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Value of Echo-Doppler Derived Pulmonary Vascular Resistance, Net-Atrioventricular Compliance and Tricuspid Annular Velocity in Determining Exercise Capacity in Patients With Mitral Stenosis

Eui-Young Choi, MD; Jaemin Shim, MD; Sung-Ai Kim, MD; Chi Young Shim, MD; Se-Jung Yoon, MD; Seok-Min Kang, MD, PhD; Donghoon Choi, MD, PhD; Jong-Won Ha, MD, PhD; Se-Joong Rim, MD, PhD; Yangsoo Jang, MD, PhD; Namsik Chung, MD, PhD

Background The present study sought to determine if echo-Doppler-derived pulmonary vascular resistance (PVR_{echo}), net-atrioventricular compliance (Cn) and tricuspid peak systolic annular velocity (Sa), as parameters of right ventricular function, have value in predicting exercise capacity in patients with mitral stenosis (MS).
Methods and Results Thirty-two patients with moderate or severe MS without left ventricular systolic dysfunction were studied. After comprehensive echo-Doppler measurements, including PVR_{echo}, tricuspid Sa and left-sided Cn, supine bicycle exercise echo and concomitant respiratory gas analysis were performed. Measurements during 5 cardiac cycles representing the mean heart rate were averaged. Increment of resting PVR_{echo} ($r=-0.416$, $p=0.018$) and decrement of resting Sa ($r=0.433$, $p=0.013$) and Cn ($r=0.469$, $p=0.007$) were significantly associated with decrease in $\%\dot{V}O_2$ peak. The predictive accuracy for $\%\dot{V}O_2$ peak could increase by combining these parameters as Sa/PVR_{echo} ($r=0.500$, $p=0.004$) or $Cn\cdot(Sa/PVR_{echo})$ ($r=0.572$, $p=0.001$) independent of mitral valve area, mean diastolic pressure gradients or presence of atrial fibrillation.
Conclusions Measurement of PVR_{echo}, Cn and Sa might provide important information about the exercise capacity of patients with MS. (*Circ J* 2007; **71:** 1721 – 1727)

Key Words: Doppler echocardiography; Exercise capacity; Mitral stenosis; Pulmonary vascular resistance; Tricuspid annular velocity

Mitral stenosis (MS) is known to comprise 2 stenotic lesions: the mitral valve itself and pulmonary arteriolar stenosis, anatomically or functionally[1,2] MS initially produces pulmonary venous hypertension and subsequently, pulmonary arterial hypertension develops because of the combined effect of back pressure, pulmonary arteriolar constriction and obliterative changes in the pulmonary vascular bed[1,2] Pulmonary vascular resistance (PVR), representing pre-capillary resistance, reflects pulmonary arteriolar stenosis or pulmonary vascular reactivity, and is a major determinant of exercise capacity and right ventricular (RV) afterload in MS[3] Net-atrioventricular compliance (Cn), a determinant of pressure decay across the stenotic mitral valve, is related to post-capillary resistance and is also a major determinant of inappropriate elevation of pulmonary arterial pressure during exercise[4] Recent reports demonstrate that the RV systolic functions are significantly impaired, even in the absence of clinical signs of systemic venous congestion in patients with MS[5] which could be related to increased PVR or direct RV involvement in rheumatic heart disease[5] RV function significantly affects symptoms, exercise capacity, peri-operative mortality and postoperative results;[6] however, measurement of PVR or RV function has limitations because of the invasiveness of the procedure and the geometric complexity of the RV. Development of the Doppler technique has enabled measurement of new parameters representing PVR and RV function[7,8] and the major advantage of these Doppler-derived parameters is that they are highly reproducible. Based on this, we aimed to determine if echo-Doppler derived PVR (PVR_{echo}), Cn and peak systolic tricuspid annular velocity (Sa) as parameters of RV function are relevant in predicting the cardiopulmonary exercise (CPX) capacity of patients with MS.

