Preoperative Supervised Exercise Improves Outcomes After Elective Abdominal Aortic Aneurysm Repair

A Randomized Controlled Trial

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Objective: The aim of the study was to assess the impact of a preoperative medically supervised exercise program on outcomes after elective abdominal aortic aneurysm (AAA) repair.

Background: Functional capacity is an important predictor of postoperative outcomes after elective AAA repair. Improving patients' preoperative fitness with exercise has the potential to positively influence recovery.

Methods: A randomized controlled trial was performed at a tertiary vascular unit. Patients scheduled for open or endovascular AAA repair were randomized to either 6 weeks of preoperative supervised exercise or standard treatment using sealed envelopes. The primary outcome measure was a composite endpoint of cardiac, pulmonary, and renal complications. Secondary outcome measures were 30-day mortality, lengths of hospital and critical care stay, Acute Physiology and Chronic Health Evaluation II (APACHE II) scores, reoperation, and postoperative bleeding.

Results: One hundred twenty-four patients were randomized (111 men, mean [SD] age 73 [7] y). Fourteen patients sustained postoperative complications in the exercise group (22.6%), compared with 26 in the nonexercise group (41.9%; $P = 0.021$). Four patients (2 in each group) died within the first 30 postoperative days. Duration of hospital stay was significantly shorter in the exercise group (median 7 [interquartile range 5–9] vs 8 [interquartile range 6–12.3] d; $P = 0.025$). There were no significant differences between the groups in the length of critical care stay ($P = 0.845$), APACHE II scores ($P = 0.256$), incidence of reoperations ($P = 1.000$), or postoperative bleeding ($P = 0.343$).

Conclusions: A period of preoperative supervised exercise training reduces postoperative cardiac, respiratory, renal complications, and length of hospital stay in patients undergoing elective AAA repair.

Keywords: abdominal aortic aneurysm, exercise, outcomes, recovery

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M ore than 4000 elective abdominal aortic aneurysm (AAA) repairs are performed in the United Kingdom each year.[1]

Changes in multidisciplinary perioperative management of patients undergoing elective AAA repair, guided by a national quality improvement program, have reduced postoperative mortality rates to below 3% over the past 5 years.[2–5] Importantly, however, postoperative complications, which are directly related to early recovery, long-term survival, and overall costs of health care,[6–8] are not routinely reported.

Major surgical interventions are associated with a variety of perioperative cardiopulmonary, neuroendocrine, and metabolic changes, resulting in a stress response generally due to an increase in tissue oxygen demands. The patients' ability to withstand this stress depends primarily on their cardiopulmonary fitness. Patients with vascular disease, including AAA, generally have lower fitness levels when compared with age-matched controls, owing to a history of cigarette smoking, cardiopulmonary comorbidities, and a sedentary lifestyle. Impaired aerobic fitness is directly related to postoperative morbidity and mortality; thus interventions to improve preoperative patient fitness have the potential to be beneficial.[9,10]

Exercise training can improve the parameters of cardiopulmonary fitness in older patients,[11,12] and in patients with AAA.[13–15] Two literature reviews suggest that preoperative exercise has the potential to reduce the postoperative morbidity in surgical patients,[16] and specifically in those undergoing AAA repair.[17] Arthur et al[18] showed that a perioperative intervention, including a defined exercise program, reduced postoperative hospital stay in patients undergoing coronary artery bypass surgery. To date, there are no studies to assess for the effect of preoperative exercise interventions on postoperative outcomes in patients undergoing AAA repair.

The aim of this study was to assess the effect of a hospital-based, preoperative, medically supervised exercise intervention on postoperative outcomes after elective AAA repair. The hypothesis was that exercise-associated improvements in cardiorespiratory function would enhance patients' ability to withstand the perioperative stress associated with AAA repair, reducing complications and facilitating more rapid recovery.

METHODS

Study Design and Settings

We undertook a single-center, prospective, randomized controlled trial (RCT) at a tertiary vascular surgical center, providing specialized services for a catchment area population of approximately 1.2 million.

