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Systolic blood pressure response during exercise testing in symptomatic severe aortic stenosis

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ABSTRACT

Aims Exercise testing remains underused in patients with aortic stenosis (AS), partly due to concerns about an exercise-induced drop in systolic blood pressure (SBP). We aimed to study the SBP response to exercise in patients with severe symptomatic AS prior to surgery and 1 year postoperatively.

Methods Patients scheduled for aortic valve replacement due to severe symptomatic AS were enrolled at a single centre in a prospective observational cohort study. Maximal cardiopulmonary exercise testing (CPET) was performed on a cycle ergometer at baseline and 1 year postoperatively, using standard termination criteria. The SBP response was categorised according to the last measurements of SBP during exercise, in relation to workload (the SBP/watt-slope) as 'normal' (>0.25 mm Hg/watt), 'flat' (0–0.25 mm Hg/watt) or 'drop' (<0 mm Hg/watt).

Results 45 patients (28 male, 66±9 years, left ventricular ejection fraction 59%±5%, aortic jet velocity 4.6±0.5 m/s) were included, with pairwise comparison available in 31 cases. There were no adverse events. Preoperatively, 4/45 patients were categorised as 'drop', 23 as 'flat' and 18 as 'normal'. There was a change in the distribution of categories from preoperative to postoperative measurements (43% 'normal' vs 74% 'normal', p=0.0046). Maximal SBP and workload-indexed SBP were higher postoperatively than preoperatively (203±26 vs 182±28 mm Hg, p<0.001 and 0.43±0.14 vs 0.29±0.15 mm Hg/watt, p<0.001).

Conclusion As a drop in SBP was infrequent (<10%) in patients with severe symptomatic AS and no adverse events occurred, our results indicate that CPET may be performed under careful monitoring in AS patients. Postoperatively, the SBP reaction improved, with no patient having a drop in SBP.

Trial registration number NCT02790008.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Exercise testing (ET) remains underused in aortic stenosis (AS). Most insights into AS exercise physiology, including systolic blood pressure (SBP) response, are derived from studies on asymptomatic patients.

WHAT THIS STUDY ADDS

⇒ In a cohort of severe symptomatic AS patients, we examined the SBP response during preoperative and postoperative cardiopulmonary ET (CPET), including new data on the frequency of SBP drops or flat responses.

⇒ Preoperatively, a drop in SBP during maximal CPET was uncommon (<10%), and no adverse events occurred when using standard termination criteria. Postoperatively, no patients experienced a drop in SBP during CPET.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ CPET may be of value for selected patients with severe AS, with or without symptoms, as part of clinical decision-making and preoperative evaluation.

INTRODUCTION

In patients with aortic stenosis (AS), the decision on surgical intervention is mainly based on symptoms and/or left ventricular (LV) dysfunction, according to both European[1] and American guidelines.[2] As symptoms can be modest and subjective, cardiopulmonary exercise testing (CPET) is advised for demasking symptoms and to provide an objective evaluation of cardiopulmonary function.[3] However, fewer than 10% of patients with AS had performed exercise testing according to the latest EuroHeart Survey,[4] indicating that important information regarding preoperative cardiopulmonary function may be missed in these patients.

In general exercise testing guidelines,[5] exercise testing is not recommended for patients with symptomatic severe AS, mainly due to the risk of a drop in systolic blood pressure (SBP) during exercise, ultimately resulting in syncope. However, the frequency of exercise-induced SBP drops in patients with symptomatic AS is largely unknown, and this could be valuable information, to be weighed against the useful exercise test data that might be gained for operation decisions in borderline cases. In addition, data on the

SBP response to exercise before and after aortic valve replacement (AVR) are lacking.

The aim of this study was to provide a detailed evaluation of exercise SBP during a preoperative CPET among patients with severe symptomatic AS, as well as 1 year postoperatively.

METHOD

Study population

Adult patients referred for AVR due to AS at the Department of Cardiothoracic surgery, Linköping University Hospital between April 2014 and February 2020 were considered for inclusion. Exclusion criteria were (a) other heart disease such as concomitant heart valve disease, congenital heart disease, haemodynamic instability, previous cardiac surgery, coronary artery disease and history of myocardial infarction, (b) symptomatic lung disease, (c) significant arrhythmia during CPET potentially affecting the SBP measurements or heart rate response or (d) any mental or physical disability limiting participation. The study was registered at ClinicalTrials.gov, ID: NCT02790008.