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Cardiology Division, Yonsei Cardiovascular Center and Cardiovascular Research Institute, Yonsei University College of Medicine, Seoul, South Korea
Mailing address: Namsik Chung, MD, PhD, Cardiology Division, Yonsei Cardiovascular Center and Cardiovascular Research Institute, Seoul, South Korea, Seodaemun-gu, Shinchon-dong 134, Seoul 120-752, South Korea. E-mail: namsikc@yumc.yonsei.ac.kr

Methods

Study Population

Thirty-two consecutive patients (25 females, age 52.0± 9.4 years) with moderate or severe MS (mitral valve area (MVA) by 2-dimensional (2D) planimetry: 0.7–1.5 cm^2) were studied. Exclusion criteria included patients with left ventricular (LV) systolic dysfunction (ejection fraction (EF) <50%), mitral regurgitation more than grade I, history of underlyng ischemic heart disease or exercise-induced ST segment change on 12-lead electrocardiogram (ECG) suggeting myocardial ischemia, valvular heart disease other

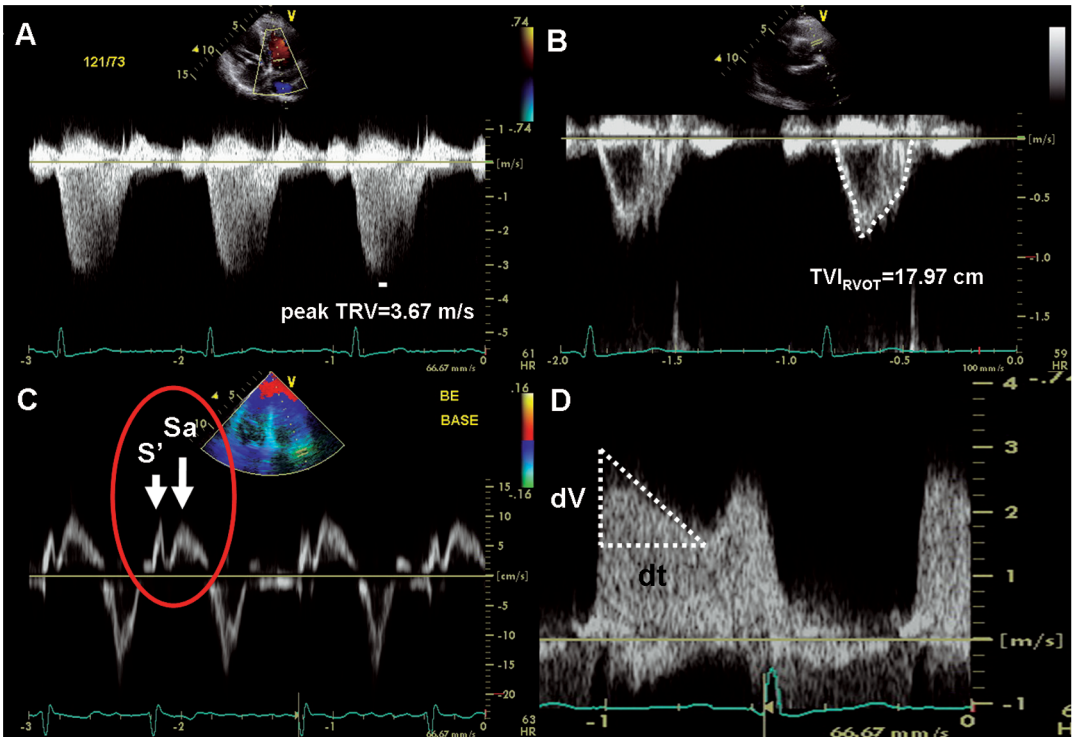

Fig 1. Doppler images show tricuspid regurgitant velocity (TRV) (A) and the time-velocity integral at the right ventricular outflow tract (TVIRVOT) (B) at resting stage. The echo-Doppler-derived pulmonary vascular resistance, calculated as 10×(peakTRV/TVIRVOT)+0.16, is 2.2 Wood unit. Tricuspid annular tissue Doppler image (C) shows peak systolic annular velocity (Sa), first positive reflection of annular velocity, indicates isovolumic contractional velocity (S'). Net-atrioventricular compliance can be calculated from the deceleration rate (dV/dt) (D) of the mitral velocity profile (E-wave downslope) and effective mitral orifice area determined equation continuity.

than secondary tricuspid regurgitation, congenital heart disease, and chronic pulmonary disease. The study protocol was approved by the institutional review board and all the patients gave informed consent.