Patients

Consecutive patients scheduled for elective open aneurysm repair (OAR) or endovascular repair (EVAR) were identified via the waiting lists or the vascular outpatient clinics, and directly approached with information and contact details explaining the procedures of the trial from September 2009 to January 2014.

Patients older than 18 years, with AAA $\geq$5.5 cm in maximum diameter, who were able to give informed written consent, were invited to participate in the trial. Exclusion criteria included the presence of factors that may limit exercise participation, such as severe musculoskeletal disorders, or those requiring expedited or urgent aneurysm repair. Patients with thoracic aortic aneurysms were also excluded.

The trial was registered at www.clinicaltrials.gov (NCT01062594) and was approved by the North East Yorkshire and Humber National Research Ethics Service, and by the local research and development department. All participating patients gave written informed consent, and the trial was conducted in accordance with the principles of Good Clinical Practice stated in the Declaration of Helsinki.

Randomization and Study Interventions

Randomization was performed using opaque, sealed, identical envelopes containing the treatment allocation, according to a computer-generated sequence prepared by an independent professional. Patients were randomized into one of the 2 groups—the exercise (intervention) group or the standard treatment (control) group. The randomization process was witnessed by an independent research professional and was carried out during the initial visit after obtaining informed consent, but before preoperative assessments and interventions. Clinicians including consultant surgeons, anesthetists, department's medical and nursing staff, and interventional radiologists were blinded to patient group allocation. This was ensured by explaining the importance of blinding to all study participants and performing all study procedures in the separate Academic department.

Patients allocated to the intervention arm, that is, exercise, were provided with instructions and a time table to join hospital-based exercise classes, carried out 3 times a week, for 1-hour duration, in the physiotherapy gym. The scheduled exercise program was for a total of 6 consecutive weeks immediately preceding the intended operation date. Each exercise class consisted of the following: 5-minute warm up and stretching, cycle ergometer against moderate resistance for 2 minutes, heel-raise repetitions for 2 minutes, knee extensions against resistance repetitions for 2 minutes, dumbbells' biceps/arm curls repetitions for 2 minutes, step-up lunges repetitions for 2 minutes, knee bends (bodyweight) repetitions for 2 minutes, and 5 minutes for cool down and stretching. Between each of the exercise stations, patients either walked around the gym or on a treadmill, or rested for 2 minutes before moving on to the next exercise. Patients allocated to the control group were clearly instructed to continue with their normal lifestyle, and avoid any additional, unsupervised exercises.

Operative interventions were either open or endovascular AAA repair for all patients. These were all carried out by the vascular surgical and interventional radiology consultants at the study center. All open repairs were performed using a transperitoneal approach via a transverse abdominal incision. Remote ischemic preconditioning techniques were not used. All patients were admitted the night before the scheduled interventions and transferred postoperatively to either a high-dependency unit (HDU) or to the intensive care unit (ITU) for observation.

Assessments and Outcome Measures

All participants underwent an initial baseline assessment aimed at establishing a preoperative risk profile, including a complete medical history and clinical examination, body mass index (BMI) measurement, resting electrocardiogram, a symptom-limited treadmill cardiopulmonary exercise test (CPET), and blood tests such as full blood count, urea, and serum electrolytes. The parameters recorded during CPET were as follows: peak oxygen consumption (VO_2 peak), the ventilatory anaerobic threshold (AT), total time of exercise on the treadmill, and the ventilator equivalents for oxygen and carbon dioxide (V_E/VO_2 and V_E/VCO_2, respectively).

Cardiac risk assessment was done by a cardiac radionuclide ventriculography to assess cardiac function and left ventricular ejection fraction (LVEF), and by measurement of serum N-terminal pro-B-natriuretic peptide (NT-proBNP). During the baseline assessment visit, patients were also asked to report any impairment on their mobility, usual activities, or ability to self-care.

In the immediate postoperative period, patients' observations on HDU were assessed hourly or more frequently as indicated. Blood tests (full blood count, urea, and serum electrolytes) were performed on a daily basis for the first 3 days, and arterial blood gases were sampled during the first 6 hours postoperatively and repeated when indicated. After discharge from HDU to the vascular ward, observations were performed every 4 to 6 hours.

