

## Original Research

## Acute Exacerbation Impairs Right Ventricular Function in COPD Patients

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**Echocardiography, chronic obstructive pulmonary disease, isovolumic myocardial acceleration, right ventricular function, tissue Doppler imaging.**

**Introduction:** Chronic obstructive pulmonary disease (COPD) may impair right ventricular (RV) function. Tissue Doppler imaging (TDI) is helpful in the noninvasive evaluation of RV longitudinal function. The aim of this study was to assess the impact of acute COPD exacerbation on RV function assessed by TDI.

**Methods:** The study included 30 COPD patients who had acute exacerbation and 30 controls. RV function was assessed echocardiographically during acute exacerbation and after recovery. In addition to conventional echocardiographic parameters, tricuspid annular plane systolic excursion, tricuspid annulus peak systolic velocity (Sa), and TDI-derived isovolumic myocardial acceleration (IVA) were determined.

**Results:** During exacerbation, COPD patients had a significantly larger RV and higher pulmonary artery systolic pressure, with significantly lower IVA, Sa and tricuspid annular plane systolic excursion compared to controls. After recovery, IVA and Sa significantly increased, while RV diameter and pulmonary artery systolic pressure significantly decreased to levels similar to controls. There were statistically significant, but modest correlations between IVA and Sa ( $r=0.441$ ,  $p=0.003$ ), tricuspid annular plane systolic excursion ( $r=0.628$ ,  $p<0.001$ ), pulmonary artery systolic pressure ( $r=-0.391$ ,  $p=0.002$ ) and RV diameter ( $r=-0.309$ ,  $p=0.018$ ). Sa correlated with pulmonary artery systolic pressure ( $r=-0.350$ ,  $p=0.007$ ) and RV diameter ( $r=-0.344$ ,  $p=0.008$ ).

**Conclusions:** COPD exacerbations have a negative impact on RV function. TDI-derived IVA and Sa may be used in the assessment of subclinical RV dysfunction in COPD patients with exacerbation.

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**C**hronic obstructive pulmonary disease (COPD) is a multicomponent disease characterized by an inflammatory response of the lungs to noxious particles, and extrapulmonary effects, including cardiovascular system abnormalities, that contribute to disease severity.<sup>1-4</sup> COPD exacerbations are considered to be the key drivers of morbidity and mortality associated with this disease.

Pulmonary hypertension is frequently seen in COPD patients. Severe and prolonged pulmonary hypertension may result in right ventricular (RV) dysfunction and systemic congestion by increasing RV afterload. The prevalence of RV failure

secondary to COPD is estimated to be 10-30%.<sup>5</sup> There is evidence that RV dysfunction is present in the early stages of the disease, even before systemic venous congestion develops. It is important to identify patients with RV dysfunction, as it further worsens the prognosis of COPD patients who are already suffering from ventilatory insufficiency.<sup>6-8</sup>

The evaluation of RV function is difficult, because of its complex geometry. Radionuclide ventriculography, cardiac catheterization and cardiac magnetic resonance imaging are suggested techniques for the assessment of RV volumes and ejection fraction.<sup>9-11</sup> Since these tech-

niques are time consuming and not widely available, they are not suitable for screening purposes. Echocardiography with the use of tissue Doppler imaging (TDI) provides an easy, quantitative and reproducible noninvasive evaluation of RV function. Tricuspid annular systolic velocity (Sa) by TDI is well correlated with RV ejection fraction. However, loading conditions may affect TDI-derived systolic myocardial velocities.<sup>12-14</sup> Isovolumic acceleration during isovolumic contraction (IVA) has been proposed as a useful index of RV contractile function that is unaffected by preload and afterload changes in a physiological range.<sup>15</sup> The role of IVA in assessing RV dysfunction has been shown in COPD patients, even in the early stages of the disease when they have subclinical RV systolic dysfunction.<sup>16,17</sup>

Acute exacerbation periods may impair RV function in COPD patients, even when there is no clinical evidence of RV dysfunction. The aim of this study was to determine the effect of acute COPD exacerbation on RV function assessed by TDI.

