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Original article

Exercise right heart catheterization predicts outcome in asymptomatic degenerative aortic stenosis

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ABSTRACT

Introduction and objectives: Degenerative aortic stenosis (DAS) is the most frequent valvular heart disease. It remains unclear how to identify asymptomatic DAS patients with normal left ventricular ejection fraction who have a high probability of event occurrence and would thus benefit from early intervention. Here, we describe a protocol for exercise hemodynamics in true asymptomatic patients with moderate or severe DAS and assess the prognostic value of the data obtained in this population.
Methods: This study involved a prospective single-centre registry of consecutive asymptomatic patients with moderate or severe DAS. Patients underwent cardiopulmonary exercise testing to confirm symptom absence during exercise and then right heart catheterization (RHC) at rest and during exercise. Events were defined as death, surgical aortic valve replacement, or transcatheter aortic valve implantation according to clinical guidelines.
Results: Thirty-three patients underwent baseline and exercise RHC. The mean aortic valve area was 1.08 cm^2 and the aortic gradient was 39 mmHg. The mean pulmonary artery pressure was 21 mmHg with a pulmonary artery occlusion pressure of 14 mmHg and cardiac output of 5.6 L/min. The mean pulmonary artery pressure at peak exercise was 34 mmHg. After a mean follow-up of 27 months, 8 patients experienced an event (24%). There were no differences in baseline variables, aortic valve area, or cardiopulmonary exercise testing parameters between the event and event-free groups. Patients with an event did not have higher pulmonary or filling pressures after peak exercise but had lower pulmonary artery oxygen saturation on effort (median, 48% vs 57%, $P = .03$).
Conclusions: Exercise RHC is feasible and safe in this population. Peak pulmonary artery oxygen saturation might identify patients with increased risk of serious adverse events.

El cateterismo cardiaco derecho de esfuerzo predice eventos en los pacientes con estenosis aórtica degenerativa asintomática

Palabras clave:
Hipertensión pulmonar
Estenosis aórtica
Cateterismo cardiaco
Test de ejercicio

RESUMEN

Introducción y objetivos: La estenosis aórtica degenerativa es la valvulopatía más frecuente. Aún no está claro cómo identificar a los pacientes asintomáticos con fracción de eyección del ventrículo izquierdo normal y alta probabilidad de eventos que por ello pudieran beneficiarse de una intervención valvular precoz. En este estudio se describe un protocolo de hemodinámica de esfuerzo para los pacientes asintomáticos con estenosis aórtica moderada o grave para evaluar su valor pronóstico para esta población.
Métodos: Estudio prospectivo unicéntrico de una población de pacientes con estenosis aórtica moderada o grave asintomáticos. Los pacientes realizaron una ergoespirometría para confirmar la ausencia de síntomas en esfuerzo. Después los pacientes se sometieron a un cateterismo cardiaco derecho basal y de esfuerzo. Se definió evento como muerte o necesidad de reemplazo de válvula aórtica quirúrgico o percutáneo basado en las guías clínicas.
Resultados: Se sometió a 33 pacientes a cateterismo cardiaco derecho basal y de esfuerzo. El área valvular aórtica media fue de 1,08 cm^2 y el gradiente aórtico medio, 39 mmHg. La presión arterial pulmonar media fue de 21 mmHg, con una presión de oclusión en la arteria pulmonar de 14 mmHg y un gasto cardiaco de 5,6 l/min. La presión pulmonar media en ejercicio máximo fue de 34 mmHg. Tras un seguimiento medio de 27 meses, 8 pacientes sufrieron un evento (24%). No hubo diferencias en las

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variables basales, el área valvular aórtica o los parámetros de ergoespirometría. Los pacientes con evento no tuvieron mayores presiones pulmonares o presiones de llenado en ejercicio máximo, pero el grupo con eventos mostró menor saturación de oxígeno en la arteria pulmonar en esfuerzo (mediana, el 48 frente al 57%; p = 0,03).