The primary outcome measure was a composite endpoint of postoperative cardiac, pulmonary, and renal complications.

Cardiac complications were defined as the occurrence of postoperative:

1. Acute myocardial infarction; 2 out of 3 criteria: characteristic ischemic symptoms lasting >20 min, ECG changes: ST elevation, new persistent T-wave inversion, Left Bundle Branch Block, or new ST-segment depression, which persists for >24 hours and a positive troponin T, that is, >0.10 ng/mL
2. New-onset arrhythmia: prolonged (>1 h), or requiring therapy
3. Congestive heart failure defined as both clinical and radiological changes
4. Use of inotropic support for at least 12 hours
5. The development of unstable angina.

Pulmonary complications were defined as:

1. Pneumonia defined as an appropriate clinical history with either a positive sputum culture or infiltrate seen on chest radiograph)
2. Mechanical ventilation in the postoperative period (>48 h)
3. Unplanned reintubation after surgery
4. Pulmonary embolism as determined by a positive computed tomography (CT) pulmonary angiogram.

Renal complications were defined as:

1. Acute renal failure, requiring dialysis or ultrafiltration postop only
2. Renal insufficiency, a >20% decrease in creatinine clearance postoperatively

All complications were prospectively recorded and actively sought during hospital stay and the duration of follow-up.

Secondary outcome measures included the following: length of hospital stay in days, length of HDU or ITU stay in days, APACHE II scores recorded at HDU/ITU admission, the occurrence of systemic inflammatory response syndrome (SIRS), 30-day mortality, postoperative bleeding requiring reoperation or transfusion of more than 4 units of blood products within 72 hours, and the need for reoperation.

A subgroup of patients underwent a repeat CPET on the last preoperative day. Those were participants from both study groups who agreed to undertake an additional preoperative test. The same fitness parameters were recorded to assess for any changes in aerobic fitness parameters.

Patients were followed up for 3 months after the date of discharge. Specific enquiries were made on general condition, mobility, dependence, and the occurrence of any of the above mentioned outcome measures after discharge from hospital.

Statistical Analysis

The trial's data were recorded and transcribed in a dedicated database (Microsoft Excel, Redmond, WA). This database was password-protected at all times and stored only on a secured, hospital-based, computer drive. A Statistical Package for the Social Sciences Program (SPSS) version 20 (IBM Corp., Armonk, NY) was used for statistical analysis. This analysis was done according to a standardized, prospectively determined protocol, with an intention-to-treat analysis.

A sample size calculation was performed based on the estimated incidence of postoperative composite cardiac, pulmonary, and renal complication rate of 30%.[6,19–22] An independent medical statistician calculated the sample size based on a power of 80% to detect a fall in the complication rate, from 30% to 10%, and a 5% significance level. The sample size was estimated at 62 patients in each group.

The loss to follow-up was estimated at 10%, thereby increasing the number of patients needed to 136 (68 patients in each group). Comparisons between the intervention group and the exercise group in terms of the primary outcome measures was estimated by chi-square test, including the calculation of relative risk reduction (RRR), absolute risk reduction (ARR), and the number needed to treat (NNT) statistics. The following formulas were used:

1. RRR = CER − EER/CER
2. ARR = CER − EER
3. NNT = 1/ARR

where, CER indicates the control (control group) event rate and EER the experimental (exercise group) event rate.

Comparisons between the 2 study groups at baseline were performed using the unpaired Student t test for parametric variables (normally distributed data) and the Mann-Whitney U test for non-parametric variables (non-normally distributed data). Cross-table methods (chi-square test of Fisher exact test) were used dichotomous categorical variables. These tests were also used for comparison between the 2 groups in terms of the secondary outcome measures. A per-protocol analysis for the primary outcome measures was also performed using chi-square test as appropriate.

To assess for changes in CPET parameters in patients who had 2 preoperative assessments, intragroup analysis of paired data (ie, before and after, for the same patient) were carried out using the nonparametric Wilcoxon rank test for all variables. A P value of less then 0.05 was considered statistically significant for all statistical analyses presented.