## Methods

The investigation conformed with the principles outlined in the Declaration of Helsinki. The study was approved by Marmara University Faculty of Medicine Research Ethics Committee (approval number: MAR-YC-2007-0038). All participants gave written informed consent. Patients were selected from among cases admitted to the outpatient clinics of the Pulmonary and Critical Care Department between October 2007 and December 2008.

Thirty-three consecutive patients with acute COPD exacerbation were recruited into the study, after exclusion of patients with the following conditions: any clinical evidence of right or left heart failure, severe exacerbation of COPD requiring intubation or respiratory arrest, decreased level of consciousness, presence of neurological diseases, atrial fibrillation, hemodynamic instability, malignancy, and severe endocrine, hepatic or renal diseases. All patients had COPD according to the American Thoracic Society/European Respiratory Society guidelines.<sup>18</sup> Acute exacerbation of COPD was defined in terms of worsening dyspnea, an increase in the amount of sputum production, and a change in sputum purulence that was acute in onset and warranted a change in the regular medication regimen.<sup>19-21</sup> All patients had Anthonisen type I COPD exacerbation (all three symptoms were present) and none needed hospitalization.

All patients underwent echocardiographic examination within 48 hours after the diagnosis of COPD exacerbation. Three patients were excluded because of poor echogenicity. The remaining 30 patients were included in the study protocol.

The most recent pulmonary function tests of the COPD patients were noted; the mean forced expiratory volume in one second (FEV1) was  $50 \pm 14\%$ , forced vital capacity (FVC) was  $61 \pm 11\%$ , FEV1/FVC was  $58 \pm 12\%$  and the average rate of flow between the 25% and 75% volume point of an FVC maneuver (FEF 25-75) was  $29 \pm 15\%$ .

All COPD patients were given the same medication, including antibiotics (amoxicillin  $1 \times 2$  g per day for 14-21 days) and bronchodilators (tiotropium bromide, long acting beta<sub>2</sub> agonist plus inhaler steroid), to prevent any confounding effect of the treatment. No change was made to the patients' other medications throughout the study. The patients were followed at 1-week intervals. A control echocardiographic examination was performed after the exacerbation resolved completely. The interval between the first and second echocardiographic examinations was  $42 \pm 11$  days.

Thirty age- and sex-matched patients without any signs or symptoms of COPD were consecutively included in the study as a control group.

## Echocardiographic examination

All COPD patients and controls underwent transthoracic echocardiography by a General Electric Vingmed System Five (GE Vingmed Ultrasound, Horten, Norway) echocardiography device, equipped with a 2.5 MHz phased-array transducer with harmonic capability. Echocardiographic examinations were evaluated by a single blinded cardiologist. Two-dimensional echocardiography, pulsed and continuous wave Doppler, and color-flow Doppler studies were performed using standard techniques in each patient. All patients were in sinus rhythm at the time of examination and none of the patients had any conduction abnormality. All measurements were calculated from three consecutive cycles and the average of the three measurements was recorded.

In addition to conventional echocardiographic parameters, including left atrial diameter, left ventricular end-diastolic and end-systolic diameters, interventricular septum and posterior wall thickness, and left ventricular ejection fraction, RV diameter and the area of the right atrium were measured. RV di-

ameter was measured from the parasternal long-axis view using M-mode, from the RV anterior wall to the right side of the septum at the R-wave of the electrocardiogram, while the M-mode cursor was placed at the left ventricular chordal level. Right atrial area was measured in the apical 4-chamber view at end-systole. Tricuspid annular plane systolic excursion was measured in M-mode, apical four-chamber view, with the cursor at the junction of the tricuspid valve with the RV free wall. The maximum displacement during systole was evaluated.<sup>22,23</sup> Pulmonary artery systolic pressure was estimated using the Bernoulli equation (by adding RV systolic pressure determined from peak tricuspid regurgitant velocity to estimated right atrial pressure).<sup>24</sup>

Conventional pulsed Doppler imaging of mitral inflow was recorded in the apical four-chamber view. Early (E) and atrial (A) peak velocities of the mitral valve, their ratio (E/A), E velocity deceleration time (DT) and isovolumic relaxation time were measured.

