

Evaluation of a Rehabilitation Program With Blood Pressure-Guided Exercise Intensity Restrictions for Patients With Thoracic Aortic Dissection or Aneurysm

Karoline Stentoft Rybjerg Larsen, PT, MHSc; Mariann Tang, MD, PhD; Jacob William Budtz-Lilly, MD, PhD; Lotte Sørensen, PT, PhD

Purpose: Aortic disease presents a significant risk of mortality and morbidity, with hypertension considered the primary driver of disease progression. Blood pressure naturally increases during physical activity, and patients need guidance on the optimal level of exercise. The purpose of this study was to evaluate change in cardiopulmonary fitness after attending a rehabilitation program using blood pressure-guided exercise intensity.

Methods: The cohort included patients with thoracic aortic dissection (type A and B) and surgically operated thoracic aortic aneurysm. All participated in a rehabilitation program with maximum workload recommendations based on cardiopulmonary exercise tests which were performed before and after the rehabilitation program.

Results: 63 patients were included. At ventilatory threshold, workload increased by 17-32 watt and oxygen uptake by 1.8-2.9 ml/kg/min. 22 patients were able to perform both tests to exhaustion without exceeding blood pressure restrictions of 160-180 mmHg. These patients improved maximum workload by 20.6 watt (95% CI, 13.0-28.3) and peak oxygen uptake by 2.3 ml/kg/min (95% CI, 1.2-3.5). Only two cases of light dizziness at the end of test were reported.

Conclusions: Generally, patients with aortic disease improved oxygen uptake and workload during the rehabilitation program. One-third of the patients were able to perform both cardiopulmonary exercise tests to exhaustion without exceeding blood pressure restrictions. No serious adverse events occurred during test or exercise.

Key Words: aortic disease • aortic dissection • exercise capacity • rehabilitation

Aortic disease is associated with high mortality and morbidity, although advancing diagnostic, medical, and surgical therapies have led to improvements.¹ The incidence of aortic disease is approximately 2.5-7.2 per 100 000-person years, while the 5-year survival after aortic dissection is estimated to be 70-80%.¹⁻⁴ One of the most important long-term factors in both operated and medically treated patients is believed to be strict lifelong blood pressure control, as high blood pressure strains the tissue in the aortic wall and,

KEY PERSPECTIVES

What is novel?

- Patients with thoracic aortic dissection or aneurysms attending a rehabilitation program with blood pressure-guided exercise intensity were able to improve their cardiorespiratory fitness.
- One-third of the patients could perform cardiopulmonary exercise testing to exhaustion without exceeding blood pressure restrictions.

What are the clinical and/or research implications?

- No serious adverse events happened during test or exercise.
- Further investigation is required to explore how blood pressure-guided exercise intensity affects quality of life, disease progression, or prevention in both the short- and long-term.

in worst cases, leads to rupture and sudden death.^{5,6} Current guidelines recommend a systolic blood pressure below 120 mmHg at rest.¹ Blood pressure rises as work intensity increases, and intense strength training can result in extreme blood pressure levels, reaching up to 300 mmHg.^{7,8} Recommendations are light to moderate exercise intensity for patients with aortic disease. Preferably, exercise intensity is individualized depending on risk profiles.¹

Many patients experience a fear of dying when diagnosed with aortic disease, with generalized anxiety and, more tangibly, a fear of physical exertion. Many have had an active life style prior to the acute onset of disease and experience a lack of freedom due to limitations in physical activities.^{9,10} Therefore, the physical restrictions imposed by blood pressure control can exacerbate the impacted quality of life.^{11,12} Inactivity is also detrimental to health, both physically and mentally. Physical activity is well-documented as protective against cardiovascular disease, diabetes, and many other diseases.¹³ Exercise and physical activity have a positive effect on lowering blood pressure and are indeed recommended for patients with hypertension.¹⁴ Mice-model studies have also shown that moderate cardiorespiratory fitness may even have a protective impact against aortic disease, and exercise reduces mortality, reversing inflammation and promoting remodelling of the aortic wall.^{15,16} Very few studies have investigated the effect of exercise and rehabilitation in humans with aortic disease.^{17,18}

In 2017, Aarhus University Hospital (AUH) commenced a rehabilitation program for patients with aortic disease consisting of supervised exercise and patient education.

Author Affiliations: Department of Physiotherapy and Occupational Therapy, Aarhus University Hospital, Aarhus N, Denmark (Mrs Larsen and dr Sørensen); and Department of Cardiothoracic and Vascular Surgery, Aarhus University Hospital, Aarhus N, Denmark (Drs Tang and Budtz-Lilly).

No fundings received for this study.

All authors declare no conflicts of interest.

Correspondence: Karoline Stentoft Rybjerg Larsen, PT, MHSc, (karoande@rm.dk).

Copyright © 2025 Wolters Kluwer Health, Inc. All rights reserved.