Cardiopulmonary exercise testing

CPET was performed prospectively at baseline within 2 weeks prior to surgery (CPET1) and 1 year postoperatively (CPET2). Current medication, body weight and height were recorded and haemoglobin and troponin-T levels were analysed at both visits. Each test was supervised by an experienced physician and a technician and consisted of a maximal exercise test on a cycle ergometer (eBike Basic, GE Medical Systems, Freiburg, Germany). Gas exchange and ventilation were measured breath by breath (Vyntus CPX Carefusion or Jaeger Oxycon Pro, Viasys Healthcare, Hoechberg, Germany), with calibration of gas, pressure and volume before each test. Patients were monitored with ECG (Marquette CASE 8000, GE Medical Systems, Milwaukee, Wisconsin, USA), rating of perceived exertion (Borg RPE scale), chest pain and dyspnoea (Borg CR-10 scale).[6] The exercise protocol included a 5 min steady-state at 20–50 watts, followed by a continuous increase in the workload of 10 or 20 watts per minute, aiming at a total test duration of 10–12 min. The test termination criteria included maximal exertion, severe ventricular arrhythmia, severe chest pain (>5/10) or a sustained drop in SBP>10 mm Hg. The type of SBP response was categorised in all patients (figure 1), while only those with a maximal respiratory exchange ratio (RER≥1.05) were included in the detailed analysis.

Blood pressure measurement and calculations

Auscultatory blood pressure was measured in the right arm before exercise after 5 min of rest in the supine position (SBP_{supine} and diastolic blood $pressure_{supine}$), as well as sitting on the bike (SBP_{sitt}). During exercise, SBP was measured in the right arm using a radial Doppler probe every 1–2 min until the end of the exercise. In the case of a drop in SBP, the measurement was confirmed immediately with a second measurement. Each SBP measurement was recorded in the digitalised work protocol with the corresponding test time, heart rate and workload (watts) added automatically.

The last SBP recorded during the 5 min steady-state (SBP_{SS}), the highest SBP during the test (SBP_{max}), as well as the last three SBP measures during exercise (SBP_{last}, $SBP_{2nd\ to\ last}$, $SBP_{3rd\ to\ last}$), were analysed. The type of SBP response was categorised as 'normal', 'flat' or 'drop' (figure 1), based on the change in SBP between the three last SBP measures, while also considering the corresponding change in workload.

The SBP/watt-slope was calculated as the increase in SBP between steady-state and last SBP measurement during exercise (SBP_{last}–SBP_{SS}), divided by the corresponding increase in workload ($Watt_{last}$–$Watt_{SS}$). SBP_{max} and the SBP/watt-slope values were compared with predicted values from a healthy reference population based on sex, age, height, exercise capacity and SBP_{sitt}.[7] Delta SBP was calculated as the difference between maximum SBP and SBP at rest. In cases with missing data for SBP_{sitt}, we instead used SBP_{supine} minus 4 mm Hg, as previously proposed.[8]

Echocardiographic data

Transthoracic echocardiography was performed at rest, according to current guidelines,[9] on the same day as the CPET. LV ejection fraction (LVEF) was calculated by the Simpson biplane summation of discs method. Peak systolic velocity over the aortic valve (AoV_{max}) was registered. The aortic valve area (AVA) was calculated using the continuity equation.

Statistical analysis

For analyses, SPSS V.26.0.0.2 (SPSS) was used. Two-sided statistical significance was set at a p≤0.05. Normality was assessed with Shapiro-Wilk's test. Continuous variables are presented as mean (SD) or as percentages. Paired t-tests were used for comparison between preoperative and postoperative measurements for continuous data. To evaluate the differences in preoperative CPET and baseline variables among the three SBP categories, we conducted Levene's test for homogeneity of variances. One-way analysis of variance was conducted and followed by post hoc tests according to Levene's test (Scheffe's test or Dunnett's T3 test) as appropriate to the data. Marginal homogeneity testing for categorical data was performed using R Studio V.2021.09.0, Build V.351 (R Studio, Vienna, Austria) with package R companion V.2.4.1.

Patient and public involvement

Patients or the public were not involved.

RESULTS

A total of 50 patients underwent AVR and were considered eligible (figure 2). Five patients were excluded. Thus, data on the type of SBP response were available for 45 patients at CPET1, of which 35 also underwent CPET2.