Conclusiones: El cateterismo cardiaco de esfuerzo es seguro y factible en esta población. La saturación de oxígeno en la arteria pulmonar en esfuerzo podría identificar a un grupo de pacientes con un aumento del riesgo de eventos adversos graves.

Abbreviations

DAS: degenerative aortic stenosis
CPET: cardiopulmonary exercise testing
RHC: right heart catheterization
VO_2: peak oxygen uptake
PaO_2s: pulmonary artery oxygen saturation

INTRODUCTION

Degenerative aortic stenosis (DAS), already the most frequent valvular heart disease, is showing ever increasing prevalence in western societies due to population aging.[1] In symptomatic patients, the only effective treatments are surgical aortic valve replacement or percutaneous transcatheter aortic valve implantation.[1] Despite its frequency, it is unclear how to identify asymptomatic patients with normal left ventricular ejection fraction but a high probability of event occurrence. Serial testing and follow-up of asymptomatic patients with moderate-to-severe aortic stenosis is the most usual approach, but some parameters, such as severe pulmonary hypertension, the hemodynamic progression rate of the stenosis, and elevated plasma levels of natriuretic peptides,[1] suggest an adverse prognosis and might tip the balance in favor of early elective intervention.

Although exercise-induced symptoms are the main reason for intervention in most patients, noninvasive resting parameters are used to indicate early surgery in asymptomatic patients. Exercise noninvasive hemodynamic results have been linked to poor outcomes in several cardiac conditions and in asymptomatic aortic stenosis.[2] However, the evidence regarding their true value is controversial because pulmonary pressures during exercise depend not only on pulmonary vascular resistance and left ventricular end-diastolic pressure, but also on cardiac output, which is not usually measured during exercise echocardiography and whose reliability during exercise is unclear. High exercise pulmonary pressures have been found on stress echocardiography even in healthy young individuals[3] and show well-documented variability when compared with invasive hemodynamics.[4]

Invasive hemodynamics have been proven to provide accurate prognostic information in a wide range of cardiac conditions, especially in heart failure, but information on exercise invasive hemodynamics is lacking and exercise protocols for right heart catheterization (RHC) have not been standardized. In this study, our objective was to describe the protocol for exercise hemodynamics in true asymptomatic patients with moderate or severe aortic stenosis and to assess the prognostic value of the data obtained in this population.

METHODS

Study population

This study involved a prospective single-centre registry of consecutive asymptomatic patients with moderate or severe valvular DAS detected by echocardiography. Patients were enrolled from May 2015 to April 2018. The study was approved by the local ethics committee before patient inclusion. Absence of cardiovascular symptoms was confirmed at the enrollment visit and echocardiography was repeated to confirm the presence of DAS. We excluded patients with reduced left ventricular systolic function ($< 50\%$), other severe valvular diseases, or other cardiac conditions that contraindicated treadmill testing. Only patients younger than 85 years of age able to provide informed consent and to perform exercise by walking on the treadmill were included.

By protocol, patients underwent cardiopulmonary exercise testing (CPET) to confirm the absence of symptoms during exercise or blood pressure falls or other CPET parameters of poor prognosis according to the investigator's criteria. Within 1 month after the CPET, patients underwent RHC at rest and during exercise. All patients had a clinical follow-up every 6 months in a dedicated clinic. Events were defined as the occurrence of death, surgical aortic valve replacement, or transcatheter aortic valve implantation according to clinical guidelines, or the development of symptoms related to aortic stenosis with an intervention planned.

Evaluation of aortic stenosis severity

Echocardiography assessment was performed according to clinical guidelines.[5] Continuous-wave Doppler was used to measure transaortic velocities. Peak and mean transaortic pressure gradients were calculated using the simplified Bernoulli equation. Aortic valve area was calculated using the continuity equation. The aortic stenosis was considered severe if the valve area was ≤ 1 cm.[2]