DOI: 10.1097/HCR.0000000000000965

Recommended exercise intensity is set based on the increase in blood pressure during cardiopulmonary exercise testing (CPX) aiming to keep blood pressure below 160 mmHg or, in special cases with low risk of dissection, 180 mmHg. The aim of the rehabilitation program is to restore and maintain exercise capacity and quality of life by teaching safe habits of physical activity. The long-term objective is to potentially limit the progression of lifestyle-related diseases and reduce the need for additional surgery. The purpose of this study was to evaluate whether patients with aortic disease were able to improve cardiorespiratory fitness when attending a rehabilitation program with blood pressure restrictions.

METHODS

PATIENTS

This was a retrospective cohort study of patients who participated in the rehabilitation program for aortic disease at AUH between April 2017 and August 2023. This included patients who were surgically treated for either thoracic aortic dissection or aneurysm as well as those medically treated for a type B thoracic aortic dissection. In general, all treated patients were referred for rehabilitation. Patients who completed the rehabilitation program and the follow-up exercise test were included in the study, which was mainly patients from the Aarhus municipality.

SETTING

Echocardiography was performed in all patients prior to discharge from hospital. Computerized tomography of the entire thoracic and abdominal aorta was also carried out within the first one to 3 months after surgery. Patients that had undergone valve surgery had an additional echocardiogram 1 month after surgery. Cardiac and vascular surgeons evaluated the images, where attention was directed to residual dissection or aneurysms, their diameters, and atherosclerotic burden. Furthermore, the overall risk factor profile of patients was based on existing comorbidities, hypertension, and potential dispositions such as connective tissue disorders. The final important parameter was the evaluation of whether and when future intervention was necessary, which influenced when the patient could undergo rehabilitation.

Electively operated patients (thoracic aneurysm or dilatation with or without valve replacement) typically started rehabilitation 6 weeks postoperatively, while patients with thoracic aortic dissection (type A or B), regardless of treatment, awaited a 3-month computerized tomography scan.

The rehabilitation program included CPX with breath-by-breath gas exchange, electrocardiographic monitoring, and blood pressure measurements. A physiotherapist and

a nurse experienced in the cardiac surgical field were present. The test was performed on a cycle ergometer using a ramp protocol estimated to reach maximal workload between 8 and 12 minutes. The initial warm-up phase was set to 2 minutes without or with minimal workload to acclimatize and avoid a prompt rise in blood pressure. If the systolic blood pressure exceeded 160 mmHg during the test without the patient being strained in any way, antihypertensive treatment was subsequently increased, if possible, and the patient was later retested. The result of CPX was used to recommend a maximum workload corresponding to a systolic blood pressure ≤ 160 mmHg when exercising. Any uncertainties about the test results and exercise recommendations were discussed in the multidisciplinary aortic team (consisting of physiotherapists, nurses, cardiologists, and cardiac and vascular surgeons).

Thereafter, patients participated in supervised physical exercise, combined with patient education in topics related to aortic disease (eg, antihypertensive drugs and adverse effects, diet, psychological aspects, and lifting and moving techniques). Training sessions lasted one hour and were scheduled two to three times a week for a period of 10 weeks. Every training session consisted of 20 to 30 minutes of cardiorespiratory fitness with an intensity comparable to 14-15 on Borg's rate of perceived exertion,¹⁹ if possible, without exceeding the recommended workload. In addition, the training sessions included a short warm-up, stretching, and muscle endurance training (90 second exercise intervals) for approximately 20 minutes. Patients were advised against contact sports, heavy lifting involving Valsalva maneuvers, and strength training defined as ≤ 15 repetitions of maximum repetition.

OUTCOMES

Demographic and clinical variables were registered at hospitalization, except for the body mass index (BMI), which was measured on the day of CPX. Cardiorespiratory fitness was measured by CPX. The test was performed on a cycle ergometer using a ramp protocol aiming to reach maximal workload between 8 and 12 minutes. Blood pressure was measured at rest, after unloaded cycling for 2 minutes, at 3 and 6 minutes of cycling with increasing workload, and hereafter every 90 seconds during the rest of the test. The test was terminated if systolic blood pressure exceeded 160 mmHg. Cardiorespiratory fitness was defined as peak oxygen uptake and maximal workload. Change in sub-maximal variables was evaluated when assessable: ventilatory threshold (VT), defined as respiratory exchange ratio (RER) = 1.0,²⁰ and oxygen uptake efficiency slope (OUES), estimated as oxygen uptake divided by the logarithm