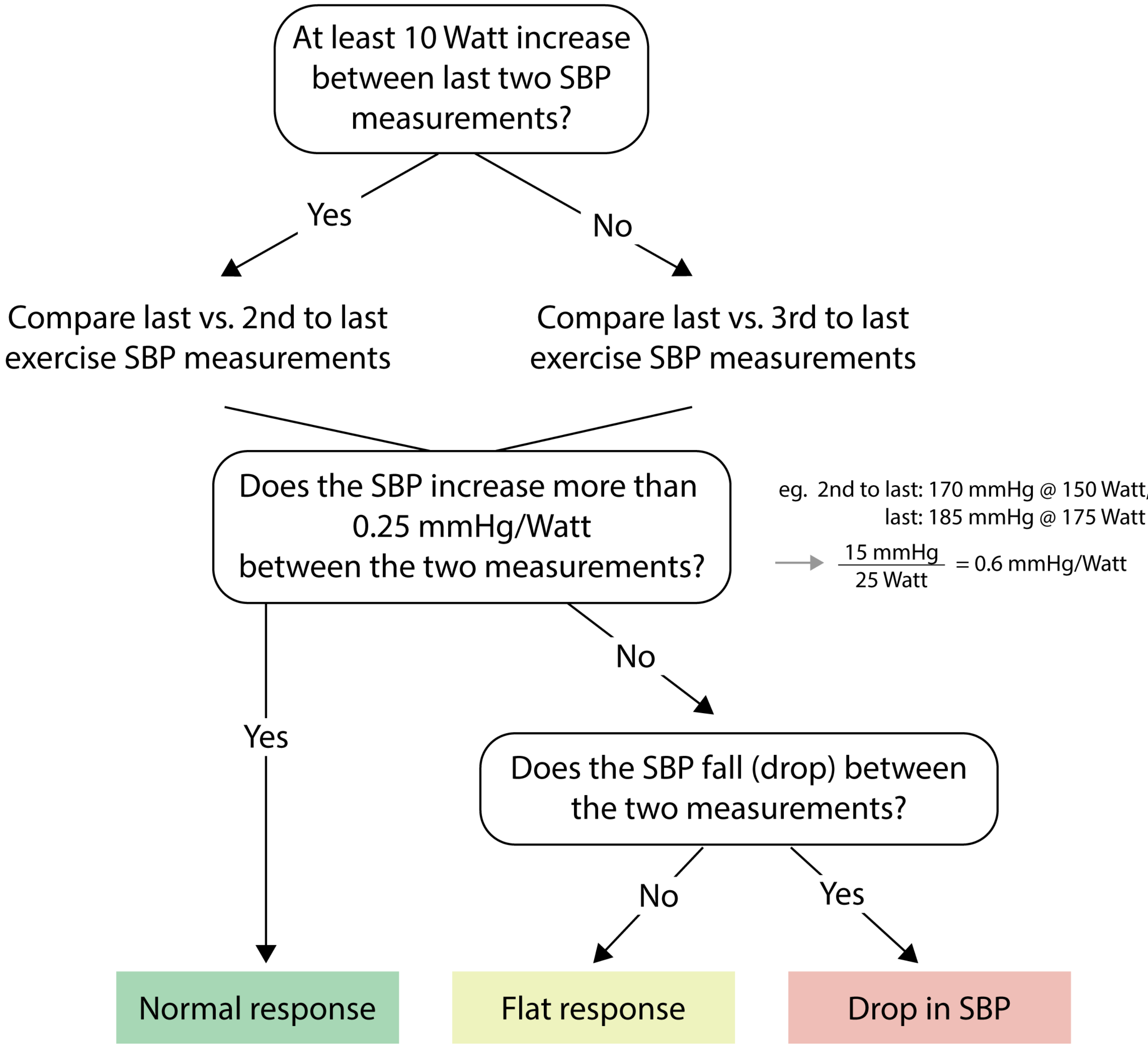

Figure 1 Categorisation of the systolic blood pressure (SBP) response. The type of SBP response at cardiopulmonary exercise testing was categorised as 'normal', 'flat' or 'drop' based on the change in SBP between the three last SBP measures, while also considering the corresponding change in workload.

For the detailed, non-categorical analysis, we further excluded three patients at CPET1 and two patients at CPET2 with a submaximal exercise test (ie, RER<1.05), leaving 42 preoperative and 33 postoperative measurements for detailed analyses. Pairwise comparisons were possible in 31 patients.

Patient characteristics

Baseline characteristics are presented in table 1. CPET1 was performed 10±12 days before AVR and CPET2 53±2 weeks after surgery. No patient had a pacemaker at CPET1. At the time of CPET2, one patient had received a pacemaker.

Cardiopulmonary exercise test

A total of 42 patients were included in the detailed analysis of CPET1. The mean steady-state workload was 43±10 watts, the mean peak workload was 133±40 watts and the mean peak RER was 1.15±0.07. The mean maximum rating of perceived exertion was 17±1 and the mean maximum rating of dyspnoea was 6±2. Five patients experienced chest pain, with the highest recorded rating of 3.5. In three cases, the CPET was terminated by the test leader; due to a sustained drop in SBP in two cases and one due to a pathological ECG response.

