8 ±6.7		
LVM, g/m ²	55.9 ±11.9		
PRF, %	27.2 ±16.6		
median ARF, %	1 (0–2)		
median peak RVOT g	20 (12–35)		

Data are presented as median (interquartile range) or number (percentage).

Abbreviations: ARF – aortic regurgitation fraction, CMR – cardiac magnetic resonance, IQR – interquartile range, LVEDV – left ventricular end-diastolic volume, LVEF – left ventricular ejection fraction, LVESV – left ventricular end-systolic volume, LVM – left ventricular mass, PRF – pulmonary regurgitation fraction, RVEDV – right ventricular end-diastolic volume, RVEF – right ventricular ejection fraction, RVESV – left ventricular ejection fraction, RVEDV – right ventricular end-systolic volume, RVEF – right ventricular late gadolinium enhancement, RVM – right ventricular mass, RVOT – right ventricular outflow tract, TOF – tetralogy of Fallot, VSD – ventricular septal defect

with LVEF and RVEF, and the Pearson correlation coefficients were obtained.

Multiple regression was performed with the following variables (candidate predictors) entered into the model irrespective of the results of the univariate analysis: age at TOF repair, palliative shunt in history, time the patient remained palliated, age at CMR imaging study, time since initial correction, number of previous cardiothoracic surgeries, sex, RVOT aneurysm/akinesia, PRF, peak RVOT gradient, ARF, presence of residual VSD, RVM, LVM, and RV-LGE score (data on LV-LGE score were not entered because of a small number of patients with positive LV-LGE precluding reasonable analyses). Additionally, in the case of the model predicting LVEF, we entered such RV parameters to the model as: RVEF and RVEDV (considering strong correlation between RVEDV and RVESV, only RVEDV was entered). In the case of the model predicting RVEF, we entered the following LV parameters: LVEF and LVEDV

(considering strong correlation between LVEDV and LVESV, only LVEDV was entered). Given that ejection fraction of the respective ventricle is calculated on the basis of end-diastolic volume and end-systolic volume of the ventricle, we did not enter either LVEDV or LVESV into the multivariable model predicting LVEF. Similarly, neither RVEDV nor RVESV were entered into the multivariable model predicting RVEF. A separate model was constructed for the prediction of cRVEF. After entering all variables to the model, the variables that showed the least significant associations were subsequently excluded until all variables remained significant (P < 0.05).

The model fit for multiple regression was assessed with the use of R^2 (coefficient of determination) and adjusted R^2 (coefficient of determination adjusted for the number of independent variables in a model).

A two-sided *P* value of less than 0.05 was considered to indicate statistical significance. Statistical analyses were performed with the use of MedCalc 12.1.4.0 trial software (MedCalc, Mariakerke, Belgium).

RESULTS Study population During the analyzed period, 182 patients after TOF repair underwent CMR imaging study. Overall, 60 patients met the exclusion criteria: artifacts precluding analysis (n = 7), incomplete CMR data set (n = 4), incomplete echocardiographic dataset (n = 3), known coronary artery disease (n = 1), age at TOF repair of 18 years or older (n = 21), and no available LGE data (n = 24). The remaining 122 patients were included in the study.

Baseline characteristics and findings of imaging studies Baseline characteristics and findings of imaging studies are presented in **TABLE 1**. Eighty-four patients (68.9%) had significant PR, and 41 patients (33.6%) had a peak gradient of 30 mmHg or higher. RV-LGE was present in 82 patients (67.2%), and LV-LGE in 4 patients (3.3%). In the case of the left ventricle, LV-LGE was localized in the ventricular apex in all patients.