Pulsed TDI was performed to assess RV longitudinal function. In the apical four-chamber view, a 5 mm pulsed Doppler sample volume was placed on the tricuspid annulus at the place of attachment of the anterior leaflet of the tricuspid valve. Settings were adjusted for a frame rate between 120 and 180 Hz, Nyquist velocity range  $\pm 20$  cm/s, and horizontal record velocity of 90-100 m/s. Care was taken to obtain an ultrasound beam parallel to the direction of tricuspid annulus motions. Sa, IVA, peak myocardial early (Ea) and late (Aa) diastolic velocities were measured. IVA was defined as the mean slope of the isovolumic contraction velocity wave (peak myocardial velocity during isovolumic contraction/acceleration time,  $\text{m/s}^2$ ).

The myocardial performance index, a Doppler index of combined systolic and diastolic myocardial performance, was determined using the following equation: myocardial performance index = (isovolumic contraction time + isovolumic relaxation time) / ejection time.

From the TDI recordings, the time interval from the end to the onset of the tricuspid annular velocity pattern during diastole (a) was measured. The duration of the Sa (b) was measured from the onset to the end of the Sa. The RV myocardial performance index was calculated as  $(a - b)/b$ .

### Reproducibility

To determine the intraobserver variability of Sa and

IVA, the observer repeated the Sa and IVA measures of 10 randomly selected COPD patients and 10 controls one day after the first examination and the measurements were compared using the Wilcoxon test. The p-value of the test was not significant. The intraobserver variability for repeated measurements (the mean of the differences) was  $0.04 \pm 0.17 \text{ m/s}^2$  for IVA and  $0.21 \pm 0.44 \text{ cm/s}$  for Sa. Intraobserver reliability was very good for IVA and Sa ( $r=0.96$  and  $r=0.97$ , respectively).

### Statistical analysis

All statistical tests were performed using commercially available statistical analysis software (SPSS 11.0 for Windows). Continuous variables were expressed as mean  $\pm$  standard deviation, while categorical variables were expressed as a ratio. The Wilcoxon test was used to compare quantitative nonparametric data between acute COPD exacerbation and recovery. The Mann-Whitney U test was used to compare quantitative nonparametric data between COPD patients and controls. Correlation analysis was performed using Spearman's correlation test. A multiple linear regression model with Sa, tricuspid annular plane systolic excursion, myocardial performance index, pulmonary artery systolic pressure, RV diameter and age correlating with IVA was performed. Receiver operating characteristic (ROC) curve analysis was performed to determine the cutoff levels of IVA, Sa, RV diameter, pulmonary artery systolic pressure and tricuspid annular plane systolic excursion to determine acute COPD exacerbation. Logistic regression analysis was performed to explore the odds ratios and 95% confidence intervals for combined echocardiographic parameters to predict acute COPD exacerbation. All p-values  $<0.05$  were interpreted as statistically significant.

### Results

The general characteristics of the COPD patients and controls are presented in Table 1. There were no significant differences in age, sex, or comorbidities between COPD patients and controls.

Table 2 and Table 3 demonstrate the conventional left ventricular and RV, and the TDI-derived RV echocardiographic parameters of the COPD patients and controls, respectively. The RV diameters of COPD patients during acute exacerbation were significantly larger than those measured after recovery