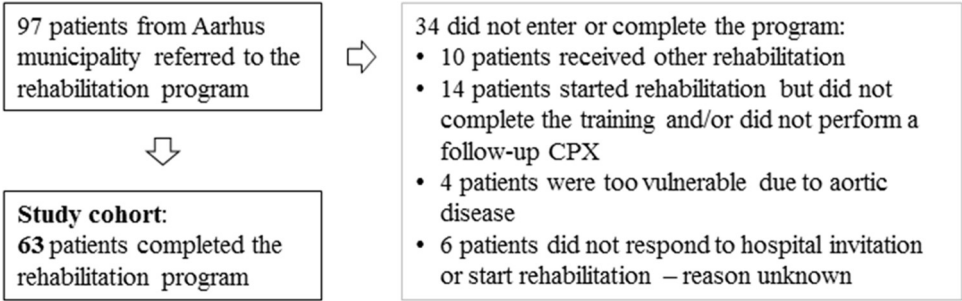


Figure 1. Flow chart of patients participating in a rehabilitation program in Denmark with blood pressure-guided exercise intensity restrictions for patients with thoracic aortic dissection or aneurysm, 2017-2023. Abbreviation: CPX, cardiopulmonary exercise test.

of minute ventilation.²¹ These were available for patients tested from May 2019 and onwards.

STATISTICAL ANALYSES

Patient data were entered in a Research Electronic Data Capture (REDCap) database hosted at AUH.²² Continuous variables were presented as mean ± SD or CI if normally distributed and median (IQR) if non-normally distributed. Categorical variables were described using proportions and compared by the χ2 test. Results were presented in groups of a) patients who were tested to exhaustion in both CPX and b) patients who were stopped by technicians in one or both CPX due to high blood pressure. Groups were compared using unpaired the *T* test or Wilcoxon Mann-Whitney test depending on data distribution. Changes from baseline to follow-up were analyzed by a paired *T* test or Wilcoxon signed-rank test as appropriate. A conventional *P* value of .05 was used for the determination of statistical significance. All analyses were performed using Stata MP version 18 (Stata Corp).

RESULTS

Overall, 97 patients were referred to the rehabilitation program at AUH. For different reasons, a third of the cohort did not start or complete the rehabilitation program (Figure 1). In total, 63 patients completed the rehabilitation program and were included in the study. Demographic and clinical characteristics are presented in Table 1.

The median (IQR) time to program initiation was 4.4 months (3, 6) after hospitalization. They participated in a median (IQR) of 17 training sessions (15, 24). Antihypertensive treatment was prescribed for 89% of the patients, and on average, they were prescribed a median (IQR) of 2 (1, 4) types of antihypertensive drugs when starting the program. During the program, the antihypertensive treatment was adjusted for one-third of the patients; the dose was increased for 12 patients (19%) and decreased for 7 patients (11%). 41 patients (65%) were stopped by technicians in either one or both CPX because of excessive systolic blood pressure readings. There was no difference between groups with respect to change in the antihypertensive dose from baseline to follow-up CPX (*P* = .77). Patients continuing CPX to exhaustion had a lower BMI than patients who were stopped, but no statistically significant differences were seen in other variables (Table 1). The patients had no change in body weight from baseline to follow-up in either group.

ADVERSE EVENTS

No major adverse events indicating disease progression or requiring hospitalization were reported in relation to CPX testing and exercise. Two patients reported light dizziness at the end of testing but recovered quickly.

CARDIORESPIRATORY FITNESS

Changes in cardiorespiratory fitness from baseline to follow-up are detailed in Tables 2 and 3. In the group consisting of subjects who performed both CPX tests to exhaustion, 13 (59%) reached RER ≥ 1.05. The maximum workload increased by 20.6 watt (95% CI, 13.0-28.3) equivalent to 19%, while peak oxygen uptake increased by 2.3 ml/kg/min (95% CI, 1.2-3.5) equivalent to 15% from baseline to follow-up. Furthermore, the OUES improved by 0.2 (95% CI, 0.06-0.4) corresponding to a 14% increase. Four patients were stopped before reaching VT at baseline testing, while five were stopped at the follow-up CPX. The 14 patients who reached VT in both tests showed an improvement in workload of 32 watt (95% CI, 13-51) and

Table 1

Demographic and Clinical Characteristics of Patients Participating in a Rehabilitation Program in Denmark with Blood Pressure-Guided Exercise Intensity Restrictions for Patients With Thoracic Aortic Dissection or Aneurysm, 2017-2023^a