Resting Echo-Doppler Measurements

All patients underwent a complete standard echocardiographic examination. The transmitral mean diastolic pressure gradients (MDPG) were obtained from the continuous-wave Doppler signal of mitral flow velocity. Stroke volume (SV) was calculated as LV outflow tract (OT) area multiplied by the time-velocity integral (TVI) at the LVOT. OT area was determined as $D^2\pi/4$, where D is its diameter measured from a zoomed systolic freeze-frame in the parasternal long-axis view. Cardiac output (CO) was calculated as a product of SV and heart rate (HR). With the continuity equation, the effective orifice area of the mitral valve (EOA) was calculated as SV divided by mitral TVI[9,10] Cn was calculated from the deceleration rate (dV/dt) (Fig 1) of the mitral velocity profile (E-wave downslope) and EOA as 1,270×(EOA/dV/dt) and the result is expressed in milliliters per millimeter of mercury.[4] MVA was also measured by 2D planimetry method.[11] The left atrial volume index (LAVI) was calculated by the prolate ellipsoid method.[12] The TVIRVOT (cm) was obtained by placing a 1- to 2-mm pulsed wave Doppler sample volume in the proximal RVOT just within the pulmonary valve when imaged from the parasternal short-axis view. Continuous wave Doppler was used to determine the peak tricuspid regurgitant velocity (TRV) (m/s). The highest velocity obtained from multiple views was used. The 10×(peak TRV/TVIRVOT)+0.16 was then calculated and used as PVR$_{echo}$ (WU).[7] To measure the systolic tricuspid annular velocities, the spectral pulsed Doppler was adjusted to obtain a Nyquist limit of 20–30 cm/s. We used minimal gain to ensure clear- and well-defined pulsed Doppler tissue imaging wave borders. Tricuspid annular tissue velocity was obtained in the apical 4-chamber view. Care was taken to use an ultrasound beam parallel to the direction of the tricuspid motion. To exclude the effect of respiration, measurements were acquired during end-expiratory apnea. For the evaluation of peak systolic velocity, the initial peak occurring during isovolumic contraction was ignored (Fig 1). Measurements during 5 consecutive cardiac cycles representing the mean HR were averaged and used for further calculations.[13]

Exercise Echocardiography and Respiratory Gas Analysis

All patients underwent symptom-limited exercise tests on a supine bicycle ergometer (Medical Positioning, Inc, Kansas City, MO, USA) with simultaneous respiratory gas analysis and blood pressure recording. The CPX test was performed immediately after echocardiographic examination (Vivid 7 ultrasound machine, GE Medical Systems). Exercise began with 25 W after a 1-mine unload phase, followed by a ramp protocol with increments of 25 W every 3 min. At each stage, HR, transmitral and transtricuspid continuous wave Doppler, and pulsed wave Doppler of the LVOT and RVOT were obtained and MDPG, peak TRV, TVILVOT and TVIRVOT were measured using a post-processing program (EchoPAC, GE Medical Systems). Using these parameters, CO and PVR$_{echo}$ were calculated. Measurements were performed by 2 independent investigators. Be-

Table 1 Clinical Characteristics and Resting Echo-Doppler Parameters

	SR (n=15)	AF (n=17)	Total (n=32)
Age (years)	50.5±11.5	53.4±7.1	52.0±9.4
Female	14 (93%)	11 (65%)	25 (78%)
SBP (mmHg)	110.7±14.1	122.3±17.3	116.9±16.7
Heart rate (beats/min)	68.9±11.4	65.1±11.7	66.8±11.5
LVEF (%)	59.2±5.2	59.4±5.1	59.3±5.1
MVA (cm^2)	1.30±0.20	1.30±0.26	1.30±0.23
Peak TRV (m/s)	2.62±0.38	2.64±0.38	2.63±0.37
TVI_{RVOT} (cm)	15.92±2.40	13.21±3.02	14.48±3.03
MDPG (mmHg)	6.75±3.06	6.50±3.27	6.61±3.12
LAVI (ml/m^2)	54.8±21.3	74.1±22.7*	65.0±23.8
Cardiac output (ml/min)	4,781.5±1,422.0	4,119.7±1,740.1	4,439.9±1,603.3
Cn (ml/mmHg)	5.19±2.40	4.10±1.67	4.61±1.68
Sa (cm/s)	11.0±1.22	9.02±1.95*	10.1±1.9
PVR_{echo} (WU)	2.01±0.42	2.25±0.39	2.14±0.41
PVR_{echo}/Cn	0.43±0.17	0.64±0.27*	0.54±0.25
Sa/PVR_{echo}	5.56±1.43	4.45±1.59*	4.98±1.60
$Cn\cdot(Sa/PVR_{echo})$	29.4±12.0	19.0±14.3*	23.9±14.1

SR, sinus rhythm; AF, atrial fibrillation; SBP, systolic blood pressure; LVEF, left ventricular ejection fraction; MVA, mitral valve area; TRV, tricuspid regurgitant velocity; TVI_{RVOT}, time-velocity integral at right ventricular outflow tract; MDPG, transmitral mean diastolic pressure gradient; LAVI, left atrial volume index; Cn, net-atrioventricular compliance; Sa, peak systolic tricuspid annular velocity; PVR_{echo}, echo-Doppler derived pulmonary vascular resistance.
**p<0.05 compared with parameter of normal SR.*