**Table 1.** General characteristics of the COPD patients and controls.

	COPD patients (n=30)	Controls (n=30)	p
Age, years	64.2 ± 10.9	61.3 ± 7.8	0.240
Male sex, n (%)	22 (73.3%)	21 (70.0%)	0.774
Body mass index, kg/m <sup>2</sup>	29.13 ± 3.95	28.92 ± 3.74	0.847
Hypertension, n (%)	26 (86.7%)	27 (90.0%)	1.000
Diabetes, n (%)	13 (43.3%)	14 (46.7%)	0.795
Hyperlipidemia, n (%)	17 (56.7%)	23 (76.7%)	0.100
Coronary artery disease, n (%)	10 (33.3%)	13 (43.3%)	0.426
Smoking, n (%)	27 (90.0%)	30 (100%)	0.237
Systolic blood pressure, mmHg	140.0 ± 24.8	135.8 ± 20.0	0.469
Diastolic blood pressure, mmHg	81.8 ± 14.0	79.3 ± 10.7	0.429
Heart rate, /min	94 ± 8	77 ± 11	<0.001

Continuous variables are expressed as mean ± standard deviation. COPD – chronic obstructive pulmonary disease.

**Table 2.** The conventional echocardiographic parameters of the COPD patients and controls.

	COPD patients (n=30)	Controls (n=30)	p
Left atrium (mm)	38.8 ± 6.6	38.1 ± 4.3	0.621
Left ventricular end-diastolic diameter (mm)	49.2 ± 7.2	46.9 ± 4.2	0.142
Left ventricular end-systolic diameter (mm)	32.0 ± 8.7	29.8 ± 4.4	0.232
Interventricular septum thickness (mm)	11.5 ± 1.1	12.1 ± 1.4	0.091
Posterior wall thickness (mm)	10.5 ± 0.8	10.9 ± 0.9	0.054
Left ventricular ejection fraction (%)	58.4 ± 10.2	61.5 ± 6.1	0.074
Mitral E velocity (m/s)	0.70 ± 0.24	0.66 ± 0.17	0.441
Mitral A velocity (m/s)	0.82 ± 0.19	0.75 ± 0.15	0.101
E/A ratio	0.85 ± 0.39	0.91 ± 0.28	0.499
E wave deceleration time (ms)	204.7 ± 68.9	214.6 ± 58.5	0.551
Isovolumic relaxation time (ms)	100.1 ± 17.0	100.9 ± 16.0	0.862

Continuous variables are expressed as mean ± standard deviation. COPD – chronic obstructive pulmonary disease.

**Table 3.** Comparison of conventional and TDI-derived RV echocardiographic parameters.

	COPD patients (n=30)		Controls (n=30)
	During acute exacerbation	After recovery	
Right atrium area (cm <sup>2</sup> )	15.67 ± 2.06	15.22 ± 4.91	14.03 ± 3.47
RV (mm)	38.0 ± 7.8	32.3 ± 5.5 *	27.3 ± 3.8*†
Tricuspid annular plane systolic excursion (mm)	14.47 ± 2.40	15.27 ± 2.24	16.33 ± 1.97*
Pulmonary artery systolic pressure (mmHg)	40 ± 13	27 ± 9*	29 ± 5*
RV TDI-Sa (cm/s)	11.58 ± 2.21	12.90 ± 2.79*	13.50 ± 1.83*
RV TDI-Ea (cm/s)	10.84 ± 2.78	10.46 ± 3.09	10.95 ± 2.65
RV TDI-Aa (cm/s)	15.91 ± 4.64	16.31 ± 3.92	16.07 ± 2.66
RV TDI-Ea/Aa	0.71 ± 0.27	0.64 ± 0.17	0.80 ± 0.31
RV TDI-IVA (m/s <sup>2</sup> )	2.45 ± 0.37	2.82 ± 0.53*	3.02 ± 0.90*
RV TDI- myocardial performance index	0.42 ± 0.28	0.35 ± 0.16	0.36 ± 0.10

\*p<0.05 vs. COPD patients – acute exacerbation; †p<0.05 vs. COPD patients – recovery. Continuous variables were expressed as mean ± standard deviation. COPD – chronic obstructive pulmonary disease; RV – right ventricle; TDI – tissue Doppler imaging; Sa – peak systolic myocardial velocity; Ea – peak early diastolic myocardial velocity; Aa – peak atrial diastolic myocardial velocity; IVA – myocardial acceleration during isovolumic contraction