	All Patients (N = 63)	CPX to Exhaustion (N = 22)	BP-limited ^b CPX (N = 41)	P Value
Male	42 (67%)	13 (59%)	29 (71%)	.35
Age, yr	61 ± 11	62 ± 10	60 ± 11	.40
BMI, kg/m ²	25.7 ± 4.0	24.0 ± 3.3	26.6 ± 4.0	.01
Connective tissue disease ^c	10 (19%)	2 (11%)	8 (24%)	.22
Hypertension	42 (71%)	14 (67%)	28 (74%)	.56
Chronic obstructive pulmonary disease	2 (3%)	1 (5%)	1 (2%)	.58
Diabetes mellitus	2 (3%)	1 (5%)	1 (2%)	.58
Left ventricular ejection fraction				
30-50%	11 (17%)	5 (23%)	6 (15%)	
<30%	4 (6%)	3 (14%)	1 (2%)	.27
Type of aortic disease				
Dissection, type A	26 (41%)	7 (32%)	19 (46%)	
Dissection, type B	13 (21%)	7 (32%)	6 (15%)	
Dilatation/aneurysm	24 (38%)	8 (36%)	16 (39%)	.25
Treatment				
Aortic replacement	51 (81%)	16 (73%)	35 (85%)	.22
Valve replacement	25 (40%)	9 (40%)	16 (39%)	.88
Coronary artery bypass grafting	3 (5%)	2 (9%)	1 (2%)	.28
Other open thoracic surgery ^d	3 (5%)	1 (5%)	2 (5%)	1.00
Aortic stenting	8 (13%)	2 (9%)	6 (15%)	.70
Medical treatment	4 (6%)	0 (0%)	4 (10%)	.28
Urgency of open thoracic surgery ^e				
Elective surgery	29 (55%)	13 (76%)	16 (44%)	
Subacute	4 (8%)	0 (0%)	4 (11%)	
Acute	12 (23%)	3 (18%)	9 (25%)	
Vital indication	8 (15%)	1 (6%)	7 (19%)	.16
EuroSCORE II ^f	2.9 (1.8, 5.8)	2.9 (1.5, 3.8)	3.1 (1.8, 6.4)	.40

Abbreviations: BMI, body mass index; BP, blood pressure; CPX, cardiopulmonary exercise test.
^aData are represented as n (%), mean ± SD if normally distributed, and median (IQR) if non-normally distributed. *P* value expresses differences between sub-groups.
^bCPX was terminated by technicians if systolic BP exceeded 160-180 mmHg.
^cConnective tissue disorders cover hereditary thoracic aortic conditions, vasculitis, aortitis, Marfan syndrome, and Danlos Ehlers.
^dOther surgery such as re-operation of earlier composite graft, debranching.
^eElective = planned and preventive surgery, subacute = must stay on hospital until surgery, acute = surgery required before the next working day from diagnosis, vital indication = need for external heart massage on the way to surgery or before onset of anesthesia.
^fEuroSCORE II: estimated risk of surgery on basis of comorbidity and other factors.

oxygen uptake of 2.9 ml/kg/min (95% CI, 1.0-4.8) at VT, a relative increase of 24% each.

In the group stopped by technicians in one or both CPX, 19 patients (46%) reached RER ≥ 1.05. The group improved

Table 2

Variables Estimated by CPX on Patients Participating in a Rehabilitation Program in Denmark With Blood Pressure-Guided Exercise Intensity Restrictions for Patients With Thoracic Aortic Dissection or Aneurysm Who Continued CPX to Exhaustion (N = 22), 2017-2023^a

	Baseline CPX	Follow-up CPX	Mean Difference	P Value
Rest phase				
Systolic BP, mmHg	124 ± 20	115 ± 16	-10 (-22 to 2)	.11
Diastolic BP, mmHg	83 ± 11	75 ± 9.7	-8 (-15 to -1)	.03
Submaximal effort	(n = 18)	(n = 17)	(n = 14)	
Workload at VT ^b , watt	89 (64, 105)	109 (86, 147)	32 (13-51)	<.01
VO ₂ at VT ^b , mL/kg/min	15.6 ± 4.6	18.4 ± 3	2.9 (1.0-4.8)	<.01
Maximum effort				
Maximum workload, watt	112 (76, 160)	139 (94, 174)	20.6 (13.0-28.3)	<.01
Maximum workload, % of predicted	107 (75, 123)	124 (103, 143)	17 (10-25)	<.01
Peak VO ₂ , mL/kg/min	19.5 ± 6.2	21.9 ± 5.7	2.3 (1.2-3.5)	<.01
Peak VO ₂ , % of predicted	78.0 ± 23	91 ± 21	12 (6-18)	<.01
Respiratory exchange ratio	1.11 ± 0.12	1.11 ± 0.12	0.002 (-0.10 to 0.05)	.93
HR, beats/min	119 ± 24	118 ± 23	-2 (-7 to 4)	.55
HR, % of predicted	75 ± 14	75 ± 14	0.6 (-0.2 to 4)	.72
Oxygen pulse, mL/beat	12.6 ± 4.6	14.5 ± 4.8	2.2 (1.1-3.4)	<.01
Oxygen pulse, % of predicted	106 ± 30.4	127 ± 42	21 (7-34)	<.01
Systolic BP, mmHg	154 ± 22	152 ± 25	-2 (-10 to 7)	.70
Diastolic BP, mmHg	83 ± 14	76 ± 12	-7 (-11 to -2)	<.01
VE, L/min	49 (39, 77)	64 (45, 87)	5.5 (0.3-10.6)	.03
VE, % of predicted	66 ± 23	73 ± 19	7 (2-13)	.01
VE/VCO ₂ slope	30.5 ± 6.1 ^c	30.7 ± 3.9 ^c	0.2 (-1.8 to 2.3) ^c	.83
VO ₂ /watt	9.2 ± 1.9 ^c	9.2 ± 1.04 ^c	0.04 (-0.9 to 1.0) ^c	.94
OUES	1.5 (1.4, 2.4) ^c	1.9 (1.4, 2.7) ^c	0.2 (0.06-0.40) ^c	.01

Abbreviations: BP, blood pressure; CPX, cardiopulmonary exercise test; HR, heart rate; OUES, oxygen uptake efficiency slope; VCO₂, carbon dioxide production; VO₂, oxygen uptake; VE, minute ventilation; VT, ventilatory threshold.