Table 2 Exercise Echo-Doppler Parameters and Respiratory Gas Analysis

	SR (n=15)	AF (n=17)	Total (n=32)
Exercise duration (s)	431.5±156.9	424.9±146.3	428.0±148.9
METs	4.7±1.2	4.7±1.1	4.7±1.1
SBP peak (mmHg)	161.1±25.0	152.3±25.1	156.4±25.0
Heart rate at peak (beats/min)	135.6±18.4	135.8±26.3	135.7±22.6
Peak TRV peak (m/s)	3.70±0.46	3.97±0.56	3.82±0.51
CO peak (ml/min)	7,525.7±1,247.9	7,476.9±2,489.1	7,501.3±1,934.8
Change in CO (ml)	2,694.3±1,207.9	2,759.2±2,085.1	2,729.7±1,934.8
Peak $\dot{V}O_2$ ($ml\cdot kg^{-1}\cdot min^{-1}$)	20.2±5.7	16.2±4.2*	18.1±5.3
$\%\dot{V}O_2$ peak	73.9±14.2	58.8±9.9*	65.9±14.1
$\dot{V}E/\dot{V}CO_2$ at AT	36.5±23.5	37.7±24.2	37.2±24.7

METs, metabolic equivalents; SBP peak, systolic blood pressure at peak exercise; TRV peak, tricuspid regurgitant velocity at peak exercise; CO peak, cardiac output at peak exercise; $\dot{V}E/\dot{V}CO_2$ at AT, ventilatory equivalent for CO_2 at anaerobic threshold. Other abbreviations see in Table 1.
**p<0.05 compared with the parameter of normal SR.*

cause the area of the LVOT and the RVOT has been shown to remain constant during exercise[13,14] the resting values were used to calculate both rest and exercise SV. Oxygen uptake, CO_2 production and minute ventilation were measured using a breath-by-breath gas analysis (Medical Graphics, St Paul, MN, USA). A 12-lead ECG was continuously registered to exclude significant myocardial ischemia. Blood pressure was recorded every 3 min by cuff sphygmomanometer. Peak oxygen consumption (peak $\dot{V}O_2$) was defined as the mean of the highest values obtained over the last 10 s of exercise. Minute ventilation, oxygen consumption, and CO_2 production were calculated online every 10 s with the use of a standard inert gas dilution technique. Predicted values for peak oxygen consumption ($\%\dot{V}O_2$ peak) were calculated from a gender-specific regression equation incorporating age, height, and weight[15]

Statistical Analysis

Results are presented as mean value ± standard deviation. Interobserver variability was calculated as the standard deviation of the differences between the measurements made by 2 independent observers as a percentage of the average value. Comparison of several parameters between patients with normal sinus rhythm (NSR) and patients with atrial fibrillation (AF) was performed with Mann-Whitney test and Fisher's exact test. Differences between rest and peak exercise values were tested for significance by use of a paired 2-samples t-test. Univariate and multiple stepwise linear regression analyses were generated between echo-Doppler parameters and CPX parameters. A receiver-operating characteristic analysis was used to obtain the optimal cutoff Sa/PVR_{echo} and $Cn\cdot(Sa/PVR_{echo})$ values for predicting higher than 65% of $\%\dot{V}O_2$ peak. We used the SPSS 13.0 statistical package (SPSS Inc, Chicago, IL, USA) with p-values <0.05 considered as statistically significant.

Results

Baseline Characteristics

Of the 32 subjects, 17 (53.1%) had AF and 25 patients (78.1%) were female. The patients' clinical and resting echo-Doppler characteristics according to baseline rhythm are presented in Table 1. Interobserver variability of PVR_{echo}, Sa, Cn was 4% and 3% and 6%, respectively. The MVA measured by 2D planimetry method was 1.3±0.2 cm^2, peak TRV was 2.63±0.37 m/s, TVI_{RVOT} was 14.48±3.03 cm and