RESULTS

A total of 293 patients were assessed for eligibility; 157 patients were excluded because they declined to participate, or did not meet the inclusion criteria. One hundred thirty-six patients were randomized in the 2 study groups between September 2009 and January 2014 (Supplemental Digital Figure – CONSORT Flowsheet, http://links.lww.com/SLA/A945).

Twelve patients—6 from each group—withdrew from the study before operative interventions as their procedures were cancelled or postponed. No patients were lost to follow-up. Sixty-two patients from each group were included in the final analysis. The 2 study groups were well matched in terms of age, sex, baseline comorbidities, medications, baseline aerobic fitness parameters measured by CPET, LVEF, and serum NT-proBNP measurements (Table 1). At baseline, 50 patients (40.3%) reported some degree of impairment to mobility (27 were randomized in the exercise group and 23 in the control group; $P = 0.464$). All 124 patients included in analysis lived at their own homes.

Attendance of the exercise classes varied within the exercise group. Eleven patients randomized to exercise did not attend any classes, whereas 18 patients attended all the scheduled classes. Attendance was associated with a significant difference in primary outcome event rate (Table 2). Patients randomized to exercise, who attended more than 75% of the scheduled exercise classes, had a significantly lower incidence of postoperative complications (3 endpoints in 32 patients; 9.4%) compared with those who attended less than 75% (7 endpoints recorded in 19 patients; 36.9%) ($P = 0.020$).

Overall, the primary endpoint of postoperative cardiac, pulmonary, and/or renal complications was significantly reduced in the exercise group (n = 14, 22.6%) compared with the control group (n = 26, 41.9%) ($P = 0.021$). RRR was 46.1% and the NNT was 5 (95% confidence interval [CI], 3−35). The recorded postoperative complications are summarized in Table 3. The largest effect of intervention was seen for isolated cardiac (5 in the exercise group [8.1%] vs 14 in the control group [22.6%]; $P = 0.025$) and renal complications (4 in the exercise group [6.5%] vs 13 in the control group [21.0%]; $P = 0.019$). Twenty pulmonary complications were recorded (7 in the exercise group and 13 in the control group; $P = 0.143$).

A total of 46 patients underwent EVAR (23 from each of the study groups). Two out of 23 patients in the exercise group had a recorded primary endpoint (8.7%) in comparison to 8 endpoints recorded in the control group (34.8%; $P = 0.032$). On the contrary, of those undergoing open repair (39 patients in each of the 2 study groups), 12 from those randomized to exercise had a recorded endpoint (30.8%), compared with 18 from the control group (46.2%; $P = 0.163$).

A per-protocol analysis showed that out of the 51 patients who attended exercise, 10 patients developed a primary endpoint (19.6%). For the remaining 73 patients who did not exercise, 30 patients developed an endpoint (41.1%; $P = 0.012$).

In terms of secondary outcome measures, patients in the exercise group had a shorter hospital stay (median 7.0, interquartile range [IQR] 5.0−9.0 d vs median 8.0, IQR 6.0−12.3 d; $P = 0.025$). There were no other statistically significant differences between the 2 groups in any of the remaining secondary outcome measures (Table 4). Four patients (3.2%) died within 30 days of surgery in this study (2 from each study group; $P = 1.000$). Three patients died in hospital (2 from myocardial infarction and 1 from respiratory failure) and 1 patient died having suffered a stroke after hospital discharge.

Forty-eight patients completed their 2 preoperative CPET assessments (CPET 1 and CPET 2): 33 patients in the exercise group, and 15 in the control group. The main parameters of aerobic fitness (VO_2 peak, AT, and total exercise time) significantly improved in those who exercised, whereas no significant changes were seen in those who did not. The changes in CPET parameters for both groups of patients are presented in Table 5.

At the end of follow-up, 18 patients (30.0%) from the exercise group reported some degree of impairment to mobility compared with 27 patients (45.0%) from the control group ($P = 0.090$).