Determinants of LVEF and RVEF: univariate analysis A univariate linear regression analysis demonstrated a weak positive correlation between LVEF and RVEF (r = 0.39, P < 0.0001) as well as between LVEF and time from TOF correction to CMR imaging study and age at CMR imaging study (of borderline significance, TABLE 2). In addition, there was a negative correlation of LVEF with LVEDV, LVESV, LVM, RVEDV, RVESV, RVM, PRF, and male sex (TABLE 2). In the univariate analysis, negative predictors of RVEF were LVESV, RVEDV, RVESV, RVM, and male sex (TABLE 3). Additionally, a trend toward lower RVEF in patients with a larger number of previous cardiothoracic surgeries was observed (TABLE 3). An inverse correlation between the presence of RVOT aneurysm/akinesia and RVEF was also observed (TABLE 3).

TABLE 2 Predictors of left ventricular ejection fraction

Predictors	Univariate analysis		Multivariate analysis	
	β (SE)	P value	β (SE)	P value
LVEDV	–0.15 (0.03)	<0.0001	_	-
LVESV	-0.42 (0.03)	<0.0001	-	-
LVM ^a	-0.11 (0.05)	0.04	-	-
RVEF ^a	0.30 (0.07)	<0.0001	0.25 (0.06)	0.0002
RVEDV ^a	-0.05 (0.01)	0.0001	-	-
RVESV	-0.07 (0.01)	<0.0001	_	_
RVMª	-0.13 (0.06)	0.04	_	_
PRFª	-0.08 (0.03)	0.03	-0.08	0.01
peak RVOT gradient ^a	0.02 (0.03)	0.48	_	_
ARFª	–0.13 (0.15)	0.41	-	-
residual VSD ^a	-0.17 (1.6)	0.92	_	_
sex (for male sex)ª	-5.0 (1.2)	<0.0001	-3.8 (1.1)	0.001
age at TOF repair ^a	0.02 (0.18)	0.91	-	-
palliative shunt in history ^a	-2.1 (1.4)	0.13	_	_
time remained palliated ^a	-0.02 (0.03)	0.47	-	-
number of previous cardiothoracic surgeries ^a	0.28 (0.82)	0.73	-	-
age at CMR imaging study ^a	0.14 (0.07)	0.06	_	-
time from TOF correction to CMR imaging study ^a	0.21 (0.09)	0.02	-	-
RVOT aneurysm/akinesia ^a	-1.6 (1.2)	0.19	-	-
RV-LGE score ^a	0.30 (0.39)	0.44	-	-
model performance				
<i>R</i> ²	-		0.27	
adjusted R ²	-		0.25	

a These variables were entered into the multivariate model. LVEDV and LVESV were not included because LVEF is calculated on the basis of these data. Considering strong correlation between RVEDV and RVESV, only RVEDV was entered. Candidate predictors were entered into the model irrespective of the results of the univariate analysis. After entering all variables to the model, the variables that showed least significant associations were subsequently excluded until all variables remained significant (P < 0.05).

Abbreviations: SE - standard error, others - see TABLE 1

Determinants of LVEF and RVEF: multivariate analysis

A multivariate analysis revealed that RVEF, PRF, and male sex were independent predictors of LVEF (RVEF, positive predictor; PRF and male sex, negative predictors; TABLE 2). In the multivariate analysis, significant predictors of RVEF were LVEF and LVEDV (positive predictors) as well as RVM and the number of previous cardiothoracic surgeries (negative predictors) (TABLE 3). In the model predicting cRVEF, only LVM was a positive predictor of cRVEF, and RVM, PRF, male sex, and RV-LGE score were independently associated with cRVEF (TABLE 3).

DISCUSSION We demonstrated an independent association between PR severity and LVEF in a large cohort of patients after TOF repair, underscoring the impact of RV disease on LV performance. Oosterhof et al.⁷ showed that PRF was an independent predictor of LVEF; however, the study was conducted in a substantially smaller heterogeneous study population (n = 42) consisting mainly, but not exclusively (76%), of patients with repaired TOF. Two milestone studies by Geva et al.² and Davlouros et al.³ revealed no association between PR severity and LVEF.