For CPET 2, the mean steady-state workload was 45±9 watts and 94% (29/31 patients) used the same load as

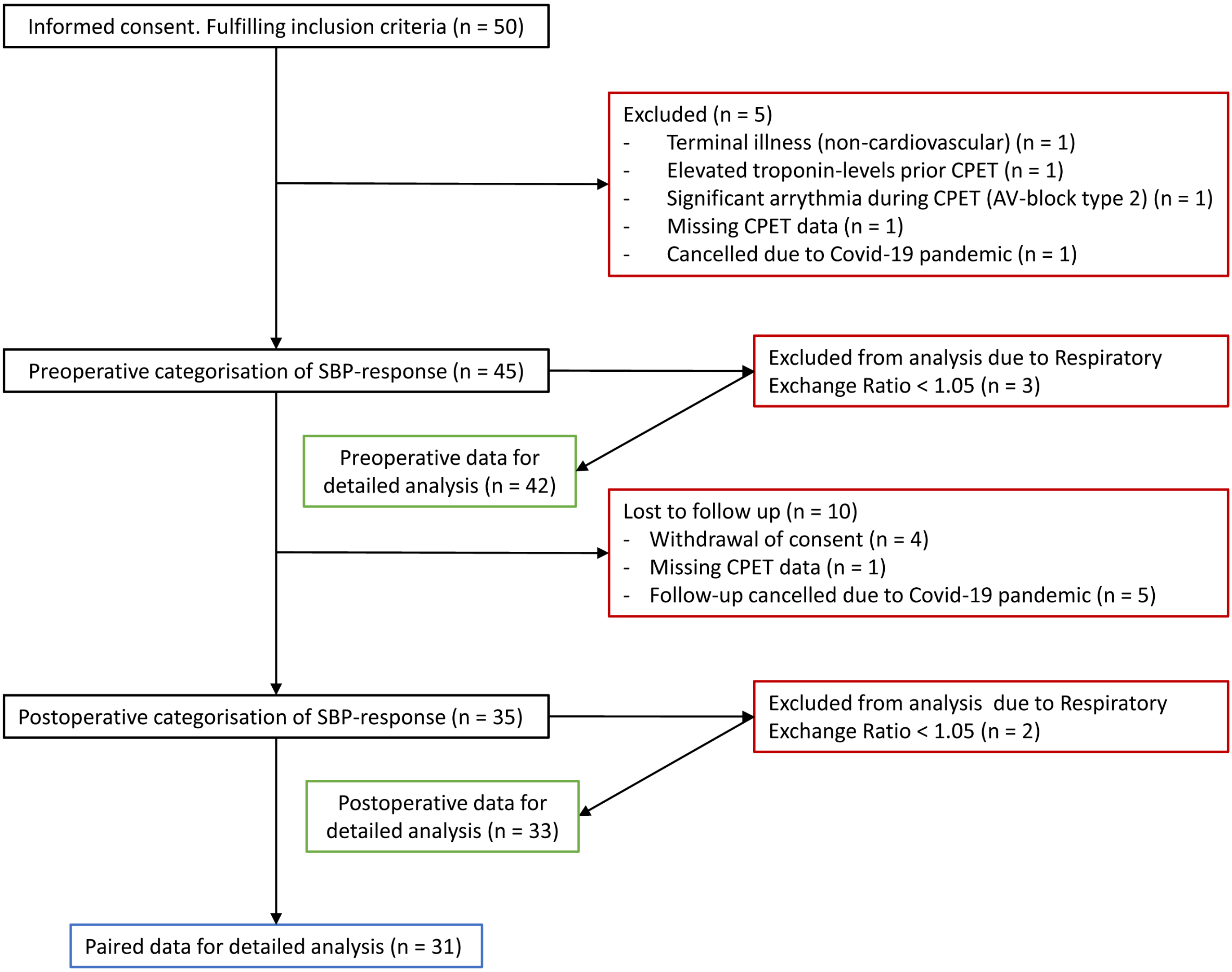

Figure 2 Study flow chart. Study flow chart of patients participating in the study. All CPETs were categorised according to type of SBP response to exercise testing, while detailed analyses were performed only for CPETs exceeding RER≥1.05 indicating maximal effort. AV, aortic valve; CPET, cardiopulmonary exercise testing; RER, respiratory exchange ratio; SBP, systolic blood pressure.

for CPET1. The mean peak workload was 151±44 watts and the mean peak RER was 1.17±0.08. The mean maximum rating of perceived exertion was 17±2 and the mean maximum rating of dyspnoea was 5±2. One patient rated experienced chest pain as 1. No test was terminated prematurely due to the fulfilment of the termination criteria.