No adverse events were recorded during preoperative assessments or exercise training. All, but 1 patient, were discharged from hospital to their own homes. This patient was discharged to an

TABLE 1. Baseline Demographics of 2 Study Groups

Variables	Total (n = 124)	Exercise Group (n = 62)	Control Group (n = 62)	P
Age*	73.4 (7.2)	73.8 (6.5)	72.9 (7.9)	0.519§
Female sex (no.)‡	13 (10.5%)	6 (9.7%)	7 (11.3%)	0.769||
EVAR‡	46 (37.1%)	23 (37.1%)	23 (37.1%)	1.000||
Hypertension‡	88 (71.0%)	45 (72.6%)	43 (69.4%)	0.692||
CAD‡	47 (37.9%)	24 (38.7%)	23 (37.1%)	0.853||
Hyperlipidemia‡	52 (41.9%)	27 (43.5%)	25 (40.3%)	0.716||
History of smoking‡	117 (94.4%)	60 (96.8%)	57 (91.9%)	0.243||
Current smokers‡	39 (31.5%)	18 (29.0%)	21 (33.9%)	0.562||
Previous smokers‡	78 (62.9%)	42 (67.7%)	36 (51.1%)	0.309||
Never smoked‡	7 (5.6%)	2 (3.2%)	5 (8.1%)	0.272**
Peripheral arterial disease‡	17 (13.7%)	9 (14.5%)	8 (12.9%)	0.794
Diabetes‡	13 (10.5%)	4 (6.5%)	9 (14.5%)	0.143||
Cerebrovascular disease‡	21 (16.9%)	10 (16.1%)	11 (17.7%)	0.811||
COPD‡	41 (33.1%)	18 (29.0%)	23 (37.1%)	0.340||
High serum creatinine‡	25 (20.2%)	15 (24.2%)	10 (16.1%)	0.263||
Statin use‡	102 (82.3%)	52 (83.9%)	50 (80.6%)	0.638||
Antiplatelet use‡	76 (61.3%)	37 (59.7%)	39 (62.9%)	0.719||
Beta blocker therapy‡	30 (24.2%)	16 (25.8%)	14 (22.6%)	0.417||
AAA diameter*	6.2 (0.8)	6.0 (0.7)	6.3 (0 9)	0.111§
Body mass index*	27 0 (3.9)	26 7 (3.5)	27.4 (4.2)	0.281
VO_2 peak*	17.5 (4.5)	17.8 (4.2)	17.2 (4.8)	0.471§
AT*	12.5 (3.9)	12.3 (3.4)	12.6 (4.3)	0.699§
V_E/VO_2†	28.0 (25.0–32.0)	28.0 (25.0–32.0)	28.0 (24.3–31.8)	0.653¶
V_E/VCO_2†	32.0 (27.3–36.0)	33.0 (29.2–36.0)	31.0 (21.9–36.2)	0.125¶
NT-proBNP†	153.0 (72.0–258.0)	158.5 (62.5–304.8)	135.0 (85.0–251.0)	0.541¶
LVEF†	40.0 (36.8–46.3)	41.5 (36.0–50.0)	40.0 (37.0–44.0)	0.285¶

*Mean (±SD).
†Median (IQR).
‡n (%).
§Unpaired *t* test.
¶Mann-Whitney *U* test.
||Chi-square test.
**Fisher exact test.

AT indicates anaerobic threshold; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; LVEF, left ventricular ejection fraction; NT-proBNP, N-terminal pro-B-natriuretic peptide; V_E/VCO_2, ventilatory equivalent for carbon dioxide; V_E/VO_2, ventilatory equivalent for oxygen; VO_2 peak, peak oxygen consumption.

intermediate and rehabilitation facility where she spent 5 weeks before being eventually discharged home.

DISCUSSION

This RCT showed that a 6-week exercise program before elective AAA is safe and significantly reduces postoperative complications and length of hospital stay. This is likely to be an under-representation of the effects of the program as almost 20% of patients randomized to exercise, failed to attend a single session.