(p<0.001). Although RV diameters decreased significantly after recovery, they were still significantly larger than those of controls (p<0.001). The tricus-

pid annular plane systolic excursion was significantly lower in COPD patients during acute exacerbation than in controls (p=0.002). The tricuspid annular

plane systolic excursion measures of COPD patients increased after recovery, but the difference was not significant. Pulmonary artery systolic pressure levels of COPD patients during acute exacerbation were significantly higher than those of controls ( $p < 0.001$ ). They decreased significantly with recovery (from  $40 \pm 13$  mmHg to  $27 \pm 9$  mmHg,  $p < 0.001$ ). COPD patients had significantly lower tricuspid annulus Sa and IVA during acute exacerbation compared to controls ( $p = 0.001$  and  $p = 0.003$ , respectively). Both parameters increased significantly with recovery ( $p = 0.038$  and  $p = 0.002$ , respectively).

IVA was significantly correlated with Sa ( $r = 0.441$ ,  $p = 0.003$ ). The significant association persisted when correlation analyses were repeated separately for measures obtained during acute exacerbation ( $r = 0.411$ ,  $p = 0.009$ ) and after recovery ( $r = 0.484$ ,  $p = 0.001$ ). IVA was also significantly correlated with tricuspid annular plane systolic excursion ( $r = 0.628$ ,  $p < 0.001$ ), myocardial performance index ( $r = -0.361$ ,  $p = 0.005$ ), pulmonary artery systolic pressure ( $r = -0.391$ ,  $p = 0.002$ ), and RV diameter ( $r = -0.309$ ,  $p = 0.018$ ). Similarly, Sa correlated significantly with RV myocardial performance index ( $r = -0.409$ ,  $p = 0.001$ ), pulmonary artery systolic pressure ( $r = -0.350$ ,  $p = 0.007$ ), and RV diameter ( $r = -0.344$ ,  $p = 0.008$ ).

We modeled a multiple linear regression analysis to derive the independent determinants of IVA. Age, Sa, tricuspid annular plane systolic excursion, myocardial performance index, pulmonary artery systolic pressure and RV diameter were incorporated into the model as independent variables. The adjusted R square of the model was 0.702 with  $p < 0.001$ . The linear regression model revealed that Sa and tricuspid annular plane systolic excursion were still significantly and positively correlated with IVA (standardized beta = 0.246,  $p = 0.035$  and standardized beta = 0.518,  $p < 0.001$ , respectively) (Table 4).

ROC curve analysis demonstrated cutoff values for IVA as  $< 2.64$  m/s<sup>2</sup>, Sa as  $\leq 12.50$  cm/s, RV diameter as  $\geq 35.0$  mm, pulmonary artery systolic pressure as  $\geq 32$  mmHg, and tricuspid annular plane systolic excursion as  $< 15$  mm to determine COPD exacerbation in our cohort. Table 5 shows the sensitivity, specificity, positive and negative predictive values for IVA, Sa, RV diameter, pulmonary artery systolic pressure, and tricuspid annular plane systolic excursion. Table 6 presents the combined echocardiographic parameters for prediction of acute COPD exacerbation and indicates that pulmonary artery systolic pressure  $\geq 32$  mmHg, especially in the presence of IVA  $< 2.64$  m/s<sup>2</sup>, was a strong predictor of COPD exacerbation in our cohort.

**Table 4.** Linear regression analysis for deriving the independent determinants of IVA.

Independent variables	$\beta$ (coefficient)	t-test value	p
Sa	0.246	2.171	0.035
Tricuspid annular plane systolic excursion	0.518	4.783	$< 0.001$
Pulmonary artery systolic pressure	-0.107	-0.844	0.403
Myocardial performance index	-0.164	-1.375	0.175
RV diameter	-0.031	-0.251	0.803
Age	-0.012	-0.117	0.907

$R^2 = 0.702$ ,  $p < 0.001$ . IVA – myocardial acceleration during isovolumic contraction; Sa – peak systolic myocardial velocity; RV – right ventricle.