Previous studies in patients treated with pulmonary valve replacement (PVR) provided an insight into abnormal RV and LV function prior to PVR and the ventricular responses after treatment either with surgery or percutaneous pulmonary valve implantation.^{6,18-20} Particularly, those studies demonstrated a beneficial response of LV, in terms of improved LVEDV and LVEF, to changes in RV loading conditions. The mechanisms responsible for improved LV function after PVR and deleterious effects of PR on LVEF are multifactorial.^{1,6,21} A ventricular–ventricular interaction has been shown to be an important factor determining ventricular systolic function. Additionally, the restoration of pulmonary valve competence leads to an improved net pulmonary blood flow, better LV filling, and better LVEF. Finally, electrical remodeling of the ventricles and mechano--electric interactions are important. Hence, though there may be RV-LV interdependence, just treating an RV physiological lesion, namely RV overload, can lead to improved LV function. In our study, there was only a poor correlation between RVEF and LVEF (r = 0.39). This gives an R^2 value of 0.15, which means that 85% of the total variation between the RVEF and LVEF

TABLE 3 Predictors of right ventricular ejection fraction

Predictors	Univariate analysis		Multivariate analysis (RVEF)		Multivariate analysis (cRVEF)	
	β (SE)	P value	β (SE)	P value	β (SE)	P value
LVEF ^a	0.50 (0.11)	<0.0001	0.53 (0.11)	<0.0001	-	-
LVEDVa	-0.05 (0.04)	0.23	0.08 (0.03)	0.04	_	_
LVESV	-0.20 (0.06)	<0.0001	_	_	_	_
LVM ^a	-0.07 (0.07)	0.31	_	_	0.33 (0.07)	<0.0001
RVEDV	-0.08 (0.01)	< 0.0001	_	_	_	_
RVESV	-0.16 (0.02)	< 0.0001	_	_	-	_
RVMª	-0.36 (0.08)	< 0.0001	-0.33 (0.07)	< 0.0001	-0.33 (0.07)	< 0.0001
PRF ^a	0.01 (0.05)	0.80	_	_	-0.39 (0.04)	< 0.0001
peak RVOT gradient ^a	-0.04 (0.04)	0.32	_	_	-	_
ARFª	-0.22 (0.20)	0.26	_	_	_	_
residual VSD ^a	-1.3 (2.0)	0.52	_	_	-	_
sex (for male sex)ª	-4.9 (1.5)	0.001	-	-	-8.9 (1.4)	< 0.0001
age at TOF repair ^a	0.07 (0.23)	0.77	-	-	-	-
palliative shunt in the history ^a	–1.5 (1.8)	0.40	-	-	-	-
time the patient remained palliated (months) ^a	0.006 (0.03)	0.86	-	-	-	-
number of previous cardiothoracic surgeries ^a	–1.9 (1.0)	0.07	-2.6 (0.9)	0.005	-	-
age at CMR imaging study ^a	-0.02 (0.10)	0.80	-	-	-	-
time from TOF correction to CMR imaging study ^a	-0.06 (0.12)	0.64	-	-	-	-
RVOT aneurysm/akinesiaª	–5.1 (1.5)	0.001	-	-	-	-
RV-LGE score ^a	-0.83 (0.50)	0.10	-	-	-1.1 (0.4)	0.008
model performance						
<i>R</i> ²	-		0.32		0.65	
adjusted R ²	-		0.29		0.64	

a These variables were entered into the multivariate model. RVEDV and RVESV were not included because RVEF is calculated on the basis of these data. Considering strong correlation between LVEDV and LVESV, only LVEDV was entered. Candidate predictors were entered into the model irrespective of the results of the univariate analysis. After entering all variables to the model, the variables that showed least significant associations were subsequently excluded until all variables remained significant (P < 0.05).

Abbreviations: cRVEF - corrected RVEF, others - see TABLES 1 and 2

remains unexplained. This underscores the fact that, in addition to the ventricular–ventricular interaction, other factors play a crucial role in determining ventricular ejection fractions. The results of the multivariate analysis, demonstrating additional predictors of both RVEF and LVEF, provide further evidence to support this hypothesis.