The conception of this trial was stimulated by the growing need to improve surgical outcomes in vascular surgery. The Vascular Society's quality improvement program led the implementation of

TABLE 2. Exercise Attendance Rates and the Number of Postoperative Complications Recorded in Each Subgroup

Classes Attended	No. Participants	No. Complications Recorded
13–18 classes	32	3 (9.4%)
EVAR	13	0
OAR	18	3
6–12 classes	19	7 (36.9%)
EVAR	6	1
OAR	14	6
Did not attend	11	4 (36.4%)
EVAR	4	1
OAR	7	3

EVAR indicates endovascular repair; OAR, open aneurysm repair.

evidence-based perioperative care pathways in patients undergoing elective AAA repair in the United Kingdom, resulting in a notable recent reduction in mortality rates.[1] Our research represents an extension of this important national program, investigating interventions that can further improve patient experience and operative outcomes. The primary outcome measure, therefore, was chosen to be a composite endpoint of relevant organ-specific complications rather than postoperative mortality, as these are equally important outcome measures that are still frequently observed and not commonly reported in the literature.

The most likely explanation for the reduction in complications seen with exercise in this trial is an improvement in preoperative aerobic fitness after a defined duration of regular exercise. Several studies have shown a clinically relevant improvement in CPET parameters, considered good predictors of postoperative morbidity and mortality in AAA patients, with appropriate exercise interventions in this patient population.[13–15,23] Kothmann et al[13] conducted a small, randomized, pilot study in patients under AAA surveillance and demonstrated an improvement in the AT in patients who underwent 6 weeks of exercise training compared with a smaller control group of patients. Tew et al[14] demonstrated a greater improvement in AT with a longer, 12-week, exercise program. They also found an improvement in markers such as C-reactive protein and systolic blood pressure in those patients who exercised. They commented that their findings were boosted by high patient compliance with training. More recently, Myers et al[23] reported the results of a randomized trial in which a large group of patients with small AAAs exercised for an average of over 20 months, aimed primarily at assessing the effect on

TABLE 3. Summary of the Cardiac, Pulmonary, and Renal Complications in the 2 Study Groups

Complications	Total	Exercise Group	Control Group	*P*
Cardiac*	19 (15.3%)	5 (8.1%)	14 (22.6%)	0.025†
	5: myocardial infarction (2 fatal)	EVAR: 1 (4.3%)	EVAR: 3 (13.0%)	0.608
	5: prolonged inotropic support	OAR: 4 (10.3%)	OAR: 11 (28.2%)	0.044
	5: new-onset arrhythmia (without evidence of myocardial damage or ischemia)			
	3: new-onset arrhythmia with elevated troponin T levels			
	1 – Unstable angina with Troponin level of 0.05			
Pulmonary*	20 (16.1%)	7 (11.3%)	13 (21.0%)	0.143†
	14: postoperative pneumonia	EVAR: 0 (0.0%)	EVAR: 4 (17.4%)	0.109
	3: severe postoperative pneumonia resulting in reintubation or respiratory support	OAR: 7 (17.9%)	OAR: 9 (23.1%)	0.575
	1: postoperative pneumonia and an exacerbation of COPD			
	1: unplanned reintubation			
	1: reintubation and aspiration pneumonia (fatal)			
Renal*	17 (13.7%)	4 (6.5%)	13 (21.0%)	0.019†
	15: more than 20% decrease in creatinine clearance	EVAR: 1 (4.3%)	EVAR: 1 (4.3%)	1.000
	2: renal insufficiency postoperatively requiring hemodialysis/hemofiltration	OAR: 3 (7.7%)	OAR: 12 (30.8%)	0.033
Endpoints (composite outcome measure)	40 (32.3%)	14 (22.6%)	26 (41.9%)	0.021

*n (%).
†Chi-square test.
EVAR indicates endovascular aneurysm repair; OAR, open aneurysm repair.

AAA expansion. Whereas exercise training did not influence rate of AAA enlargement, it did significantly improve several fitness parameters including VO_2 peak, AT, treadmill exercise time, and other measures of energy expenditure. We have previously validated the aerobic exercise regime used in this current randomized trial, demonstrating an associated improvement in aerobic fitness parameters in patients with large (≥5.5 cm) AAAs awaiting operative intervention.[15] In this study, a significant improvement on aerobic fitness parameters was demonstrated in patients who exercised compared with those who did not. The collective research performed to date adequately quantifies the changes in cardiopulmonary fitness measures with exercise in patients with AAA.