For paired analyses between measurements (n=31), the peak workload (139±38 vs 157±42 watts, p<0.001) and the peak RER (1.14±0.07 vs 1.18±0.07, p=0.008) increased from CPET1 to CPET2. There was no difference in heart rate at rest (73±13 vs 73±11 beats/min, p=0.796) or at peak exercise (139±21 vs 138±20 beats/min, p=0.521) between CPET1 and CPET2.

There was no case of any serious adverse event, such as myocardial infarction, syncope or cardiac arrest observed during CPET1 or CPET2.

SBP response during exercise

Among the 45 patients who performed CPET1, regardless of RER, 4 patients were categorised as having a 'drop' in SBP, while 23 patients had a 'flat' and 18 patients had a 'normal' response. The SBP responses preoperatively and postoperatively in the 35 patients who underwent both CPET1 and CPET2 are presented in figure 3. There was a significant change of distribution in categorised SBP responses between CPET1 and CPET2 (p=0.0046), with 43% (n=15) vs 74% (n=26) of patients having a 'normal' response at CPET1 and CPET2, respectively. Stratified baseline data according to SBP categories are presented in online supplemental eTable 1. Comparison of differences in preoperative baseline and CPET variables between the categories showed significant differences only for SBP/watt slope (F(2.42)=3.32, p=0.024) and maximal SBP of predicted (F(2.34)=3.87 p=0.048) while neither remained statistically significant after post hoc testing.

Table 1 Patient characteristics at baseline (CPET 1)

	All (n=45)	Male (n=28)	Female (n=17)
Age (years)	66.3±8.7	66.6±10.0	65.9±6.4
Height (cm)	173±10	178±7	163±8
Weight (kg)	83±13	88±12	75±11
BMI (kg/m^2)	27.8±3.9	27.7±3.3	28.1±4.8
Hb (g/L)*	143±9	147±8	137±7
AoVmax (m/s)	4.6±0.5	4.7±0.4	4.4±0.5
AVA (cm^2)	0.71±0.21	0.74±0.20	0.65±0.22
LVEF (%)	59±6	59±6	58±5
Hypertension† (n, %)	25 (56)	16 (57)	9 (53)
Beta-blocker (n, %)	11 (24)	6 (21)	5 (29)
ACE-Inhibitor or ARB (n, %)	10 (22)	7 (25)	3 (18)
SBP_{supine} (mm Hg)	136±17	141±15	127±16
DBP_{supine} (mm Hg)	78±10	79±10	76±9
HR at rest (beat/min)	67±10	66±9	69±12

Data are presented as mean±SD (continuous data) or as n (percentage) for categorical data.
*One missing data, n=44.
†Hypertension is defined as usage of antihypertensive medication and/or a clinical diagnosis.
AoVmax, peak systolic velocity over the aortic valve; ARB, angiotensin II receptor blocker; AVA, aortic valve area; BMI, body mass index; CPET, cardiopulmonary exercise testing; DBP, diastolic blood pressure; Hb, haemoglobin; HR, heart rate; LVEF, left ventricular ejection fraction; SBP, systolic blood pressure.

Detailed analysis of the four patients categorised as ‘drop’ at CPET1 (see online supplemental eTable 2), revealed that, in three cases, the test was terminated by the test leader (one due to a pathological ECG response, two due to a sustained drop in SBP during exercise). The pathological ECG response consisted of a right bundle branch block with premature ventricular complex in bigeminy after 8 min of ramp exercise, while SBP decreased −5 mm Hg at two consecutive measurements during the last minute of exercise. The two sustained drops in SBP during exercise included one case with a −20 mm Hg drop after approximately 10 min of ramp exercise and one case with a −15 mm Hg drop after only 1 min of ramp exercise. Furthermore, one case consisted of a −10 mm Hg drop at the very end of exercise just prior to terminating the test due to maximal exertion.

Blood pressure data

At CPET1, 10/45 patients (22%) reached 100% or higher of predicted maximal SBP as compared with 18/35 patients (51%) at CPET2. Details on the SBP response to exercise for patients with RER>1.05 are presented in table 2. Paired analysis between measurements showed that 26/31 (84%) patients reached a higher maximal SBP at CPET2 and that 22/27 (81%) patients had a steeper SBP/Watt-slope at CPET 2.

DISCUSSION

This study sought to investigate the SBP response to exercise in patients with severe symptomatic AS before and 1 year after AVR. Our main findings were that (a) a drop in SBP during CPET occurred in only 4 out of 45 patients (<10%) preoperatively, without any adverse event; (b) no patient had a drop in SBP postoperatively and there was a trend of change in category from both ‘drop’ and ‘flat’ to ‘normal’ SBP response to exercise from preoperatively to postoperatively; (c) the SBP/watt-slope increased from preoperative to postoperative measurements. Overall, our findings indicate a favourable effect of AVR on exercise haemodynamics in this cohort of patients with severe, symptomatic AS.