^aBaseline and follow-up data are presented as mean ± SD when normally distributed and median (IQR) and when not-normally distributed. Differences between baseline and follow-up are presented as mean (95% CI).

^bVT estimated by respiratory exchange ratio = 1.0.

^cData are only available for 15 participants.

OUES by 0.3 (95% CI, 0.15-0.46) equivalent to 14%. The 26 patients who continued both CPX until VT showed an improvement in workload of 17 watt (95% CI, 9-24) and oxygen uptake by 1.8 mL/kg/min (95% CI, 0.6-2.9) at VT, a relative increase of 18% and 11%, respectively. Six of the patients who were stopped before reaching VT had missing data on OUES.

When comparing the two groups at baseline, the patients who performed CPX to exhaustion had a lower mean BMI (24.0 ± 3.3 vs. 26.6 ± 4.0 kg/m², *P* = .01) and OUES (median 1.5 [IQR 1.4, 2.4] vs. 2.2 [IQR 1.9, 2.5], *P* = .04) than patients who were stopped by technicians.

DISCUSSION

Recognizing that high blood pressure strains the aortic wall, it is logical to engineer exercise prescriptions based on CPX testing and evaluation of how quickly the blood pressure rises for the individual patient. Attention must be given to risk stratification, particularly among aortic dissection patients, to avoid any undue or excessive stress on the aortic wall, when recommending maximum of systolic blood pressure during exercise. There were no major adverse events as previously reported by similar studies on this subject.^{5,13,23,24}

Among patients attending rehabilitation with blood pressure-guided exercise intensity, the majority of patients improved workload and oxygen uptake at VT or peak level. The only statistically significant differences between groups were a lower baseline BMI and higher change in OUES among patients performing CPX to exhaustion.

When comparing the results to other studies, notably only two have evaluated change in exercise capacity after completion of rehabilitation.^{17,18} One study was a case-control study by Fuglsang et al. including 10 patients with type A aortic dissection.¹⁸ In a similar fashion, an improved peak oxygen uptake was observed from 25.3 ± 7.9 to 28.6 ± 8.4 mL/kg/min (*P* = .001). The study was carried out at the same university hospital as the current study but at a time period (2010-2014) when referral for rehabilitation was in its infancy and without any blood pressure restrictions during exercise. These patients showed a higher peak oxygen uptake compared to patients from the current study. However, only 10 of the referred 60 patients referred to rehabilitation performed a CPX to exhaustion (five were excluded due to incomplete testing), which raises questions about the criteria for allowing CPX or exercise. The other noted study was a cohort analysis conducted by Corone

Table 3

Variables Estimated by CPX on Patients Participating in a Rehabilitation Program in Denmark With Blood Pressure-Guided Exercise Intensity Restrictions for Patients With Thoracic Aortic Dissection or Aneurysm Who Performed Blood Pressure-Limited CPX (N = 41), 2017-2023^{a,b}

	Baseline CPX	Follow-up CPX	Mean Difference	P Value
Rest phase				
Systolic BP, mmHg	129 ± 16	129 ± 14	−1 (−7 to 4)	.57
Diastolic BP, mmHg	83 ± 13	80 ± 11	−2 (−7 to 3)	.42
Submaximal effort	(n = 31)	(n = 31)	(n = 26)	
Workload at VT ^c , watt	99 (77, 148)	106 (83, 161)	17 (9-24)	<.01
VO ₂ at VT ^c , mL/kg/min	16.4 ± 5	18.3 ± 7	1.8 (0.6-2.9)	<.01
Maximum effort				
Maximum workload, watt	117 (73, 153)	131 (105, 173)	19.4 (10-29)	<.01
Maximum workload, % of predicted	88 ± 29	104 ± 31	16 (6-26)	<.01
Peak VO ₂ , mL/kg/min	17.7 (15.4, 23.8)	18.1 (15.3, 24.8)	1.3 (0.3-2.4)	.02
Peak VO ₂ , % of predicted	78 ± 18	84 ± 21	6 (1-10)	.01
Respiratory exchange ratio	1.06 ± .13	1.07 ± .11	0.02 (−0.02 to 0.06)	.41
HR, beats/min	118 ± 24	121 ± 25	4 (−2 to 9)	.19
HR, % of predicted	75 ± 13	76 ± 14	1.3 (−1 to 4)	.30
Oxygen pulse, mL/beat	13.6 ± 4.0	14.8 ± 4.4	1.1 (0.4-1.8)	<.01
Oxygen pulse, % of predicted	108 ± 28.2	115 ± 28	5 (−0.9 to 12)	.09
Systolic BP, mmHg	174 ± 19	179 ± 22	4 (−4 to 13)	.33
Diastolic BP, mmHg	88 ± 15	82 ± 12	−7 (−13 to −2)	.01
VE, L/min	60 (42, 73)	57 (45, 70)	1.7 (−4.9 to 8.3)	.60
VE, % of predicted	65 ± 22	67 ± 22	2 (−5 to 9)	.52
VE/VCO ₂ slope	30 ± 5.5 ^d	28.3 ± 5.1 ^e	−1.8 (−3.5 to 0.02) ^d	.053
VO ₂ /watt	10.1 ± 2.8 ^d	9.4 ± 1.2 ^e	−0.6 (−1.9 to 0.6) ^d	.31
OUES	2.2 ± 0.7 ^d	2.4 ± 0.8 ^e	0.3 (0.15-0.46) ^d	<.01

