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Assessment of Right Ventricular Function by Tissue Doppler, Strain and Strain Rate Imaging in Patients with Left-Sided Valvular Heart Disease and Pulmonary Hypertension

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Background: Pulmonary artery hypertension is the presentation of various types of cardiovascular and systematic diseases. There are different kinds of noninvasive methods to determine right ventricular function, pulmonary artery pressure, and effect of pulmonary hypertension on right ventricular function. These methods include the tissue Doppler imaging (TDI) of the tricuspid annulus and the longitudinal deformation indices of the right ventricular free wall.

Objectives: In some patients, the echocardiogram cannot help estimate pulmonary artery pressure. In this study, we evaluated the effect of pulmonary hypertension on the TDI of the tricuspid annulus and the longitudinal strain and strain rate of the basal segment of the right ventricular free wall in patients with left-sided valvular heart disease and pulmonary hypertension. Indeed, we sought to investigate whether we can guess the presence of pulmonary hypertension through the measurement of the TDI of the tricuspid annulus and the deformity indices of the basal segment of the right ventricular free wall.

Patients and Methods: Eighty consecutive patients with left-sided valvular disease and pulmonary artery hypertension (V/PH Group) and 80 healthy matched controls (H Group) were enrolled in this research. The TDI parameters were obtained in the tissue velocity imaging mode during systole (S, S VTI), early relaxation (E), atrial systole (A), and isovolemic relaxation time (IVRT). The deformation indices included peak systolic longitudinal strain and strain rate measured from the basal segment of the right ventricular free wall and were calculated as the relative magnitude of segmental deformation.

Results: S, E, and S VTI were reduced significantly in the V/PH Group, and there was a significant negative correlation between S velocity, S VTI with pulmonary artery systolic pressure (PASP), and right ventricular diameter (RVD). According to the ROC curve, S velocity < 10.5 cm/s had 65% sensitivity and 40% specificity for the prediction of pulmonary hypertension. E velocity had only a negative significant correlation with RVD and no significant correlation with tricuspid annular plane systolic excursion (TAPSE) and PASP. There was no significant difference in A velocity and E/A ratio between the two groups (P = 0.455 and P = 0.070, respectively), and these parameters had no significant correlation with RVD and TAPSE. IVRT was significantly increased in the V/PH Group versus the H Group, and IVRT > 40 ms had 78% sensitivity and 67% specificity for the prediction of pulmonary hypertension. In comparison with the H Group, RV longitudinal peak systolic strain (-14/35 ± 4%) and strain rate (-0.65 ± 0.12) at the basal segment of the right ventricular free wall were significantly lower in the V/PH Group (P < 0.001 and P < 0.001).

Conclusions: We observed a significant reduction in S, E velocity, and S VTI of the tricuspid annulus. Moreover, the strain/strain rate of the basal segment of the right ventricular free wall had a marked decrease in the V/PH Group in comparison with the healthy subjects.

Keywords: Hypertension; Lung; Heart ventricles; Tricuspid valve; Elasticity imaging techniques; Sprains and strains

1. Background

Pulmonary hypertension (PH) is defined as a pulmonary artery systolic pressure (PASP) > 35 mm Hg or a mean pulmonary artery pressure (PAP) > 25 mm Hg. PH is a manifestation of various types of cardiopulmonary and systemic diseases. If there is no underlying reason for PH, it is called primary PH. Pulmonary artery catheterization is the gold standard test for the measurement of PAP; nevertheless, it is both invasive and costly. In contrast, echocardiography is a noninvasive technique that has been used traditionally to measure PAP (1). The measurement of PAP is dependent on the presence of tricuspid regurgitation (TR) jet and if there is no regurgitation jet, PAP cannot be calculated by this method. In this study, we evaluated the predictive value of right ventricular diameter (RVD), tricuspid annular plane

Implication for health policy/practice/research/medical education

This project evaluated the tissue Doppler imaging parameters of the tricuspid annulus and strain/strain rate of the basal segment of the right ventricular free wall in patients with valvular heart disease with pulmonary hypertension. Further studies with large sample volumes and in separate groups of each kind of valvular dysfunction are recommended.

systolic excursion (TAPSE), tricuspid annular tissue Doppler imaging (TDI), and strain and strain rate parameters of the RV for the prediction of the presence of PH in patients with left-sided heart valve disease. Whereas previous studies have evaluated these parameters in other causes of PH, we sought to work exclusively on the left-sided valvular patients.

2. Objectives

We aimed to determine the changes in the TDI of the tricuspid annulus, TAPSE, RVD, and longitudinal strain / strain rate of the basal segment of the RV free wall in patients with left-sided heart valve disease and PH and to compare them with the same parameters in a healthy control group.