Exercise testing in the evaluation of AS severity

AS may be seen as a continuum of a chronic, slowly developing disease where the strict echocardiographic definition of its severity must be interpreted in relation to the presence of symptoms. Although the transition from asymptomatic to symptomatic AS is related to LV function and other echocardiographic markers of AS severity, the association between imaging and symptoms is poor and the mechanisms that lead to symptoms are still incompletely understood.[10] Assessment of symptoms in a clinical setting can be challenging due to comorbidities and to a decreased physical activity level in relation to age and/or loss of function. This may conceal symptoms related to AS and, therefore, patients’ symptom burden due to AS may be both underestimated and overestimated. In this context, CPET may be of great value in both providing an objective measure of functional capacity and offering a standardised evaluation of symptoms during exercise, which is critical for assessing the severity of symptoms and guiding clinical decisions. Additionally, it enables patients to make well-informed decisions regarding their treatment and care.

Given such a fine line between symptomatic and asymptomatic patients, it is important to emphasise that symptom-limited CPET has been demonstrated to be safe in asymptomatic patients with severe AS when performed adequately.[11] A more recent study underscored the value and safety of CPET in equivocally asymptomatic AS.[12] In a recent review article, Saeed *et al* conclude that exercise testing is safe, feasible and reveals symptoms in a significant proportion of patients with significant AS.[13] In the current study, including a cohort of severe symptomatic AS, regardless of SBP categorisation, no adverse effects ensued when applying and carefully monitoring established criteria for termination of the exercise test.[5]

SBP response to exercise in patients with severe symptomatic AS

This is, to our knowledge, the first description and categorisation of the SBP response during exercise preoperatively and postoperatively among patients with severe symptomatic AS. While 4 of 45 patients were categorised as having a drop in SBP, 16 patients were