Cardiopulmonary exercise testing

All patients underwent CPET on a Mortara Xscribe device (Mortara Instrument, Inc., Milwaukee, United States) and Full Vision treadmill (Full Vision, Kansas, United States). Data were processed with Blue Cherry version 1.2.2.2 software from Geratherm Respiratory (Geratherm Respiratory GmbH, Bad Kissingen, Germany). The exercise protocol (Naughton, modified Bruce, Bruce, or ramp) was selected on an individual basis according to the patient's mobility and comorbidities and at the investigator's discretion. Patients were encouraged to exercise until exhaustion. Blood pressure was carefully monitored at the end of each stage using a calibrated sphygmomanometer, and heart rate and continuous 12-lead electrocardiogram monitoring were also recorded. An experienced cardiologist closely monitored all patients during the test. The test was promptly stopped if symptoms or any other complications developed. The peak oxygen consumption (peak oxygen uptake [VO_2]), percentage of the

Figure 1. Ergospect Cardio Step device in the catheterization laboratory.

estimated VO_2, respiratory exchange ratio, VE/VCO_2 slope, VE/VO_2, VE/VCO_2, presence of exercise oscillatory ventilation, baseline and peak end-tidal CO_2 pressure, and respiratory reserve were analyzed.

Right heart catheterization at rest and during exercise

RHC was performed with a 6-French Swan-Ganz catheter through a cephalic vein under fluoroscopy guidance. Measurements were taken at rest and after performance of controlled supine exercise with a Cardio Step device (Ergospect GmbH, Innsbruck, Austria; Figure 1 and video 1 of the supplementary data) until exhaustion or symptom occurrence, with patients trying to reach the same workload as in the CPET (Watts vs peak VO_2) according to the available evidence.[6] The exercise protocol comprised incremental step resistance every 30 seconds and patients were encouraged to follow a 60 steps per minute pace. Blood pressure and electrocardiography were monitored according to usual practice during the test. After measurement of baseline pressures, pulmonary artery saturation, and cardiac output, patients started supine exercise with the Swan-Ganz catheter floating in the pulmonary artery (video 1 of the supplementary data). Pulmonary pressures at peak effort and pulmonary artery oxygen saturation (PaO_2s) were recorded. Immediately after the exercise was stopped, the catheter was moved to obtain the pulmonary artery occlusion pressure and rapidly pulled back to the right ventricle and right atrium. Baseline cardiac output was calculated using the indirect Fick method because our aim was to compare PaO_2s at rest and after exercise. Thermodilution was not considered adequate to assess peak cardiac output because the current guidelines recommend at least 3 measurements,[7] which takes too long to be reliable for assessing peak cardiac output.

Statistical analysis

All data were prospectively collected in an anonymous database. To detect events, only patients with at least 1 year of follow-up after inclusion were analyzed. Results are expressed as mean $\pm$ standard deviation, median with interquartile range, or percentage, as appropriate. Statistical differences between groups were assessed using a Mann-Whitney *U* test and chi-square test as appropriate. Values of $P < .05$ were considered significant. All statistical analyses were performed with SPSS version 20.0 (SPSS Inc., Chicago, Illinois, United States).

RESULTS

From May 2015 to April 2018, 43 patients meeting the inclusion criteria underwent CPET. Of these, 5 (11.6%) developed symptoms during exercise and were referred for surgical aortic valve replacement or transcatheter aortic valve implantation. The other 38 patients underwent CPET without showing symptoms and were scheduled to undergo baseline and exercise RHC. Four of them did not have the test because of problems with the vascular access (ie, if access was not possible through the cephalic vein, because no other access site was allowed by protocol) and 1 patient only had a baseline RHC (the exercise test was canceled due to the patients' very high blood pressure). Of the 33 patients, 1 developed transient atrial fibrillation during the procedure, which was the only complication of this study.

Baseline data are shown in Table 1. The mean age was 74 years, mean aortic valve area 1.08 cm^2, and mean aortic gradient 39 mmHg. Patients performed well on CPET with a mean peak VO_2 of 18.7 mL/kg/m^2, which resulted in a mean of 90% of the theoretical peak VO_2 adjusted by age and sex (normal $>$ 80%).