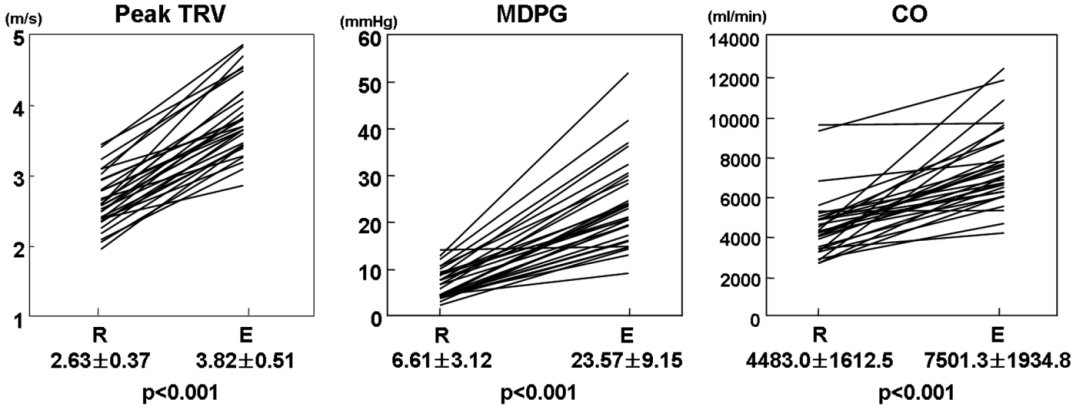

Fig 2. Exercise-induced changes in peak tricuspid regurgitant velocity (peak TRV), transmitral mean diastolic pressure gradient (MDPG) and cardiac output (CO). R, resting; E, exercise.

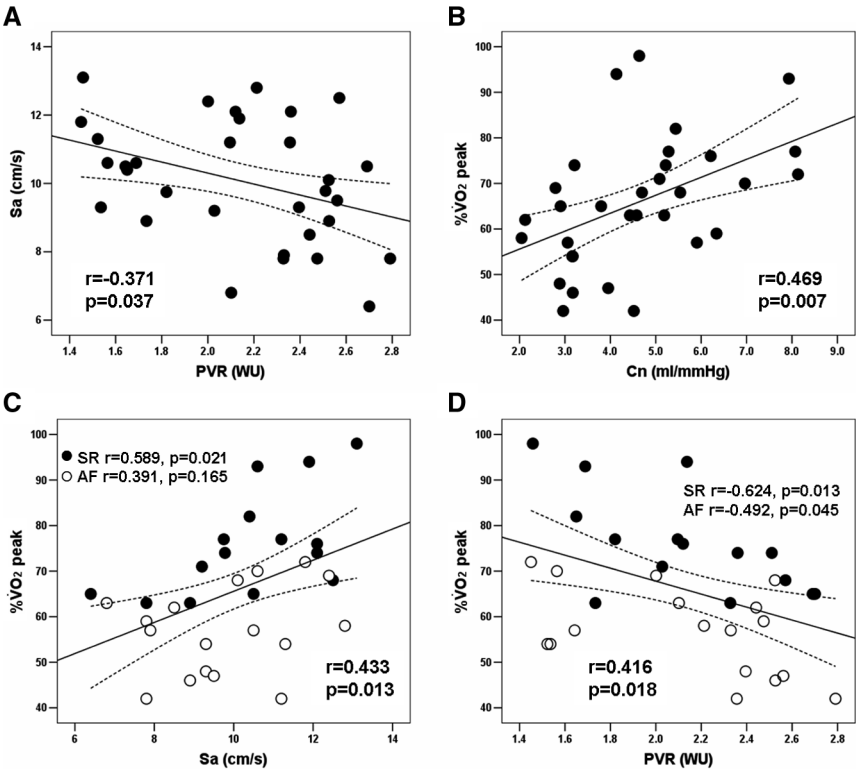

Fig 3. Correlation between resting echo-Doppler-derived pulmonary vascular resistance (PVR_{echo}), tricuspid peak systolic annular velocity (Sa), net-atrioventricular compliance (Cn) and predicted values for peak oxygen consumption (%$\dot{V}O_2$) peak. Resting PVR_{echo} correlates inversely with resting Sa (A). Decrease in resting Cn (B) and Sa (C), increase in resting PVR_{echo} (D) are significantly related with decrease in %$\dot{V}O_2$ peak. (Panels C, D) Subgroup analysis according to baseline rhythm. AF, atrial fibrillation; SR, sinus rhythm.

MDPG was 6.61±3.12 mmHg. Calculated Cn was 4.61±1.68 ml/mmHg (range 2.0–8.1 ml/mmHg), Sa 10.1±1.9 cm/s (range 6.4–13.1 cm/s), and PVR_{echo} 2.14±0.41 WU (range 1.45–2.79 WU).