**Table 5.** Sensitivity, specificity, positive and negative predictive values of IVA, Sa, RV diameter, pulmonary artery systolic pressure and tricuspid annular plane systolic excursion cutoff values for determining acute COPD exacerbation.

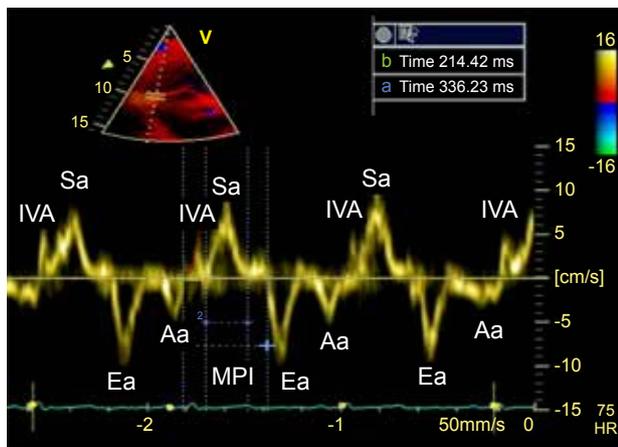
	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)
RV TDI-IVA $< 2.64$ m/s <sup>2</sup>	66.7	63.3	64.5	65.5
RV TDI-Sa $\leq 12.50$ cm/s	70.0	53.3	60.0	64.0
RV diameter $\geq 35.0$ mm	66.7	70.0	69.0	67.7
Pulmonary artery systolic pressure $\geq 32$ mmHg	76.7	83.3	82.1	78.1
Tricuspid annular plane systolic excursion (mm) $< 15$ mm	53.3	63.3	59.3	57.6

COPD – chronic obstructive pulmonary disease; RV – right ventricle; TDI – tissue Doppler imaging; IVA – myocardial acceleration during isovolumic contraction; Sa – peak systolic myocardial velocity.

**Table 6.** Combined echocardiographic parameters for prediction of acute COPD exacerbation. ORs with the respective 95% CIs for COPD exacerbation were calculated by logistic regression analysis. Echocardiographic parameters were dichotomized, and were defined as those  $\geq 35$  mm for RV diameter,  $< 2.64$  m/s<sup>2</sup> for RV TDI-IVA, and  $\geq 32$  mmHg for pulmonary artery systolic pressure (based on ROC analysis).

	OR	95% CI	P
RV diameter	4.667	1.571-13.866	0.004
RV TDI-IVA	3.455	1.195-9.990	0.020
Pulmonary artery systolic pressure	16.429	4.569-59.073	<0.001
RV diameter + RV TDI-IVA	3.824	1.150-12.713	0.024
RV diameter + pulmonary artery systolic pressure	11.769	2.919-47.458	<0.001
Pulmonary artery systolic pressure + RV TDI-IVA	16.000	3.218-79.556	<0.001
RV diameter + RV TDI-IVA + pulmonary artery systolic pressure	9.333	1.866-46.684	0.005

CI – confidence interval; OR – odds ratio; COPD – chronic obstructive pulmonary disease; RV – right ventricle; TDI – tissue Doppler imaging; IVA – myocardial acceleration during isovolumic contraction



**Figure 1.** Doppler tissue velocities obtained at the lateral corner of the tricuspid annulus. Isovolumic contraction velocity begins before the R-wave on the electrocardiogram and is followed by peak myocardial velocity (Sa). IVA was measured by dividing the peak velocity by the time interval from the onset of the wave during isovolumic contraction to the time at peak velocity of this wave (the slope of the red line). From the TDI recordings, the time interval from the end to the onset of the tricuspid annular velocity pattern during diastole (a) was measured. The duration of the Sa (b) was measured from the onset to the end of the Sa. The RV myocardial performance index was calculated as  $(a - b) / b$ . Sa – peak systolic myocardial velocity; Ea – peak early diastolic myocardial velocity; Aa – peak atrial diastolic myocardial velocity; IVA – myocardial acceleration during isovolumic contraction.