Baseline and exercise invasive hemodynamic data are shown in Table 2. The mean pulmonary artery pressure was 21 mmHg with a mean pulmonary artery occlusion pressure of 14 mmHg and mean cardiac output of 5.6 L/min. The mean peak workload was 83 Watts and the mean pulmonary artery pressure at peak exercise was 34 mmHg. The mean baseline PaO_2s was 74%, which decreased to a mean of 54% during peak exercise.

After a mean follow-up of 27.6 $\pm$ 7.8 months, 8 patients had an event (24%): 2 patients died (1 from sudden cardiac death; the other developed cardiogenic shock days after being hospitalized with pancreatitis) and 6 patients underwent aortic valve replacement or transcatheter aortic valve implantation due to the development of symptoms or left ventricular dysfunction.

Comparisons between the event-free and event groups are shown in Table 3 and Table 4. There were no statistically significant differences between the 2 groups in baseline variables, aortic valve area, and CPET parameters (Table 3), although patients who had an event tended to have higher mean aortic valve gradients. There were also no differences in baseline invasive hemodynamics (Table 4). Patients with an event did not have higher pulmonary pressures or right or left filling pressures after peak exercise but did have significantly lower PaO_2s on effort (median, 48% vs 57%; P = .03) without a difference in workload (median, 75 W vs 90 W; P = .31). This difference in peak PaO_2s was not found after stratification for severe or moderate DAS according to echocardiographic classification (median, 53% vs 55%; P = .49). Exercise PaO_2s

Table 1
Baseline characteristics of the entire cohort

Age, y	73.84 ± 8.30	End-diastolic LV volume indexed, mL/m^2	62.90 ± 18.01
Sex, % male	91	LA area, cm^2	22.10 ± 6.50
Hypertension, %	73	RA area, cm^2	17.00 ± 4.72
Diabetes mellitus, %	15	TAPSE, mm	24.02 ± 3.16
Dyslipidemia, %	60	Peak VO_2, mL/min/m^2	18.70 ± 3.68
Active smoker, %	6	%maxVO_2	90.27 ± 13.62
Atrial fibrillation, %	3	RER	0.99 ± 0.08
Coronary artery disease, %	9	VE/VCO_2 slope	33.32 ± 4.87
Stroke, %	6	Basal $PETCO_2$, mmHg	31.84 ± 4.22
Aortic valve area, cm^2	1.08 ± 0.28	Peak $PETCO_2$, mmHg	37.32 ± 3.49
Aortic valve area indexed, cm^2/m^2	0.58 ± 0.15	Grade III AR, %	21
Aortic valve mean gradient, mmHg	39.02 ± 12.78	Grade III MR, %	3
Severe aortic stenosis, %	48.5	LVEF, %	65.30 ± 6.54
End-diastolic LV volume, mL	120.39 ± 42.66		

AR, aortic regurgitation; LA, left atrium; LV, left ventricle; LVEF, left ventricular ejection fraction; MR, mitral regurgitation; $PETCO_2$, end-tidal carbon dioxide; RA, right atrium; RER, respiratory exchange ratio; TAPSE, tricuspid annular plane systolic excursion; VO_2, peak oxygen consumption.
Results are expressed as mean ± standard deviation and percentages.

performed reasonably well in the ROC curve analysis (Figure 2), with an area under the curve of 0.76. A peak PaO_2s under 51% showed a sensitivity and specificity of 75%, whereas a peak PaO_2s under 54% showed a sensitivity of 87.5% and specificity of 67%. The median peak exercise pH indicated metabolic acidosis without differences between the event and event-free groups, confirming that the patients exceeded the anaerobic threshold.