The benefits of exercise in several public health domains have recently attracted interest. A systematic review identified 12 controlled trials, which assessed the effect of preoperative exercise interventions on postoperative outcomes after several different surgical interventions.[16] There was considerable variation in exercise interventions and outcome measures between trials. Elective

TABLE 4. A Summary of the Secondary Outcome Measures Compared Between the 2 Groups

Outcome Measure	Total (n = 124)	Exercise (n = 62)	Control (n = 62)	*P*
Length of hospital stay in d*	7.0 (5.0–9.0)	7.0 (5.0–9.0)	8.0 (6.0–12.3)	0.025‡
EVAR	5.0 (4.0–7.0)	4.0 (3.0–6.0)	5.0 (4.0–9.0)	0.013‡
OAR	9.0 (7.0–10.0)	8.5 (7.0–10.0)	9.0 (7.5–13.5)	0.140‡
Length of critical care stay in d*	1.0 (1.0–2.0)	1.0 (1.0–2.0)	2.0 (1.0–2.0)	0.845‡
EVAR	1.0 (1.0–1.0)	(1.0–1.0)	1.0 (1.0–1.0)	0.211‡
OAR	2.0 (1.0–3.0)	2.0 (1.0–3.0)	2.0 (1.0–2.3)	0.744‡
APACHE II score during the first 6 h postoperatively*	10.0 (8.0 – 14.0)	9.0 (7.0–13.3)	11.0 (8.0–15.0)	0.256‡
EVAR	10.0 (8.0–12.0)	9.0 (7.0–11.0)	11.0 (8.0–14.0)	0.081‡
OAR	10.0 (7.0–15.0)	10.0 (7.0–16.0)	11.0 (7.0–15.0)	0.794‡
SIRS criteria recorded during hospital stay†	101 (81.5%)	50 (80.6%)	51 (82.3%)	0.817§
EVAR	34 (73.9%)	17 (73.9%)	17 (73.9%)	1.000§
OAR	67 (85.9%)	33 (84.6%)	34 (87.2%)	0.745§
Need for reoperation†	5 (4.0%)	2 (3.2%)	3 (4.8%)	1.000¶
EVAR	0 (0.0%)			
OAR	5 (4.0%)	2 (3.2%)	3 (4.8%)	1.000¶
Postoperative bleeding or transfusion of more than 4 units†	11 (8.9%)	4 (6.5%)	7 (11.3%)	0.343§
EVAR	0 (0.0%)			
OAR	11 (8.9%)	4 (6.5%)	7 (11.3%)	0.343§
30-d mortality†	4 (3.2%)	2 (3.2%)	2 (3.2%)	1.000¶
EVAR	1 (2.2%)	1 (4.3%)	0 (0.0%)	0.500¶
OAR	3 (3.8%)	1 (2.6%)	2 (5.1%)	0.500¶

*Median (IQR).
†n (%).
‡Mann-Whitney *U* test.
§Chi-square test.
¶Fisher exact test.
EVAR indicates endovascular aneurysm repair; IQR, interquartile range; OAR, open aneurysm repair.

TABLE 5. The Changes in the Main CPET-measured Parameters Upon Repeated Assessment on the Last Preoperative Day

Aerobic Fitness Parameter	Baseline (CPET 1)	Day Before Surgery (CPET 2)	P
Exercise group (n = 33)			
VO$_2$ peak* (mL O$_2$/kg/min)	18.4 (15.0–20.9)	20.0 (16.9–21.3)	0.004[†]
AT* (mL O$_2$/kg/min)	12.0 (10.4–14.5)	13.9 (10.6–15.1)	0.012[†]
Total exercise time* (s)	412.0 (219.0–613.0)	577.0 (398.0–705.0)	<0.001[†]
Control group (n = 15)			
VO$_2$ peak* (mL O$_2$/kg/min)	19.6 (15.4–21.3)	18.4 (15.9–20.7)	0.609[†]
AT* (mL O$_2$/kg/min)	12.3 (10.7–14.4)	12.1 (10.2–14.3)	0.532[†]
Total exercise time* (s)	519.0 (323.0–624.0)	533.0 (290.0–673.0)	0.191[†]