CPX and Echo-Doppler Parameters

There were no significant adverse outcomes during the CPX test and the results and those of the echo-Doppler parameters at peak exercise are presented in Table 2. The mean exercise duration was 428.0±148.9 s. At peak exercise, mean systolic blood pressure was 156.4±25.0 mmHg and mean HR was 135.7±22.6 beats/min. During exercise, peak TRV, MDPG and CO increased to 3.82±0.51 m/s, 23.57±9.15 mmHg and 7,501.3±1,934.8 ml/min, respectively (Fig 2). However, the exercise response of CO was more heterogeneous than other parameters. Peak $\dot{V}O_2$ was 18.1±5.3 $ml \cdot kg^{-1} \cdot min^{-1}$ (range 10.7–31.7), %$\dot{V}O_2$ peak was 65.9±14.1% (range 42.0–98.0) and $\dot{V}E/\dot{V}CO_2$ at anaerobic threshold (AT) was 37.2±24.7 (range 32.1–46.9).

Determinants of CPX Capacity

Doppler-derived CO at peak exercise correlated well with peak $\dot{V}O_2$ (r=0.572, p=0.001).

Resting PVR_{echo} correlated inversely with resting Sa (r=–0.371, p=0.037). The decrement in resting Cn was significantly related with decrease in %$\dot{V}O_2$ peak (r=0.469, p=0.007). Increase in resting PVR_{echo} and decrease in resting Sa were significantly associated with impairment of %$\dot{V}O_2$ peak (r=–0.416, p=0.018 for PVR_{echo} and r=0.433, p=0.013 for Sa) (Fig 3). Moreover, PVR_{echo} at peak exercise correlated significantly with decrease of %$\dot{V}O_2$ peak (r=–0.482, p=0.005). LAVI also inversely correlated with %$\dot{V}O_2$ peak, but did not reach the statistical significances (r=–0.318, p=0.077). Percentage of $\dot{V}O_2$ peak of patients with AF was

