Characterising recovery following Abdominal Aortic Aneurysm repair using cardiopulmonary exercise testing and patient reported outcome measures

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Abstract

Background

Major surgery is associated with a post-operative stress response, changes in cardiopulmonary reserve and increased metabolic demand. Here recovery after abdominal aortic aneurysm is investigated using cardiopulmonary exercise testing and patient reported health and activity questionnaires.

Methods

Patients undergoing open (n=30) or endovascular (n=30) aortic repair undertook a cardiopulmonary exercise test, Duke activity score index and patient reported health score questionnaires pre-operatively and at 8 and 16 weeks post-operatively. Anaerobic threshold, peak oxygen uptake and ventilatory equivalents were measured and haemoglobin concentration and renal function was recorded.

Results

Post-operatively patients showed impaired cardiopulmonary function characterised by a fall in anaerobic threshold, peak oxygen uptake and oxygen pulse at 8 weeks which normalised by 16 weeks. Certain changes seemed to be associated with operative severity; the 8 week fall in peak oxygen uptake was greater following open versus endovascular repair (3.5 vs. 1.6 ml/kg/min) and AT showed a similar tendency (3.1 vs. 1.7 ml/kg/min) . Reported health and activity scores did not show similar changes.

Conclusions

Open or endovascular aortic repair is associated falls in anaerobic threshold, peak oxygen uptake and oxygen pulse at 8 weeks post-operative. The magnitude of the changes may be linked to operative severity and resolve by 16 weeks. Thus at 8 weeks post-operative there is a 15-20% reduction in these cardiopulmonary parameters normalising by 16 weeks. During this post-operative period patients are at higher risk and less able to cope with further metabolic demands such as a cardiac event, chemotherapy, infection, or further surgery.

Key words: Abdominal aortic aneurysm; recovery; cardiopulmonary exercise testing; shielding; physiological burden

Introduction

Major surgery is associated with a post-operative systemic reaction to surgical trauma which is characterised by the activation of a range of endocrine, immune and haematological responses [1]. The magnitude of the ensuing catabolic state induced by surgery tends to be proportional to the severity of surgery and is accompanied by an oxygen deficit which needs to be overcome to achieve recovery [2,3].

Recovery from surgery is a complex interplay of physiological, psychological and socioeconomic processes which are active through a staged process which starts with an energy dependent catabolic state and culminates in a return of control and normal activity, and to the return of pre-operative wellbeing and fitness [4,5]. Patients tend to define recovery as a return to normal functioning which is somewhat simpler, and patients appear to be concerned more with the return to pre-operative physical fitness and returning to work, rather than the length of their hospital stay and other "clinically" related parameters [6,7].

Here we focus on the return to physical fitness during recovery from major surgery using cardiopulmonary exercise testing (CPET). CPET provides an objective assessment of cardiopulmonary fitness or reserve [8-10] and is now established as a useful tool in the determination of peri-operative risk such that patients with a poor CPET result are at much higher risk of peri-operative cardiac morbidity and death[8]. The anaerobic threshold (AT) is important, this the point at which aerobic respiration is supplemented by anaerobic respiration to produce energy[9,10] when measuring oxygen uptake (VO_2) during exercise, and it has the great advantage of objectivity[9]. Thus, patients with a low AT (<11 ml/kg/min) appear to be at high risk of complications and death. Other CPET values also seem to be important and predictive of post-operative complications and mortality[11-15], in particular the peak VO_2 and ventilatory equivalent for carbon dioxide (VE/VCO_2) which gives a measure of lung efficiency[10]. The reason patients with poor cardiopulmonary reserve are at greater risk appears to be associated with the systemic inflammatory response following major surgery which markedly increases peri-operative oxygen demand by some 40-50%[2]. Myocardial infarction and death are thought to arise from the inability of patients with low cardiopulmonary reserve to meet this additional demand[2,3]. Risk stratification using CPET variables has been used to determine levels of care following major surgery, successfully reducing peri-operative mortality in high risk patients[16].

The present study aimed to capitalise on the ability of CPET to provide an objective measurement of physiological status, rather than its utility in risk prediction, to characterise cardiopulmonary reserve pre- and post-operatively and thereby characterise physiological recovery following aortic repair. As previously described [17] CPET was combined with patient reported health status (PRHS) & Duke Activity Scale Index (DASI) to characterise recovery following aortic aneurysm repair using an endovascular or open approach.