Abbreviations: BP, blood pressure; CPX, cardiopulmonary exercise test; HR, heart rate; OUES, oxygen uptake efficiency slope; VCO₂, carbon dioxide production; VO₂, oxygen uptake; VE, minute ventilation; VT, ventilatory threshold.

^aBaseline and follow-up data are presented as mean ± SD when normally distributed and median (IQR) and when not-normally distributed. Differences between baseline and follow-up are presented as mean (95% CI).

^bCPX stopped by technicians if BP exceeded 160-180 mmHg.

^cVT estimated by respiratory exchange ratio = 1.0.

^dData are only available for 28 participants.

^eData are only available for 34 participants.

et al. and included 33 patients with type A aortic dissection from nine different cardiac rehabilitation centers in France.¹⁷ The thirteen patients who were tested on bicycle ergometer before and after rehabilitation also showed an increase in maximal workload from 62.7 ± 11.8 to 91.6 ± 16.5 watts ($P = .002$). Interestingly, the baseline and follow-up workload were significantly lower compared to the results in our study. Corone et al. did not describe any blood pressure termination criteria, or other reasons, for terminating the test, and it is unclear whether this could explain the difference in work capacity, or whether the patients simply had lower cardiorespiratory fitness. Both of the above-mentioned studies were limited by small sample sizes, and comparisons are further complicated by unclear inclusion criteria and CPX protocols.

Our study did not include a control group, and one could also speculate whether the improved cardiorespiratory fitness was a mere post-surgery recovery. Norton et al. investigated this thesis by a cohort study including 64 patients with aortic disease.²³ The patients were tested at three and 15 months after open repair without any intervention in between. They found

no significant change in cardiorespiratory fitness in 21 patients with type A aortic dissection (from 18.3 to 19.1 mL/min/kg, $P = .23$), but an improved peak oxygen uptake (from 20.2 to 22.4 mL/kg/min, $P = .0003$) in 43 patients with thoracic ascending aortic aneurysms. These patients achieved the same improvement in oxygen uptake 15 months after surgery as the patients in the present study did 8.6 months after surgery. A CPX termination criterion defined as systolic blood pressure ≥ 180 mmHg was noted, although this reportedly did not occur. To some extent, one would infer that cardiorespiratory fitness improves as time from surgery passes, and the effect of a rehabilitation program on cardiorespiratory fitness is therefore difficult to quantify. Likewise, the economical onus is difficult to quantify, as facilities and resources have been in place for many years for any referred cardiovascular patient. Indeed, future studies regarding improvement in physical capacity and quality of life, as well as the long-term costs and benefits of rehabilitation, would be of great value.

CHALLENGES IN EVALUATING CPX VALUES

In general, evaluations of changes in cardiorespiratory fitness are complex. One particular limitation in this study is

that many patients were unable to perform CPX to exhaustion due to blood pressure restrictions. Thus, changes in peak outcomes were limited to one-third of the cohort. Efforts were made to complement the evaluation with analyses on submaximal levels using VT. Estimating VT by methods such as V-slope calculations were deficient, as the course of the respiratory curves were often incomplete in the submaximal tests, and estimates of VT were often implausibly low. Instead, the use of RER = 1.0 was employed, as this method was more reliable under these circumstances.

Regardless of the method used, VT expressed as a percentage of maximum effort exhibits significant variability. In sedentary individuals, VT occurs at 50-60% of peak oxygen uptake but increases with age, with normal values ranging from 35 to 80% of peak oxygen uptake.²⁰ *Post hoc* analysis on patients performing CPX to exhaustion in baseline CPX showed that VT occurred at 78% of peak oxygen uptake, ranging from 47% to 97%. Thus, the exact level of intensity by CPX termination and recommended intensity of exercise is unknown when terminated by technicians. Optimally, exercise intensity should be estimated as percentage of maximal oxygen uptake to calculate individual zones of exercise intensity which requires performing CPX to exhaustion.