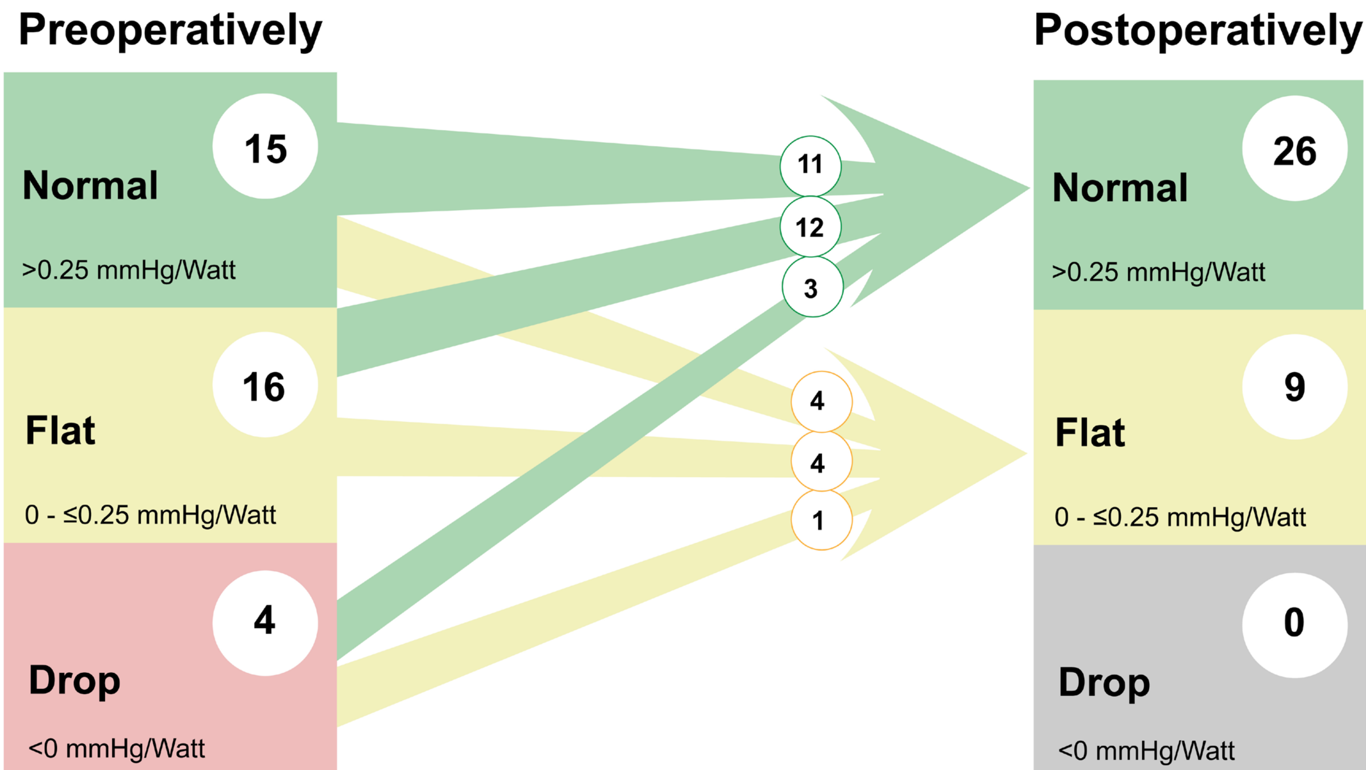

Figure 3 Systolic blood pressure (SBP) response during exercise testing for patients with symptomatic aortic stenosis preoperatively and postoperatively. SBP response during exercise testing in 35 patients with repeated measurements of CPET, regardless of peak RER. No patient had a drop in SBP postoperatively. Individual movement between categories is presented. Statistical analysis using marginal homogeneity testing for categorical data showed a significant change in distribution in categorised SBP responses between CPET1 and CPET2 (p=0.0046). CPET, cardiopulmonary exercise testing; RER, respiratory exchange ratio.

categorised as having a flat response in SBP. During exercise, there is normally an almost linear relationship between SBP and workload, as the mean arterial pressure is determined by cardiac output and the total peripheral resistance. Hence, during exercise testing with a ramp protocol, SBP is expected to increase more or less linearly up until exhaustion in normal subjects.

The most probable explanation for why 20/45 of the patients with AS in the current study did not have a normal response ('flat' or 'drop') is that the structural pathological changes in the aortic valve resulting in stenosis limit stroke volume and thus cardiac output during exercise, in turn resulting in lower mean arterial pressure and SBP.

Table 2 Blood pressure data

	Preoperatively, all patients with RER>1.05 (n=42)	Paired analyses, all patients with RER>1.05 (n=31)		
	CPET1	CPET1	CPET2	P value
SBP at rest* (mm Hg)	138±17	138±16	139±21	0.652
SBP_{SS} (mm Hg)	154±21	155±21	158±21	0.540†
Maximal SBP (mm Hg)	181±26	182±28	203±26	**<0.001**
Maximal SBP of predicted* (%)	90±11	91±11	99±10	**<0.001**
Delta SBP*	43±24	44±24	64±26	**<0.001**
SBP/Watt-slope	0.27±0.14	0.29±0.15	0.43±0.14	**<0.001‡**
SBP/Watt-slope % of predicted* (%)	56±34	59±37	88±32	**0.001‡**

Data are presented as mean±SD. Paired analyses with paired t-test. Bold p-values = p<0.05.
*Missing SBP at rest was replaced by SBP-supine minus 4 mm Hg for nine patients preoperatively and five patients postoperatively.
†Analysis performed only if there was the same SS load (watts) for both CPET1 and CPET2, n=29.
‡One negative and one flat slope removed from preoperative data and one flat slope removed from postoperative data for analysis.
CPET, cardiopulmonary exercise testing; RER, respiratory exchange ratio; SBP, systolic blood pressure; SS, steady-state.

This finding is similar to previous studies of patients with echocardiographically confirmed severe AS performing bicycle ergometry CPET with reports between 0%[14] and 27%[15] of abnormal blood pressure response as well as 18% for exercise in a semisupine position[16] while 37% was reported for a treadmill test.[17] Comparison between studies is limited due to variabilities of the definition of abnormal blood pressure. We applied a systematic categorisation of the SBP response based on the SBP response during the last minutes of the exercise. An increase in SBP of ≤0.25 mm Hg/watt (2.5 mm Hg per 10 watts) was defined as 'flat', based primarily on the inherent variability in SBP measurement during exercise. A strict 'zero-increase' definition of 'flat' would risk missing individuals with no real, but rather a measurement-related, increase in SBP. The 0.25 mm Hg/watt threshold also approximates the lower fifth percentile of the overall SBP/watt increase in a larger cohort study of the normal SBP response in healthy individuals.[7]

Previous studies including a detailed analysis of the SBP response to exercise in severe AS are scarce. In a small study (n=11 (six females), mean age 79.7±6.1 years), Poirier *et al* described SBP data from a recumbent CPET ramp protocol in patients with severe equivocally symptomatic AS. The mean maximal SBP was 159±35 mm Hg, and six patients were categorised as having a normal progression of SBP during exercise, three patients reached maximal SBP during the recovery phase and two patients had a drop in SBP. There were no reports of serious adverse effects.[18]

Dhoble *et al* examined the cardiopulmonary response to exercise in 155 patients (age 69.6±10.7 years, 86% male) with AS by a symptom-limited CPET on a treadmill. In patients with AVA<1 cm (n=76), peak SBP was 146±27 mm Hg as compared with 154±31 mm Hg for AVA 1.0–1.5 cm (n=79), p=0.110.[19] The higher overall maximal SBP for patients observed in the current study (181±14 mm Hg) compared with previous studies,[18 19] may in part be explained by our stricter exclusion of cardiopulmonary comorbidities and different exercise modalities.