DISCUSSION

One of the holy grails common to all medical specialties is the ability to predict clinical deterioration in patients with chronic conditions, particularly when this information could prompt a significant change in management, such as surgery. Exercise testing in patients with chronic cardiovascular conditions seems to be the most physiological way to evaluate clinical status, with the clinical management usually altered by the detection of symptoms during exercise, not at rest, because this situation represents a later stage of disease progression. In DAS, only conventional exercise stress testing is recommended to unmask symptoms or detect blood pressure falls in selected individuals and is not part of the routine follow-up in patients with otherwise asymptomatic DAS.[1,8] Due to their well-recognized prognostic value, invasive hemodynamics provide a direct and accurate assessment of cardiac output, pulmonary pressures, and filling pressures and are widely used in critical care and in heart failure management to guide treatment and clinical decision-making in both stable and unstable patients.[9] Exercise invasive hemodynamics are considered a highly attractive and physiological way to assess patients' status and prognosis, but a lack of standardization and evidence about their clinical significance leave them relegated to a research tool in different clinical scenarios such as scleroderma-related pulmonary hypertension and heart failure.[10,11]

In this report, we show that exercise RHC in true asymptomatic (with a normal exercise capacity in CPET) patients with moderate or severe aortic stenosis is feasible and safe and provides useful information that correlates with poor outcomes. A lower peak exercise PaO_2s in our cohort was significantly associated with the occurrence of major events (death and need for intervention) after a mean follow-up of about 2 years. Resting PaO_2s is a crucial biological parameter when assessing the hemodynamic status of heart failure and critically ill patients. PaO_2s is influenced by cardiac output and peripheral oxygen extraction, 2 of the main determinants of exercise tolerance.[12] In our cohort, there were no differences in resting PaO_2s between the event and event-free groups. The difference was only found in peak PaO_2s, suggesting poorer cardiac performance of the event group because there were no differences in workload or other baseline parameters. Although the peak PaO_2s after treadmill exercise has classically been linked to poorer functional class,[12] this is the first time that this parameter has been associated with poorer outcomes in any cardiac condition, including DAS.

Although the event group showed slightly higher exercise pulmonary artery pressures during peak exercise, the difference was not significant. It is likely that cardiac output was not as greatly increased by exercise in the event group, which is feasible

Table 2
Baseline and peak exercise right heart catheterization data

	Baseline	Exercise
Heart rate, bpm	69.06 ± 9.98	102.69 ± 16.84
SBP, mmHg	146.66 ± 18.11	171.36 ± 18.25
DBP, mmHg	76.18 ± 11.88	94.85 ± 10.42
RAP, mmHg	7.57 ± 3.65	9.45 ± 4.48
sPAP, mmHg	33.61 ± 8.31	52.75 ± 13.12
dPAP, mmHg	13.60 ± 4.98	21.81 ± 8.01
mPAP, mmHg	21.48 ± 6.14	34.63 ± 9.22
PAOP, mmHg	14.45 ± 4.84	22.21 ± 8.42
TPG, mmHg	6.96 ± 3.60	—
PVR, WU	1.70 ± 1.13	—
SVR, WU	16.56 ± 4.82	—
CO, L/min	5.59 ± 1.32	—
CI, L/min/m^2	2.91 ± 0.62	—
PaO_2s, %	73.94 ± 5.96	54.71 ± 12.55
Workload, W	—	83.07 ± 25.16

CI, cardiac index; CO, cardiac output; DBP, diastolic blood pressure; dPAP, diastolic pulmonary artery pressure; mPAP, mean pulmonary artery pressure; PaO_2s, pulmonary artery oxygen saturation; PAOP, pulmonary artery occlusion pressure; PVR, pulmonary vascular resistance; RAP, right atrial pressure; SBP, systolic blood pressure; sPAP, systolic pulmonary artery pressure; SVR, systemic vascular resistance; TPG, transpulmonary gradient.
Results are expressed as mean ± standard deviation.