Another challenge when evaluating changes in CPX values were changes in antihypertensive treatment. The variation in blood pressure increases may be multifactorial: poor compliance of antihypertensive medication, white coat syndrome, or even refractory responses to the recommended therapy. A complicating factor is the potential dampening effect of antihypertensive medication on physical exertion levels.^{25,26} Therefore, changes in antihypertensive treatment present a possible confounder when evaluating changes in cardiorespiratory fitness. However, there were more patients who increased the dose (19%) than patients who decreased their dose (11%), perhaps suggesting that the improvements registered in the current study could be underestimated rather than overestimated.

STRENGTHS AND LIMITATIONS

Data were recorded prospectively but collected and analyzed retrospectively, and therefore, some values in relation with CPX testing were not available for all patients. The criteria for exclusion were rather minimal, which strengthens the representativeness of the results. For example, patients were not excluded based on low RER at exhaustion, as they still provided valuable information on physical capacity. Some patients stopped their test before reaching VT or 3.5 metabolic equivalents (equating moderate walking pace) because of general exhaustion or fatigued leg muscles, somewhat indicative of poor cardiorespiratory fitness and muscle strength. This is not surprising, since the cohort also included patients who had undergone a long hospital stay. Provided their blood pressure limit adherence could be maintained, they were not restricted from cardiorespiratory exercise and testing.

Another strength to this analysis is the long inclusion period (2017-2023). This did not, unfortunately, equate with a cohort large enough for important subanalyses. It should be noted that the study was also interrupted by the coronavirus disease-2019 pandemic. Efforts were made, however, to provide exercise-related video consultations.

CONCLUSION

In general, patients attending a rehabilitation program with blood pressure-guided exercise intensity experienced

improved oxygen uptake and workload. One-third of the patients were able to perform both CPX studies to exhaustion without exceeding blood pressure restrictions and had little to no restrictions related to cardiopulmonary exercise. Only few minor events of light dizziness occurred at the end test, and the rehabilitation program with blood pressure-guided exercise intensity was considered a safe way of managing cardiorespiratory fitness among patients with aortic disease.

Whether or not initiating rehabilitation could have an effect on the patient quality of life is uncertain, and how rehabilitation with blood pressure-guided intensity may impact physical and mental health is still a subject for further investigation. Knowledge about benefits and risks of exercise in this patient group are tenuous, and the impact of patient education and mental support could play a more important role.

REFERENCES

1. Isselbacher EM, Preventza O, Hamilton BJ, et al. 2022 ACC/AHA guideline for the diagnosis and management of aortic disease: a report of the American heart association/American college of cardiology joint committee on clinical practice guidelines. *Circulation*. 2022;146(24):e334-e482. doi: 10.1161/CIR.0000000000001106.
2. Melvinsdottir IH, Lund SH, Agnarsson BA, Sigvaldason K, Gudbjartsson T, Geirsson A. The incidence and mortality of acute thoracic aortic dissection: results from a whole nation study. *Eur J Cardiothorac Surg*. 2016;50(6):1111-1117. doi: 10.1093/ejcts/ezw235.
3. Smedberg C, Steuer J, Leander K, Hultgren R. Sex differences and temporal trends in aortic dissection: a population-based study of incidence, treatment strategies, and outcome in Swedish patients during 15 years. *Eur Heart J*. 2020;41(26):2430-2438. doi: 10.1093/eurheartj/ehaa446.
4. Howard DP, Banerjee A, Fairhead JF, Perkins J, Silver LE, Rothwell PM. Population-based study of incidence and outcome of acute aortic dissection and premorbid risk factor control: 10-year results from the Oxford Vascular Study. *Circulation*. 2013;127(20):2031-2037. doi: 10.1161/CIRCULATIONAHA.112.000483.
5. Delsart P, Delahaye C, Devos P, et al. Prognostic value of aerobic capacity and exercise oxygen pulse in post-aortic dissection patients. *Clin Cardiol*. 2021;44(2):252-260. doi:10.1002/clc.23537.
6. Ehrman JK, Fernandez AB, Myers J, Oh P, Thompson PD, Keteyian SJ. Aortic aneurysm: diagnosis, management, exercise testing and training. *J Cardiopulm Rehabil Prev*. 2020;40(4):215-223. doi: 10.1097/HCR.0000000000000521.
7. Hatzaras I, Tranquilli M, Coady M, Barrett PM, Bible J, Eleftheriades JA. Weight lifting and aortic dissection: more evidence for a connection. *Cardiology*. 2007;107(2):103-106. doi: 10.1159/000094530.
8. Mayerick C, Carré F, Eleftheriades J. Aortic dissection and sport: physiologic and clinical understanding provide an opportunity to save young lives. *J Cardiovasc Surg (Torino)*. 2010;51(5):669-681.
9. Jönsson M, Berg SK, Missel M, Palm P. Am I going to die now? Experiences of hospitalisation and subsequent life after being diagnosed with aortic dissection. *Scand J Caring Sci*. 2021;35(3):929-936. doi: 10.1111/scs.12912.
10. Schachner T, Garrido F, Bonaros N, Krapf C, Dumfarth J, Grimm M. Factors limiting physical activity after acute type A aortic dissection. *Wien Klin Wochenschr*. 2019;131(7-8):174-179. doi: 10.1007/s00508-018-1412-2.
11. Eranki A, Wilson-Smith A, Williams ML, Saxena A, Mejia R. Quality of life following surgical repair of acute type A aortic dissection: a systematic review. *J Cardiothorac Surg*. 2022;17(1):118. doi: 10.1186/s13019-022-01875-x.
12. Ilonzo N, Taubenfeld E, Yousif MD, et al. The mental health impact of aortic dissection. *Semin Vasc Surg*. 2022;35(1):88-99. doi:10.1053/j.semvasc.2022.02.005.
13. Hornsby WE, Norton EL, Fink S, et al. Cardiopulmonary exercise testing following open repair for a proximal thoracic aortic aneurysm or dissection. *J Cardiopulm Rehabil Prev*. 2020;40(2):108-115. doi:10.1097/HCR.0000000000000446.