3. Patients and Methods

3.1. Patients

This case-control study was conducted in the echocardiography ward in a referral teaching hospital from March 2010 to December 2012. In our laboratory, both inpatients and outpatients underwent echocardiography. The most common referral causes included the presence of heart murmur, dyspnea, abnormal electrocardiographic findings, and assessment of left ventricular (LV) function. Patients were excluded if they had suboptimal two-dimensional (2D) images, previous tricuspid valve replacement or annuloplasty, a pacemaker or implantable cardioverter defibrillator, atrial fibrillation, inadequate Doppler signal, presence of other causes of PH, and eccentric TR jet. Altogether 160 patients were enrolled in the study and were divided into two groups: (1) patients who had left-sided valvular dysfunction and PH (V/PH Group) and (2) a healthy control group (H Group) with normal PAP. Left-sided valvular heart disease included isolated mitral or aortic stenosis or regurgitation, or a combination of these kinds of valvular dysfunction. The two groups of patients were matched for age and sex.

3.2. Echocardiography

Standard 2D and Doppler transthoracic echocardiographic (TTE) studies were performed using Vivid 7 with a 3.2-MHz transducer in the left lateral position by one fellow of echocardiography, who was blinded to the study. Maximal TR velocity was recorded using continuous-wave Doppler from any standard views that yielded the highest peak velocity during end expiration. This velocity reflects the pressure difference during systole between the RV and the right atrium (RA). Therefore, systolic RV pressure can be estimated by adding RA pressure to trans-tricuspid gradient derived from TR velocity. Trans-tricuspid pressure gradient was calculated using the modified Bernoulli equation. RA pressure can be estimated by the respiratory collapse of the inferior vena cava (IVC) seen on a 2D echocardiogram. When the diameter of the IVC decreases by 50% or more with inspiration, RA pressure is usually < 10 mm Hg, and those with < 50% inspiratory collapse tend to have an RA pressure > 10 mm Hg. In the absence of pulmonic stenosis, RV systolic pressure is equal to PASP. PH was defined as a PASP > 35 mm Hg in this study. RVD was measured from the apical four-chamber view at the level of one-third from the base of the RV to the apex. TAPSE was measured in the M-mode by placing the cursor through the free wall of the RV at the level of the tricuspid annuls in the apical four-chamber view. TDI velocities were obtained in the tissue velocity imaging mode in the apical four-chamber view by placing the cursor at the RV free wall of (average of three cardiac cycles). TDI parameters were measured during systole (S, S VTI), early relaxation (E), atrial systole (A), E/A ratio, and isovolemic relaxation time (IVRT) (Figure 1).

Deformation indices were obtained using the Doppler-based method. All the images were obtained from the RV basal segment with small-sector width, high-frame rate, zoom image, and best beam angle consideration. Peak systolic longitudinal strain and strain rate were measured from the basal segment of the RV free wall in three cardiac cycles, and the averages are recorded in Figure 2 and Figure 3.

3.3. Statistical Analysis

All the data analyses were performed using SPSS statistics 11.5 for Windows. The data are expressed as mean ± SD for the continuous variables and absolute value and percentage for the qualitative variables. Group comparisons were made using the Student *t*-test. The chi-squared test was used instead for the nominal data. The Kruskale Wallis one-way ANOVA test was utilized when comparisons were needed for more than two groups. The Roc curve was drawn upon to determine the specificity and sensitivity of the parameters. All the tests used were two-sided, and differences were considered statistically significant for a $P < 0.05$.

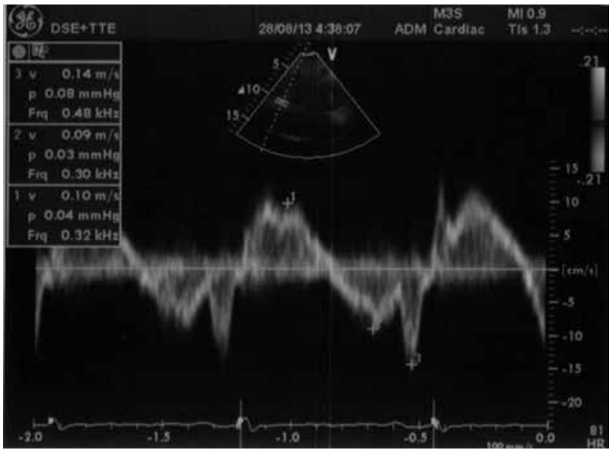

Figure 1. Tissue Doppler Imaging of the Basal Segment of the Right Ventricular Free Wall

Figure 2. Tissue Doppler Imaging-Based Strain Imaging of the Right Ventricular Free Wall (Base, Mid, and Apical Segments)