In clinical decision making concerning PVR in patients with repaired TOF, ventricular dilatation and ventricular performance are of particular importance.^{1,22} They demonstrate how the heart is coping with the burden of regurgitation. LVEF, being independently associated with PRF as demonstrated in the current study, could be used as a potential marker of systolic function adversely affected by PR. Further studies are needed to evaluate the role of LVEF in supporting patient selection for PVR. Considering the ventricular--ventricular interaction, the interplay between incompetent pulmonary valve and the decreased LV filling (low LVEDV), the use of an LV disease (low LVEF) as a marker of the severity of an RV disease (severity of PR) could be an attractive alternative to the measurements of RVEF and RVEDV. Additionally, the multivariate analysis revealed that LVEDV was a positive predictor of RVEF.

Thus, the higher LVEDV, the higher RVEF was observed. These results further support the concept that an LV disease (low LVEDV) could be used as a marker of the severity of an RV disease.

The male sex was associated with lower LVEF and lower cRVEF when compared with female sex. Although the precise mechanism or mechanisms responsible for lower ejection fractions in males remain unknown, a hormonal effect cannot be excluded. However, several studies in healthy volunteers revealed no differences in LVEF between the sexes,²³⁻²⁵ and a few reported higher LVEF in women.^{26,27} Our results are in agreement with the previous studies in patients with repaired TOF^{26,28,29} and large multiethnic studies in subjects without overt cardiovascular diseases^{30,31} demonstrating higher LVEF and RVEF in women. A previous study demonstrated that male patients after TOF repair have lower LVEF and RVEF compared with female patients.²⁶ Moreover, previous studies have proved that left and right ventricular volumes are higher in male patients after TOF repair.^{10,26}

In the univariate analysis, RVOT aneurysm/ akinesia showed a negative association with RVEF. However, in the multivariate analysis, RVOT aneurysm/akinesia did not prove to be an independent predictor of RVEF. Davlouros et al.² demonstrated that RVOT contractile dysfunction was not necessarily related to the use of a patch. In their study, RVOT aneurysm or akinesia was present in about 50% of the patients who did not undergo a patch-type repair. The authors suggested that other factors such as an extreme infundibular resection and/or ischemic injury also contribute to the formation of RVOT aneurysm or akinesia. These aneurysmal or akinetic regions were independent predictors of increased RV volumes and decreased RVEF whereas the presence of a transannular patch was not. Since the study by Davlouros et al.² demonstrated that the presence of the RVOT or transannular patch was only partially related to RVOT aneurysm/akinesia, and the latter were associated with impaired RVEF and increased RV volumes, we decided to include the presence of RVOT aneurysm/akinesia instead of RVOT patching as a predictor of RVEF.

A larger number of cardiothoracic surgeries was independently associated with lower RVEF. This can be attributed to RV scarring resulting from surgical procedures, exposure of a patient to more severe pathologies that finally required surgical intervention, and the consequences of these lesions (e.g., long-lasting volume overload caused by severe PR or chronic pressure overload due to a significant residual RVOT gradient). Interestingly, the higher number of surgeries was not associated with lower LVEF.

A higher RV-LGE score was independently associated with lower cRVEF. This is in line with previous studies demonstrating that ventricular fibrosis suggested by CMR imaging had a negative effect on ventricular systolic function.^{16,32} Nevertheless, we did not demonstrate the relationship between the RV-LGE score and RVEF not corrected for shunts or regurgitations. Moreover, the limited number of patients with LV-LGE outside the RV-LV hinge points did not allow for either the analysis of the effect of LV-LGE on LVEF or the effect of RV pathology on LV fibrosis.