## Discussion

RV dysfunction has a negative impact on the symptoms, functional capacity, prognosis, morbidity, and mortality rates of COPD patients. The novel finding of this study was the demonstration of the negative effect of acute exacerbations on RV function in COPD patients, even though they did not have overt clinical RV failure. We found that, during exacer-

bation periods, COPD patients had significantly increased pulmonary artery systolic pressure measures, which might cause increased RV afterload and impair RV function. Burgess et al<sup>7</sup> showed that RV diameter was an independent predictor of survival in COPD patients, and we found that the COPD patients had a larger RV during acute exacerbation compared to measures obtained after recovery. Our study is important in this aspect, as it shows acute COPD exacerbations may affect RV function negatively, which is in concordance with the prognosis of these patients. Recently, Akcay et al<sup>25</sup> conducted a similar study and reported that treatment of patients with acute COPD exacerbation according to guidelines improved not only pulmonary function, but also RV function and pulmonary hypertension.

The clinical assessment of RV dysfunction is difficult in COPD patients who have no signs of systemic venous congestion, and the complex RV geometry and poor echogenicity of COPD patients raise difficulties in the optimal determination of RV function.<sup>23,26,27</sup> TDI-derived myocardial velocities, Sa and IVA, have been shown to correlate with RV myocardial contractility.<sup>12,13,15</sup> Turhan et al<sup>16</sup> demonstrated the potential diagnostic value of Sa and IVA for the diagnosis of right heart failure in COPD patients. Tayyareci et al<sup>17</sup> showed that the TDI-derived RV systolic myocardial velocities decreased in COPD patients, suggesting impaired RV systolic function. Similarly, we also found that COPD patients during acute exacerbation had significantly lower IVA and Sa compared to controls. Both IVA and Sa increased significantly with recovery, suggesting an improvement in RV function. However, COPD patients still had lower Sa and IVA after recovery than controls. The COPD patients in our study had higher IVA and Sa

values compared to those in previous studies.<sup>16,17</sup> We believe that this discrepancy is most probably due to the inclusion of COPD patients with different degrees of RV impairment and severity of pulmonary disease. IVA was reported to be well correlated with FEV1 and FEV1/FVC and the severity of COPD.<sup>17</sup> We included COPD patients with no evidence of overt RV failure, and this might be the reason why our patients had higher IVA and Sa values. In addition, there are no age-, sex-, or heart rate-adjusted standardized values for IVA.

Our study supports the reports that suggest both IVA and Sa as reliable indices for the evaluation of RV function in COPD patients. However, we should also note that pulmonary artery systolic pressure had the highest accuracy, sensitivity, specificity, positive and negative predictive values as compared to other echo parameters in predicting COPD exacerbation. Pulmonary hypertension was associated with 16 times higher odds of COPD exacerbation. The addition of RV diameter and IVA did not add to the predictive power of pulmonary artery systolic pressure. This suggests that, in patients with COPD exacerbation, elevation of pulmonary artery systolic pressure is much more common, while RV enlargement and impairment of RV strain by IVA may occur only in a subset of patients. The clinical relevance of this finding is that it emphasizes the greater importance of the commonly used parameter, pulmonary artery systolic pressure, in the detection of COPD exacerbation, so much so that detection of pulmonary hypertension should continue to be the primary goal of the echocardiographer in these patients.

### Study limitations

The major limitation of the study was definitely the small sample size. The lack of data concerning the RV output or RV function of the patients before acute exacerbation and the lack of confirmation of RV function using a second method, such as three-dimensional echocardiography or MRI, are other shortcomings in this study. Since patients with overt right heart failure were not included, some of the TDI parameters were within normal limits.

### Conclusions

COPD patients had lower TDI-derived IVA and Sa measures during the acute exacerbation period. This indicates the negative impact of COPD exacerbation

on RV function, even though there is no sign of overt RV failure. IVA and Sa may be used as alternative, noninvasive parameters for the assessment of RV function in COPD patients. Whether these parameters can have prognostic value in acute COPD exacerbation and could be used to follow the effects of treatment will require further study.

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