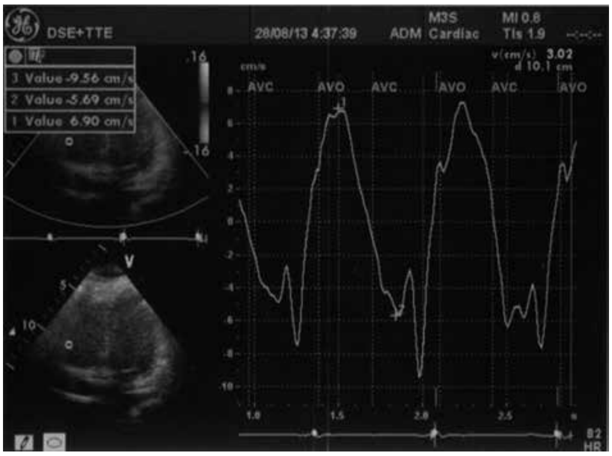

Figure 3. Off-Line Tissue Doppler Imaging of the Right Ventricular Free Wall

4. Results

The mean age of the H Group and V/PH Group was 41.55 ± 16.36 and 42.65 ± 15.44 years, respectively (t = 0.663). Out of the 80 patients in the H Group, there were 27 (33.8%) men and in the V/PH Group, there were 57 (71.3%) men (P = 0.495). In the V/PH Group, there was 38% mitral stenosis, 20% aortic stenosis, 13% mitral regurgitation, 2.5% aortic regurgitation, and 25% multi-valvular disease. A complete TTE was obtained in 160 patients, and all the data were recorded.

4.1. RVD, PASP, and TAPSE

RVD and PASP were significantly higher and TAPSE was significantly lower in the V/PH Group (Table 1). There was a significant positive correlation between RVD and PASP in the V/PH Group; it means that the increase in PASP led to an increase in RVD. In the V/PH Group, a rise in PASP was in tandem with a drop in TAPSE (Table 2).

4.2. S, E, A Velocity, E/A Ratio, IVRT, and S VTI

The mean ± SD of these parameters is summarized in Table 1. S, E, and S VTI were reduced significantly in the V/PH Group, and there was a negative significant correlation between S velocity, S VTI with PASP, and RVD. According to the ROC curve, S velocity < 10.5 cm/s had 65% sensitivity and 40% specificity for predicting PH. E velocity had only a negative significant correlation with RVD and no significant correlation with TAPSE and PASP. There was no significant difference in A velocity and E/A ratio between the two groups (P = 0.455 and P = 0.070, respectively), and these parameters had no significant correlation with RVD and TAPSE. IVRT was significantly increased in the V/PH Group versus the Control Group, and IVRT > 40 ms had 78% sensitivity and 67% specificity for predicting PH.

Table 1. Values of the Echocardiographic Parameters

	V/PH Group[a]	H Group[a]	P value
S velocity cm/s	12.24 ± 3.57	14.79 ± 2.75	< 0.001
E velocity cm/s	11.74 ± 4.86	13.93 ± 4.17	0.003
S VTI [b]	2.21 ± 0.74	2.62 ± 0.48	< 0.001
IVRT	68.98 ± 34.03	34.79 ± 31.94	< 0.001
TAPSE	21.49 ± 7.23	26.44 ± 4.06	< 0.001
RVD	37.01 ± 8.09	28.88 ± 3.29	< 0.001
A	13.25 ± 5.23	13.76 ± 4.19	0.455
E/A	1.06 ± 0.82	1.1. ± 0.49	0.070
RV strain	-14/35 ± 4%	-24% ± 3.8%	< 0.001
RV strain rate	-0.65 ± 0.12	-1.3 ± 0.3	< 0.001

[a] Data are presented as mean ± SD.
[b] Abbreviations: IVRT, isovolemic relaxation time; RV, right ventricular; RVD, right ventricular diameter; TAPSE, tricuspid annular plane systolic excursion, VTI, velocity time integral

Table 2. Spearman Correlation Coefficients Between the Echocardiographic Parameters

	Spearman Correlation Coefficients									
	S Velocity		E Velocity		E/A Ratio		Strain		Strain Rate	
	V/PH Group	H Group	V/PH Group	H Group	V/PH Group	H Group	V/PH Group	H Group	V/PH Group	H Group
RVD[a]	-0.385	-0.176	-0.340	-0.152	-0.139	-0.200	-0.371	-0.166	-.366	-0.165
P value	< 0.001	0.119	0.002	0.178	0.218	0.075	< 0.001	0.136	< 0.001	0.132
TAPSE	0.403	-0.124	0.134	0.003	-0.087	-0.072	0.398	-0.111	0.385	-0.101
P value	< 0.001	0.272	0.236	0.980	0.442	0.526	< 0.001	0.222	< 0.001	0.251
PASP	-0.303	0.138	-0.160	-0.141	0.066	-0.174	-0.299	0.110	-0.296	0.127
P value	< 0.001	0.221	0.134	0.213	0.624	0.123	< 0.001	0.154	< 0.001	0.210