We demonstrated a negative relationship between RVM and RVEF and cRVEF and a positive association between LVM and cRVEF. Davlouros at al.² also observed an inverse correlation between RVM and RVEF, suggesting that RV contractility was affected by RV hypertrophy and postulating various mechanisms responsible for this phenomenon. Of note, they demonstrated that peripheral pulmonary stenosis and RVEDV were independent predictors of RVM. Considering the lack of relationship between peripheral pulmonary stenosis and ventricular function as demonstrated by Davlouros et al.² and recently by Maskatia et al.,³³ no effect of the peak RVOT gradient on either RVEF, cRVEF, or LVEF in the present study, as well as high incidence of mixed lesions as the causes of RVOT obstruction in the study population, we decided not to perform thorough analyses on the relations between

ventricular functions and various causes of RVOT obstruction, including branch pulmonary stenosis.¹¹ Detailed analyses with the measurements of branch pulmonary artery cross-sectional area and that of the Nakata index were beyond the scope of the manuscript. Nevertheless, we and other investigators have previously demonstrated that patients after TOF repair with coexisting RVOT obstruction (including branch pulmonary stenosis) had lower RVEDV compared with patients without obstruction.^{11,33} Moreover, those with significant PR and concomitant RVOT obstruction (including but not limited to branch pulmonary stenosis) had higher RVEF in comparison with patients with isolated PR.¹¹ The relationship between various types and severity degrees of RVOT obstruction and ventricular function should be adequately addressed in further studies. Interestingly, in our study, higher LVM was associated with higher cRVEF. This may be attributed to the fact that higher LVEDV was related to higher RVEF, and in a model predicting cRVEF, LVM, being correlated with LVEDV, replaced LVEDV.

Limitations Because of the cross-sectional design, our study did not allow for a distinction between causes and effects. Thus, causal relationship between the variables demonstrating an association in our study needs to be confirmed in prospective cohort studies.

Patients from our cohort were rather old at TOF repair when compared with contemporary patients undergoing TOF repair. However, the age at TOF repair in the current study was representative for patients who underwent a surgery about 20 to 30 years earlier.^{2-5,7,26,28} Neither in the current study nor in that by Davlouros et al.,² the age at TOF repair was an independent predictor of ventricular systolic function. Broberg et al.²⁸ showed that the age at TOF repair was not significantly different between patients with normal, mildly decreased, and moderately-to-severely decreased LV, and only patients who were 18 years old and older at the time of repair were more likely to have an impaired LV systolic function.²⁸ To avoid altering ventricular function by factors such as age at repair or ischemic myocardial injury, we excluded patients with known coronary artery disease and those with primary repair performed at the age of 18 years and older.

We assessed the global systolic function and RVOT wall motion abnormalities, neglecting the analysis of other regional wall motion abnormalities, intrinsic myocardial contractility, and biventricular diastolic function.^{32,34-36} Although these issues may be of interest, their clinical value is rather unclear. The definition of heart failure in patients with congenital heart disease is challenging and the severity of the disease could be based on various parameters providing that these measures are found to have prognostic significance. We concentrated on ventricular ejection fractions since there are data providing evidence that LVEF and RVEF are independent predictors of outcome in patients with repaired TOF.³⁷ All CMR imaging studies were evaluated during a regular clinical work in a CMR imaging unit by 6 independent investigators. Although this can be regarded as a limitation of the study, it is a reflection of a normal clinical scenario and is considered superior to the consensus readings.³⁸

In conclusion, since PRF correlated inversely and independently with LVEF, and LVEDV showed a positive and independent correlation with RVEF, an LV disease (low LVEF and LVEDV due to LV compression) may be used as a marker of the severity of an RV disease (severity of PR and its consequences). Further studies are needed to evaluate the role of LVEF and LVEDV in supporting patient selection for PVR.

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ARTYKUŁ ORYGINALNY

Czynniki związane z frakcją wyrzutową lewej i prawej komory u pacjentów po korekcji tetralogii Fallota – badanie metodą rezonansu magnetycznego serca

Mateusz Śpiewak^{1,2}, Łukasz A. Małek^{2,3}, Joanna Petryka^{1,2}, Łukasz Mazurkiewicz^{2,4}, Magdalena Marczak^{2,5}, Elżbieta K. Biernacka⁶, Mirosław Kowalski⁶, Piotr Hoffman⁶, Marcin Demkow¹, Jolanta Miśko^{2,5}, Witold Rużyłło⁷