Table 3
Baseline characteristics of the event and event-free groups

	Event-free (n = 25)	Event (n = 8)	*P*
Age, y	76 [33]	74 [33]	.96
Aortic valve area, cm^2	1.1 [1.1]	1 [0.6]	.51
Aortic valve area indexed, cm^2/m^2	0.58 [0.54]	0.50 [0.49]	.31
Aortic valve mean gradient, mmHg	34 [61]	44 [31]	.09
LVEF, %	66 [23]	64.0 [13]	.55
End-diastolic LV volume, mL	108 [124]	132 [172]	.31
End-diastolic LV volume indexed, mL/m^2	57.6 [61.6]	65.8 [55.9]	.31
LA area, cm^2	20.4 [30.9]	22.6 [19.1]	.50
RA area, cm^2	15.9 [22.4]	17.4 [8.1]	.90
TAPSE, mm	24 [14]	24.2 [8]	.33
Peak VO_2, $mL/min/m^2$	18.3 [17.8]	18.1 [9.8]	.98
%maxVO_2	92 [62]	90 [21]	.99
RER	0.99 [0.38]	0.98 [0.22]	.57
VE/VCO_2 slope	32.7 [21.90]	33.6 [7.40]	.83
Basal $PETCO_2$, mmHg	31 [26]	31.5 [4]	.89
Peak $PETCO_2$, mmHg	37 [15]	36.5 [7]	.41
Grade III AR, %	20	25	.76
Grade III MR, %	4	0	.56

AR, aortic regurgitation; LA, left area; LV, left ventricle; LVEF, left ventricular ejection fraction; MR, mitral regurgitation; $PETCO_2$, end-tidal carbon dioxide; RA, right area; RER, respiratory exchange ratio; TAPSE, tricuspid annular plane systolic excursion; VO_2, oxygen consumption.
Unless otherwise indicated, results are expressed as median [range].

because PaO_2s is critical for calculating output with the Fick method. We can speculate that lower exercise cardiac output in the event group led to a less than expected increase in pulmonary pressures. Cardiac output can increase up to 5 to 8 times at peak exercise,[3] but limits to the ability of pulmonary vasodilatation to accommodate this amount of volume overload increase pulmonary pressures. This explains why, in healthy athletes, even ‘‘severe'' pulmonary hypertension has been found with noninvasive hemodynamic assessment.[3] Although severe exercise pulmonary hypertension has been linked to poor outcomes in different conditions, an association that is probably correct in many cases, this result should be taken with caution because lower pulmonary pressures could be related to even worse outcomes if cardiac output or cardiac performance is poor. In addition, there is a weak relationship between noninvasive and invasive assessment of pulmonary pressures,[4] indicating that careful consideration is required of the noninvasive calculation of pulmonary pressures.

We consider our work and its results primarily as a proof of concept, a demonstration that the idea behind it—the identification of new prognostic factors in DAS using exercise hemodynamics—is possible, feasible, and physiologically reasonable. Additionally, we believe that our findings might have a potential practical application. Accordingly, given that this study was conducted in selected patients

Table 4
Baseline and exercise right heart catheterization data in the event and event-free groups

	Baseline			Exercise		
	Event-free (n = 25)	Event (n = 8)	*P*	Event-free (n = 25)	Event (n = 8)	*P*
SBP, mmHg	149 [84]	144.5 [58]	.78	160 [80]	165 [100]	.55
DBP, mmHg	77 [57]	76 [26]	.96	90 [50]	100 [30]	.34
RAP, mmHg	7 [12]	5.5 [13]	.13	9 [15]	8 [12]	.62
sPAP, mmHg	33 [33]	32.5 [25]	.46	49 [43]	57 [48]	.41
dPAP, mmHg	14 [17]	10.5 [16]	.28	22 [32]	21 [26]	.69
mPAP, mmHg	20 [27]	20.5 [15]	.41	34 [36]	33 [32]	.86
PAOP, mmHg	14 [18]	14 [14]	.65	21 [28]	23 [26]	.58
TPG, mmHg	7 [15]	6.5 [13]	.63	—	—	—
PVR, WU	1.3 [3.2]	1.2 [4.4]	.93	—	—	—
SVR, WU	16 [16]	13 [16]	.15	—	—	—
CO, L/min	5.6 [4.4]	6.6 [4.9]	.31	—	—	—
CI, $L/min/m^2$	2.8 [2.3]	2.9 [2.4]	.88	—	—	—
PaO_2s, %	73.9 [32.2]	69.6 [16.6]	.10	57 [44]	48 [27]	.03
Workload, W	—	—	—	90 [81]	75 [71]	.31
Exercise pH				7.31 [0.07]	7.32 [0.07]	.94