AT indicates anaerobic threshold; VO$_2$ peak, peak oxygen consumption.
[†]Mann-Whitney *U* test.
*indicates that values are presented as median (IQR).

orthopedic procedures were analyzed separately from thoracic and abdominal surgeries. The review concluded that preoperative exercise decreased the overall postoperative complication rates and the length of hospital stay after cardiac, thoracic, and abdominal surgery. To our knowledge, no RCTs exist to assess the value of perioperative exercise interventions in patients undergoing vascular surgery.

The duration of the exercise intervention in this study was 6 weeks, which, in publicly-funded healthcare organizations such as the UK National Health Service, may be considered an effective utilization of preoperative "waiting time" to improve perioperative fitness. The exercise intervention in our study was effectively and safely delivered in a hospital-based physiotherapy department. To ensure safety, adequate exercise, and compliance, the training was structured to include a mixture of tolerable aerobic and resistance exercises of appropriate intensity, weekly frequency, and duration. Patients allocated to the exercise group in our study joined an established local exercise program that was originally designed for patients with intermittent claudication and ran continuously at the study center for the past 5 years. No additional funding was required. The 6-week duration was chosen as we needed it to be long enough for patients to achieve a benefit, but not to exceed the waiting time period from diagnosis to repair agreed locally (8 wks).

Compliance with the exercise intervention was found to be a key factor, with postoperative complications inversely correlating with attendance rates. Successful strategies to maintain compliance with short-term exercise programs in the older patients include behavioral approaches focused on individual physical, psychological, and/or social considerations.[24] In our experience, this was possible by maintaining continuous clinical supervision throughout the study to provide appropriate training, advice, and encouragement while ensuring participants' well being. This continuity of care is valued by patients and likely to enhance compliance.[25]

Patients undergoing elective repair of AAA were the target population in this study, whether they were scheduled for an open repair or an EVAR. The main initial interest was to illicit an improvement in fitness parameters. Including EVAR patients ensured that we had the largest possible pool of patients with AAA disease to facilitate the recruitment process and assess the benefits of exercise training. Interestingly, the benefits of exercise on the main outcome measures in this study were evident for both types of repair, despite the smaller numbers of patients undergoing EVAR.

The limitations of this study should be noted. Firstly, it was a single-center trial, with patients recruited from a defined geographical area, and undergoing assessments and interventions at a single unit. It was, however, performed at a high-volume, tertiary vascular center, with the study sample closely representing the population of patients with AAA disease, with a predominance of male patients (around 90%) and an average age of 73 years. These observations are identical to those reported in large randomized AAA trials.[26,27] The

single-center environment facilitated the logistics of organizing and conducting this project, and ensured minimal variability in the exercise intervention. Secondly, patient and investigator blinding was not possible due to the nature of the intervention. It is recognized that exercise interventions attract motivated individuals who understand clearly the benefits of exercise. Randomization, however, should effectively eliminate this potential participation bias, but because over one-third of patients who were approached declined to participate, it is feasible that these were the less motivated individuals. Therefore, it is conceivable that the patients who had the most to gain excluded themselves. It is also possible that motivated individuals randomized to the control group may have increased their preoperative activity levels, stimulated simply by the trial information and participation. We did try to negate the later effect by explaining the study process and the benefits of a randomized study design to truly assess for the value of the exercise intervention to participants. Those randomly allocated to the control group were clearly instructed to resume normal activities and avoid any strenuous or unsupervised exercise; however, adherence to these instructions was not specifically studied. Finally, this trial was powered to assess the clinical and not the cost-effectiveness of preoperative exercise program; thus formal health economic analysis was not included.

In summary, this is the first study to demonstrate that a preoperative exercise program before AAA repair is safe and effective in reducing postoperative complications and hospital stay. An exercise program should be considered in all patients before AAA repair. Compliance with the program was associated with superior outcomes, and perhaps this knowledge will promote patient uptake and adherence to the program.

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