14. Cornelissen VA, Smart NA. Exercise training for blood pressure: a systematic review and meta-analysis. *J Am Heart Assoc.* 2013;2(1):e004473. doi: 10.1161/JAHA.112.004473.
15. Gibson C, Nielsen C, Alex R, et al. Mild aerobic exercise blocks elastin fiber fragmentation and aortic dilatation in a mouse model of Marfan syndrome associated aortic aneurysm. *J Appl Physiol (1985).* 2017;123(1):147-160. doi:10.1152/japplphysiol.00132.2017.
16. Aicher BO, Zhang J, Muratoglu SC, et al. Moderate aerobic exercise prevents matrix degradation and death in a mouse model of aortic dissection and aneurysm. *Am J Physiol Heart Circ Physiol.* 2021;320(5):H1786-h801. doi:10.1152/ajpheart.00229.2020.
17. Corone S, Iliou MC, Pierre B, et al. French registry of cases of type I acute aortic dissection admitted to a cardiac rehabilitation center after surgery. *Eur J Cardiovasc Prev Rehabil.* 2009;16(1):91-95. doi:10.1097/HJR.0b013e32831fd6c8.
18. Fuglsang S, Heiberg J, Hjortdal VE, Laustsen S. Exercise-based cardiac rehabilitation in surgically treated type-A aortic dissection patients. *Scand Cardiovasc J.* 2017;51(2):99-105. doi: 10.1080/14017431.2016.1257149.
19. Scherr J, Wolfarth B, Christle JW, Pressler A, Wagenpfeil S, Halle M. Associations between Borg's rating of perceived exertion and physiological measures of exercise intensity. *Eur J Appl Physiol.* 2013;113(1):147-155. doi: 10.1007/s00421-012-2421-x.
20. American Thoracic Society/American College of Chest Physicians. ATS/ACCP Statement on cardiopulmonary exercise testing. *Am J Respir Crit Care Med.* 2003;167(2):211-277. doi:10.1164/rccm.167.2.211.
21. Akkerman M, van Brussel M, Hulzebos E, Vanhees L, Helders PJ, Takken T. The oxygen uptake efficiency slope: what do we know? *J Cardiopulm Rehabil Prev.* 2010;30(6):357-373. doi: 10.1097/HCR.0b013e3181ebf316.
22. Harris PA, Taylor R, Minor BL, et al. The REDCap consortium: building an international community of software platform partners. *J Biomed Inform.* 2019;95:103208. doi:10.1016/j.jbi.2019.103208.
23. Norton EL, Wu KH, Rubenfire M, et al. Cardiorespiratory fitness after open repair for acute type a aortic dissection - a prospective study. *Semin Thorac Cardiovasc Surg.* 2022;34(3):827-839. doi:10.1053/j.semtcvs.2021.05.017.
24. Delsart P, Maldonado-Kauffmann P, Bic M, et al. Post aortic dissection: gap between activity recommendation and real life patients aerobic capacities. *Int J Cardiol.* 2016;219:271-276. doi:10.1016/j.ijcard.2016.06.026.
25. Loprinzi PD, Loenneke JP. The effects of antihypertensive medications on physical function. *Prev Med Rep.* 2016;3:264-269. doi:10.1016/j.pmedr.2016.03.009.
26. George CJ, Hall CB, Weiss EF, Verghese J, Neptune E, Abadir P. Centrally acting ACE inhibitor use and physical performance in older adults. *J Frailty Aging.* 2023;12(2):103-108. doi: 10.14283/jfa.2023.10.