Klinika Choroby Wieńcowej i Strukturalnych Chorób Serca, Instytut Kardiologii, Warszawa 1

2 Pracownia Rezonansu Magnetycznego, Instytut Kardiologii, Warszawa

- 3 Klinika Kardiologii i Angiologii Interwencyjnej, Instytut Kardiologii, Warszawa
- 4 Oddział Kardiomiopatii, Instytut Kardiologii, Warszawa
- 5 Zakład Radiologii, Instytut Kardiologii, Warszawa
- 6 Klinika Wad Wrodzonych Serca, Instytut Kardiologii, Warszawa

7 Instytut Kardiologii, Warszawa

SŁOWA KLUCZOWE

STRESZCZENIE

dvsfunkcia skurczowa, frakcja wyrzutowa lewej komory, frakcja wyrzutowa prawej komory, interakcja komór, tetralogia Fallota

Adres do korespondencji:

dr med. Mateusz Śpiewak, Klinika Choroby Wieńcowej i Strukturalnych Chorób Serca, Pracownia Rezonansu Magnetycznego, Instytut Kardiologii, ul. Alpeiska 42, 04-628 Warszawa. tel.: 22-343-43-42, fax: 22-343-45-16, e-mail: mspiewak@ikard.pl Praca wptyneta: 08.06.2013 Przyjęta do druku: 03.07.2013. Publikacja online: 04.07.2013 Nie załoszono sprzeczności interesów.

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WPROWADZENIE Istnieją sprzeczne dane dotyczące czynników wpływających na frakcję wyrzutową lewej (left ventricular ejection fraction – LVEF) i prawej komory (right ventricular ejection fraction – RVEF) u pacjentów po korekcji tetralogii Fallota (TF).

CELE Celem badania była ocena czynników wpływających na LVEF i RVEF w dużej grupie pacjentów po korekcji TF.

PACJENCI I METODY Badaniem objęto 122 pacjentów po korekcji TF (mediana wieku 24,2 roku, przedział międzykwartylowy 20,3–30,9; 60,6% mężczyzn), u których wykonano rezonans magnetyczny serca. Czynniki związane z LVEF, RVEF oraz RVEF skorygowaną wobec obecnych przecieków i niedomykalności analizowano przy użyciu regresji liniowej.

WYNIKI Stwierdzono słabą korelację RVEF z LVEF (r = 0.39; p < 0.0001). Analiza wieloczynnikowa wykazała następujące niezależne czynniki predykcyjne LVEF: dodatnie czynniki predykcyjne - RVEF (p = 0,0002), negatywne – frakcja niedomykalności płucnej (*pulmonary regurgitation fraction* – PRF, p = 0,01) oraz płeć męska (p = 0,001). Czynnikami związanymi w sposób niezależny z RVEF były: dodatnie czynniki predykcyjne – LVEF (p <0,0001), objętość końcowo-rozkurczowa lewej komory (left ventricular end-diastolic volume – LVEDV, p = 0,04); negatywne – masa prawej komory (p < 0,0001), liczba przebytych operacji kardiochirurgicznych (p = 0,005). W modelu oceniającym czynniki predykcyjne skorygowanej RVEF jedynie masa lewej komory była niezależnym dodatnim czynnikiem predykcyjnym (p < 0,0001), a czynnikami negatywnymi były: masa prawej komory (p <0,0001), PRF (p <0,0001), płeć męska (p < 0,0001) oraz punktacja w skali późnego wzmocnienia pokontrastowego prawej komory (p = 0,008). WNIOSKI Ponieważ PRF wykazywała ujemną i niezależną korelację z LVEF, a LVEDV dodatnią korelację z RVEF, patologia lewej komory (niska LVEF i LVEDV spowodowana uciskiem lewej komory) może być uznana za wskaźnik ciężkości patologii prawej komory (stopnia ciężkości niedomykalności płucnej i jej następstw). Konieczne są dalsze badania w celu oceny roli LVEF oraz LVEDV w kwalifikacji pacjentów do wymiany zastawki płucnej.