[a] Abbreviations: PASP, pulmonary artery systolic pressure; RVD, right ventricular diameter; TAPSE, tricuspid annular plane systolic excursion

4.3. Strain and Strain Rate Imaging

RV longitudinal peak systolic strain and strain rate at the basal segment of the RV free wall were significantly lower in the V/PH Group (P < 0.001 and P < 0.001). Strain and strain rate of this segment had a significant positive correlation with TAPSE and a significant negative correlation with RVD and PASP.

5. Discussion

Valvular heart disease is the reason for 10 to 20% of surgical operations. Although the incidence of rheumatoid heart disease has decreased in many countries, a large number of people in the developing world still suffer from this disease. Failure to treat valvular heart disease will result in the occurrence of PH. In some cases, variable degrees of PH and RV dysfunction will persist for a long time, despite surgical treatment. Both RV dysfunction and PH can affect patients' survival, and early determination and intervention are very important factors (2). Cardiac catheterization is the gold standard method for determining PAP, but it is both invasive and expensive. Echocardiography is an available and noninvasive method that can calculate PASP by using TR jet; nonetheless, the requirement of the presence of TR has rendered echocardiography nugatory in some situations. In the absence of TR, other echocardiographic options can be used to predict the presence of PH (1, 3). Many recent studies have relied on the value of echocardiography for assessing RV function by various methods, including TAPSE, tissue Doppler echocardiography, and 2D strain method (4, 5). The present study demonstrated that reduced S velocity, S VTI, and strain and strain rate, which were measured by pulsed Doppler tissue imaging from the RV free wall, can predict PH and higher PASP, lower S velocity, S VTI, and strain /strain rate. This investigation also showed that the IVRT of the RV free wall can be used to predict the presence of PH.

Previous researchers have described the utility of TDI parameters for the evaluation of PAP in various conditions such as chronic obstructive pulmonary disease, primary PH, and congenital heart disease but we focused on patients with valvular heart disease and our results confirm the findings of previous studies. Koestenberger et al. (6) using TDI echocardiography in 183 patients with repaired Tetralogy of Fallot (TOF) and in 55 with PH secondary to congenital heart disease, demonstrated that S values became significantly reduced and that there was a significant positive correlation between S velocity and RV ejection fraction in patients with TOF and those with PH secondary to congenital heart disease. Significant negative correlations between S velocity and RV end diastolic volume were also seen in patients with repaired TOF. In a cohort of 80 patients with different causes of PH, Ojaghi et al. (7) reported that IVRT had a significant increase and an IVRT $\geq$ 77 ms predicted PASP $\geq$ 50 mm Hg with a sensitivity of 93% and a specificity of 80%. Haeck et al. (8) in a series of 142 patients with PH of different etiologies, observed that RV longitudinal peak systolic strain ($\leq$ 19%) was significantly associated with lower TAPSE and all-cause mortality. Puwanant et al. (9) demonstrated that in a series of 44 patients with precapillary PH, chronic RV pressure overload directly affects RV longitudinal systolic deformation and the interventricular septal and LV geometry.

Echocardiography is a pivotal screening test in symptomatic patients at risk for PH. As an imaging modality, it has the advantage of being widely available, cost-effective, and safe. It also plays an important role in assessing outcomes, monitoring the efficacy of specific therapeutic interventions for PH, and detecting the preclinical stages of diseases. Newer ultrasound techniques may provide additional key information in the assessment of the right-heart structure and function. TDI and deformation indices are pulsed Doppler-based methods and they measure the velocity (motion) of the myocardial tissue and longitudinal deformation percent and its velocity (10-14).

TDI and deformation indices have some advantages over the blood flow Doppler technique. These methods reflect the functional status of the myocardium directly and are less subject to background noise and preload; furthermore, the exact alignment of the cursor with the tissue motion is not usually very important.

We conclude that S and E velocity, S VTI, IVRT of the tricuspid annulus, and also strain and strain rate of the basal free wall of the RV have an excellent correlation with PH and these parameters should be routinely assessed during the initial evaluation.

5.1. Study Limitations

Although cardiac catheterization is the gold standard method for the measurement of PAP, we did not use this method in our study. We also evaluated all kinds of left-sided valvular disease together as one group; it may be preferable to evaluate them separately so as to prevent the impact of confounding factors.

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Authors' Contribution

All authors had equal role in design, work, statistical analysis, and manuscript writing.

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The authors declare that they have no conflicts of interest.

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