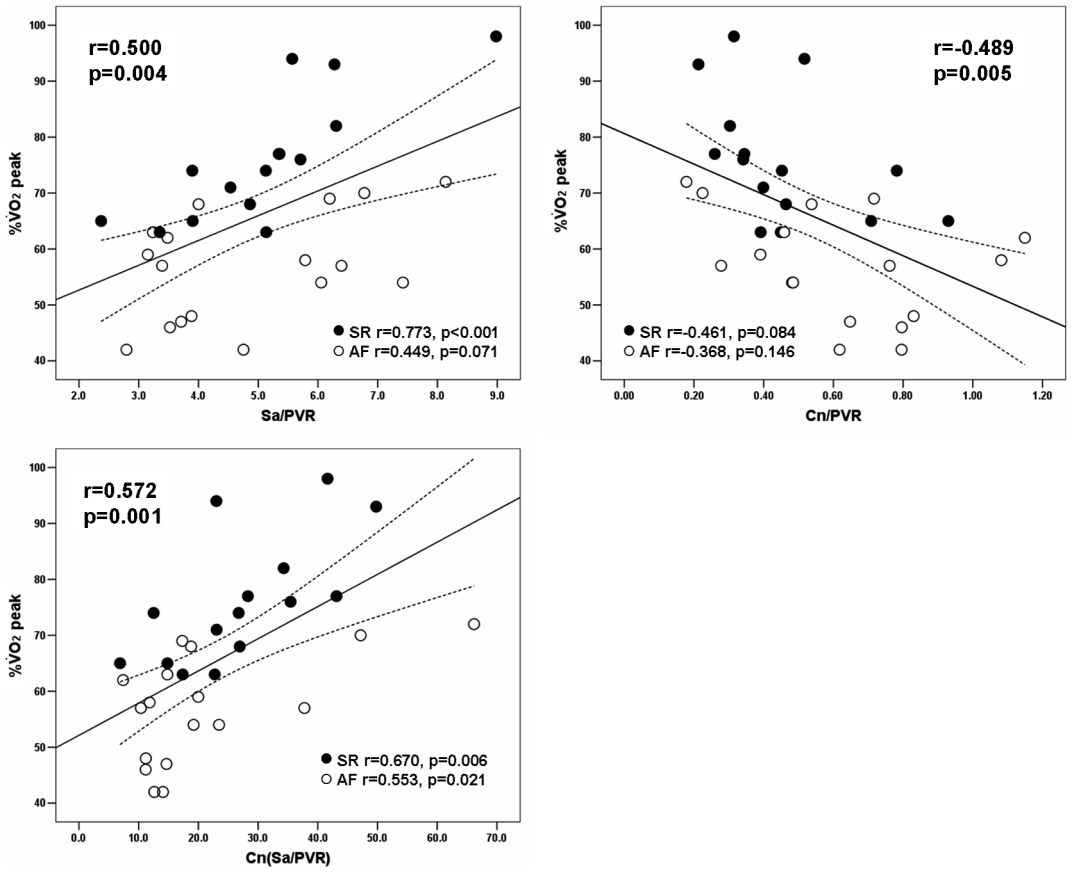

Fig 4. Sa/PVR$_{echo}$, representative of right ventricular function adjusted for afterload, PVR$_{echo}$/Cn, representative of total pulmonary resistance, and Cn·(Sa/PVR$_{echo}$) correlate significantly with %V̇O$_2$ peak. Subgroup analysis according to baseline rhythm is shown. See Fig 3 for abbreviations.

lower than that of patients with NSR (58.8±9.9% vs 73.9±14.2%, p=0.001), as a decrease of Sa (9.02±1.95 vs 11.0±1.22 cm, p=0.002) (Tables 1,2). Based on these results, we combined the indices that represented total pulmonary resistance as PVR$_{echo}$/Cn, and overall RV function incorporated with afterload as Sa/PVR$_{echo}$. We discovered these new indices of total pulmonary resistance (PVR$_{echo}$/Cn) (r=–0.489, p=0.005) and RV function (Sa/PVR$_{echo}$) (r=0.500, p=0.004) correlated more significantly with %V̇O$_2$ peak. By combing these left and right chamber parameters as Cn·(Sa/PVR$_{echo}$), which determines RV function and pre-and post-capillary resistance, we could further elevate the predictive accuracy for exercise capacity (r=0.572, p=0.001) (Fig 4). In subgroup analysis by underlying rhythm, these correlations were maintained, but the degree of correlation was weak in patients with AF (Sa/PVR$_{echo}$, r=0.773, p<0.001 in NSR and r=0.449, p=0.071 in AF; Cn·(Sa/PVR$_{echo}$), r=0.670, p=0.006 in NSR and r=0.553, p=0.021 in AF). In multiple stepwise linear regression analysis, the right chamber parameter of Sa/PVR$_{echo}$ (β=0.349, p=0.031) independently correlated with %V̇O$_2$ peak after adjusting for left-side parameters, such as Cn, LAVI, MVA, MDPG, and the presence of AF (Table 3). However, the correlation between Sa/PVR$_{echo}$ and V̇E/V̇CO$_2$ at AT did not reach statistical significance (r=–0.385, p=0.085). According to these results, we successfully obtained optimal cutoff values of Sa/PVR$_{echo}$ and Cn·(Sa/PVR$_{echo}$) for predicting %V̇O$_2$ peak higher than 65% as 4.81 (sensitivity of 71% and specificity of 67%) and 22.9 (sensitivity of 71% and specificity of 87%), respectively.

Table 3 Multiple Stepwise Linear Regression Analysis of Resting Echo-Doppler Parameters for the Prediction of %V̇O$_2$ Peak

	Standardized coefficient	*p value*
Presence of AF	*–0.447*	*0.005*
Sa/PVR$_{echo}$	*0.349*	*0.031*
MDPG	*–0.346*	*0.098*
Cn	*0.325*	*0.193*
MVA	*–0.236*	*0.226*
LAVI	*–0.113*	*0.511*

Abbreviations see in Table 1.
**p<0.05.*

Discussion

The principal finding of this study is that Sa and PVR$_{echo}$ are significantly related with exercise capacity. Therefor, their derivative as Sa/PVR$_{echo}$, reflecting RV function and the RV loading state, could be a predictor of exercise capacity independent of left-side chamber parameters and the presence of AF.

Inappropriate and excessive increase of pulmonary arterial pressure beyond changes in the left atrial pressure is known to be a major exercise-limiting factor in patients with MS.[16] Simple backward transmission of increased transmitral gradients cannot explain the entire increase in pulmonary artery pressure. Decrease of left atrial compli-

ance is one of the possible mechanisms that lead to the excessive increase of pulmonary arterial pressure![7] Another possibility is the occurrence of pulmonary arteriolar vasoconstriction because of the development of pulmonary edema and alveolar hypoxia with exercise![8] The level of oxygen saturation of the pulmonary arterial blood is reported to be the most significant factor in determining the exercise capacity in patients with valvular heart disease and chronic obstructive pulmonary disease![9] Respiratory gas analysis is an extremely useful method of detecting this pathologic response. The results of our study also show that increased PVR_{echo} and decreased Cn are significantly associated with decreased $\%\dot{V}O_2$ peak, which suggests that increased resting PVR_{echo} is a useful predictor of pulmonary vascular response and, consequently, inappropriate ventilatory response to exercise. Besides, in patients with MS, total pulmonary resistance, which is the resistance to blood flow from the pulmonary artery to the left ventricle in diastole, is more important. It represents the sum of pre- and post-capillary resistance. Based on our results, we arrived at PVR_{echo}/Cn as the index of total pulmonary resistance, in which PVR_{echo} represents pre-capillary resistance and 1/Cn reflects post-capillary resistance. We found that this index is more related to exercise capacity.