CI, cardiac index; CO, cardiac output; DBP, diastolic blood pressure; dPAP, diastolic pulmonary artery pressure; mPAP, mean pulmonary artery pressure; PaO_2s, pulmonary artery oxygen saturation; PAOP, pulmonary artery occlusion pressure; PVR, pulmonary vascular resistance; RAP, right atrial pressure; SBP, systolic blood pressure; sPAP, systolic pulmonary artery pressure; SVR, systemic vascular resistance; TPG, transpulmonary gradient.
Results are expressed as median [range].

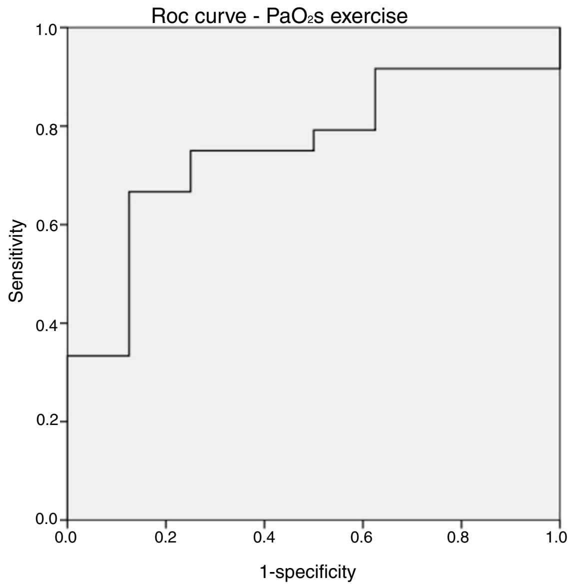

Figure 2. ROC curve analysis of peak PaO_2s. PaO_2s, pulmonary artery oxygen saturation; ROC, receiver operating characteristic.

and probably in a simpler manner than required, further research is warranted.

Limitations

A small number of patients was enrolled in this study, which otherwise is similar to other experiences in the literature.[11] This protocol is very demanding and includes an invasive procedure, and some patients were reluctant to participate, despite the approval of our ethics committee. Ideally, research such as that presented here would be performed with the inclusion of an oxygen consumption device, such as an iCPET.[13] This device would allow us to directly compare exercise cardiac output with the direct Fick method. Unfortunately, due to technical reasons, we were unable to use the CPET device in the catheterization laboratory. Although thermodilution at peak exercise was used in other experiences in the literature,[11] we did not consider this approach to be the best option, for the reasons already given. Although the workload achieved was relatively low (but higher than that of previous experiences[11]), it correlates well with the peak VO_2 achieved in the CPET, which was normal ($> 80\%$) for age and sex. In addition, compared with cycloergometer exercise, treadmill exercise achieves a higher workload and degree of tachycardia,[14] due to leg fatigue, which may be even more evident with our supine stepper.

CONCLUSIONS

Exercise RHC is feasible and safe in true asymptomatic patients with moderate-to-severe and severe aortic stenosis. Peak PaO_2s might identify patients with an increased midterm risk of serious adverse events and may be useful in selected scenarios.

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CONFLICTS OF INTEREST

None declared.

WHAT IS KNOWN ABOUT THE TOPIC?

– Some parameters, including severe pulmonary hypertension, the hemodynamic progression rate of the stenosis, and elevated plasma levels of natriuretic peptides, suggest adverse prognosis and might tip the balance in favor of early elective intervention, but strong evidence is lacking.

WHAT DOES THIS STUDY ADD?

– Exercise right heart catheterization in asymptomatic patients with moderate or severe degenerative aortic stenosis is feasible and safe and provides useful information that is correlated with poor outcomes.

APPENDIX. SUPPLEMENTARY DATA

Supplementary data associated with this article can be found in the online version, at https://doi.org/10.1016/j.rec.2019.03.005

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