SBP response to exercise following AVR

Following AVR, no patient presented with a drop in SBP during exercise, and there was a statistically significant change in the type of SBP response to more subjects having a 'normal' response. Out of the four patients preoperatively categorised as 'drop', three patients were categorised as 'normal' postoperatively, and one patient as 'flat'. 12 patients changed the category from 'flat' to 'normal', while four patients remained in the 'flat' category. In addition, maximal SBP (+12%), maximal workload (+13%) and the SBP/watt-slope (+48%) increased postoperatively. Thus, the 1-year follow-up provides evidence that this group of patients are positively affected haemodynamically by AVR surgery.

From a physiological point of view, surgical AVR reduces the afterload caused by the narrow aortic valve. In the case of reduced systolic function preoperatively, this often improves after relief of the stenosis.[20] Furthermore, a regression of the adaptive concentric LV hypertrophy can be expected 1 year postoperatively.[21] Both these adaptations would make a greater stroke volume and cardiac output increase during exercise possible and hence could in part explain an increased SBP when metabolic demands increase during exercise.

During the postoperative SBP assessment, both peak SBP and peak Workload were higher, and yet, 9/35 (26%) of patients presented a 'flat' response. One might speculate that a 'flat' response is not necessarily a precursor to a 'drop' at maximal effort in patients without severe AS, but this type of SBP response has to our knowledge not been previously studied. In addition, as peak RER was higher postoperatively, the exercise tests were postoperatively likely driven closer to maximal intensity where a slight plateau of the SBP response may be physiologically explained as maximal cardiac output is reached.

While both current exercise testing recommendations[5] and hypertension guidelines[22] acknowledge the importance of interpreting the SBP response in relation to workload, there is no consensus on how this could be done systematically. By indexing the SBP response to workload, the SBP/watt slope allows a more precise assessment of cardiovascular function during exercise and can be particularly useful in identifying patients with impaired haemodynamic responses that might not be apparent when looking at ΔSBP alone. Recently, normative values for the SBP/watt-slope were published.[7]

In the present study, the SBP/watt-slope increased from 0.29±0.15 preoperatively (59%±37% of predicted values) to 0.43±0.14 mm Hg/watt postoperatively (88%±32% of predicted values). This indicates a steeper, normalised SBP response to exercise postoperatively, yet not fully reaching predicted normal values. Both haemodynamics (eg, flow, turbulence and LV systolic function) and constraints due to the use of cardiovascular drugs may limit the possibility to reach predictive values from a healthy reference population.

Limitations

First, the key findings of this study are based on SBP measurements during exercise, obtained with the Doppler technique, which may be examiner-dependent, and invasive techniques for SBP measurements would provide more precise data. Second, we excluded patients with severe cardiopulmonary comorbidities, which may limit the generalisability to all patients with severe AS, where the burden of comorbidities may be substantial. Nevertheless, the current exclusion criteria provide a possibility to interpret the physiological findings among patients with pure severe symptomatic AS. Third, we arbitrarily chose 0.25 mm Hg/watt as the threshold to define a 'normal' response, and this does not necessarily imply an SBP increase that is normal in all aspects. However, there are currently no recommendations or consensus on how to define a 'flat' SBP response, and our threshold corresponds well to the lower fifth percentile in a healthy population.[7]

CONCLUSIONS

We found that maximal CPET was safe and tolerable when standard termination criteria and careful monitoring of SBP were applied, and less than 10% of patients with severe, symptomatic AS had a drop in SBP during exercise testing. The maximal SBP, maximal workload as well as the SBP/watt-slope increased postoperatively, and no patient had a drop in SBP 1 year following AVR.

Contributors Concept and design: HN, EN, KH and ÉT. Acquisition, analysis or interpretation of data: HN, CB, KH and ÉT. Drafting of the manuscript: HN. Critical review of the manuscript for important intellectual content: all authors. Statistical analysis: HN, KH and ÉT. Obtained funding: ÉT. Administrative, technical or material support: ÉT. Supervision: KH, ÉT. Guarantor: ÉT.

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Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by the regional ethical review board in Linköping. Id:2011/105-31. Participants gave informed consent to participate in the study before taking part.

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