The primary function of the RV free wall is to move the atrioventricular valve ring toward the apex by contraction of longitudinal myocardial fibers![10] Based on this concept, tricuspid annular longitudinal velocity measured by tissue Doppler imaging technique has been validated as an index of RV systolic function by comparing radionuclide ventriculography in patients with heart failure![8] A significant advantage of these Doppler-derived parameters is that they are highly reproducible. In our study, Sa varied from 6.8 to 13.1 cm/s and correlated weakly with PVR_{echo}, which implies that Sa can be affected by other mechanisms, as well such as by direct myocardial involvement of rheumatic processes besides RV afterload. In patients with heart failure, RVEF at rest has been reported to correlate with peak $\dot{V}O_2$, especially $\%\dot{V}O_2$ peak![11,12] Moreover, RVEF has been shown to be superior to LVEF in predicting exercise capacity![12] A recent study by Ghio et al showed that the combination of invasively measured RVEF and pulmonary arterial pressure is critically important in the prediction of prognosis in patients with advanced heart failure![13] Based on the results of previous study and our results, we combined Sa and PVR_{ehco} as Sa/PVR_{echo}, reflecting RV contractile function, adjusting for its afterload. Interestingly, we discovered that this new index correlated more significantly with exercise capacity and it could be an independent predictor of exercise capacity after adjusting for the presence of AF and left-chamber parameters such as Cn, LAVI, MVA and MDPG. Finally, by incorporating left- and right-chamber parameters, which determine exercise capacity, we could further improve the accuracy of prediction.

Our study also demonstrated that the development of AF was significantly associated with lower exercise capacity, despite similar MVA and MDPG, compared with patients with NSR. Higher LAVI and lower RV functional indices in the AF group might be related to lower exercise capacity. Despite not being proven in this study, loss of atrial contraction and decreased pulmonary venous systolic flow might be another possible explanation for the more impaired exercise capacity in patients with AF![14] However, when controlling the effect of AF, Sa/PVR was significantly related with exercise capacity. Moreover, these correlations were maintained in the subgroup analysis according to baseline rhythm. Because of the small number of subjects, possible variability of the measured value, and more complex factors contributing to exercise capacity, the accuracy of prediction was lower in patients with AF.

When we define the grade of MS, we classically consider MVA or MDPG. However, the guidelines for surgery or balloon valvuloplasty are made based on the patient's symptoms or exercise capacity. Even in patients with the same grade of MS based on MVA or MDPG, there might be heterogeneous patients in terms of exercise capacity or symptoms, as in the results of this study. Moreover, the patient's symptoms are very subjective and all the patients cannot undergo CPX; measurement of a resting predictor of exercise capacity, especially non-invasively, is important in the triage of patients. Our results suggest that RV function and PVR have independent roles, not only passively determined by backward pressure transmission, especially when determining the ventilatory response to exercise. Therefore, it might be helpful in the triage the patients and may serve as a new guideline for early interventional treatment, such as percutaneous mitral valvuloplasty or mitral valve replacement surgery.

Study Limitations

First, 53% of the present subjects had AF. Although measurements during 5 consecutive cardiac cycles representing the mean HR were averaged and used for further calculations, there could be higher variability in the value of each parameter in the subjects with AF compared with those in NSR. It might partially contribute to weak correlations between applied parameters in patients with AF compared with patients with NSR. Second, we could not invasively validate PVR_{echo}/Cn as an index of total pulmonary resistance. We only proposed this index conceptually and it needs to be validated in the future.

Conclusions

Our study showed that PVR_{echo} and Sa, determinants of RV function and loading state, and Cn, determinant of post-capillary resistance, have a significant role in predicting exercise capacity. Moreover, we could increase the predictive accuracy by incorporating these indices that represent RV contractility and pre- and post-capillary resistance. Hence, the measurement of these indices may help to differentiate the patients with reduced exercise capacity and indicate the need for early interventional procedures such as percutaneous balloon valvuloplasty or mitral valve replacement surgery.

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