Methods

Patients and Recruitment

Sixty patients undergoing abdominal aortic aneurysm (AAA) repair were recruited in the vascular outpatient's clinic or during pre-operative assessment between 2010 and 2015. Eighteen patients did not return to complete the study and forty two patients

went on to undergo endovascular aortic repair (EVAR, n=21) or open AAA repair (n=21). The reasons for patients not returning at 8 weeks included refusal (EVAR n=5; Open AAA n=5), infective complication (EVAR n=2; Open AAA n=3), bowel obstruction (Open AAA n=1) and cardiovascular complication (EVAR n=1; Open AAA n=1). The patients that left the study were not different from their respective cohort in their pre-operative demographics, blood tests (haemoglobin (Hb), estimated glomerular filtration rate (eGFR)), CPET parameters (AT, VO_2 peak, VE/VCO_2) or outcome measures (PRHS and DASI, independent t-test, data not shown).
Informed consent was obtained by a consultant or clinical research fellow trained in Good Medical Practice. All patients received consultant delivered surgical and anaesthetic care. The study received local ethical approval from our local Health Research Authority, Bristol NRES Southwest, with restrictions that limited the study design such that it was not possible to recruit consecutive patients. Patients over the age of 18 years were considered for the study, with the following exclusions; Patients that suffered post-operative complications or were considered inoperable, those patients unable or unwilling to perform a CPET test or participate in the study, and patients from outside the Bristol area for whom participation would represent a significant burden. Approval also stipulated that patients not be re-tested within 4 weeks of surgery. The study incorporated patient safety pathways to identify patients with potentially reversible cardiac or pulmonary morbidity; in such cases the surgeon was informed and the patient referred to the appropriate specialty.

Cardiopulmonary exercise testing

Each patient underwent a CPET test between 3 days and 28 days pre-operatively (median 8 days) conducted by a trained Consultant Anaesthetist and technician in accordance with the American Thoracic Society and American College of Chest Physician Guidelines [18]. Eighty nine percent of patients had a pre-operative CPET within 2 weeks of the operative date. Thereafter, patients were invited to attend repeat CPET test and routine blood tests in the 6-8 weeks post-operative (median 8 weeks, range 7-9 weeks), to coincide with surgical follow-up and again 6-8 weeks later (median 16 weeks; range 15-17 weeks) post-operatively. Of the forty two patients, twenty one patients undergoing EVAR returned at 8 weeks and eleven patients at 16 weeks post-operative, whereas those undergoing open AAA repair twenty one returned at 8 weeks and twelve patients at 16 weeks post-operative. Reasons for those that did not return at 16 weeks included refusal (n=9), loss to follow-up (n=5),

exacerbation of prior medical condition (n=3), infection (n=1) and further unrelated surgery (n=1).
Pre-operatively and at 8 weeks post-operative, routine blood tests of a full blood count and renal function tests including estimated glomerular filtration rate (eGFR) were performed. Prior to each test patients were weighed such that CPET data was weight-adjusted and each patient completed PRHS and DASI questionnaire. The following demographic data was collected; age, sex, height, weight, smoking status, chronic disease status (diabetes, hypertension, heart failure, ischaemic heart disease, peripheral vascular disease, lung disease, cerebrovascular and other endocrine disease).

CPET tests were conducted on a cycle ergometer (Ergoline P10) with continuous side stream gas exchange analysis (nSpire Health, UK), as previously described [19]. Each patient was seated on the cycle ergometer connected to a 12 lead ECG, oxygen saturation monitor and continuous non-invasive blood pressure cuff. Respiratory gas exchange was measured from a tight-fitting facemask. An initial 2 minute period of baseline data was collected at rest prior to a 90 second period of unloaded cycling. A ramp protocol was then applied and the patient was instructed to aim to continue cycling at a constant cadence of between 60-65 rpm. Patients were positively encouraged to perform to their best prior to and during all of the exercise tests performed. The test was terminated if the patient indicated that they could not continue, if cadence fell below 55 rpm due to fatigue or dyspnoea, or they developed abnormal cardiac signs or symptoms such as ischaemia or arrhythmia. The patients were continually monitored for a recovery period of 2 minutes unloaded cycling before finishing the test. Patients were kept under observation for a further 10 minutes after the test prior to being discharged.

AT was determined following each test using the V-plot technique and confirmed by ventilatory equivalents [9]. VO_2 peak was measured as the highest VO_2 attained over a 30 second period at peak exercise. V-plots and ventilatory equivalents at AT were calculated using the Zan 600 software (nSpire Health, UK). All CPET variables were determined on the day of the test and then independently verified by two researchers with CPET expertise and who were blinded to the operative intervention, PRHS and

DASI analysis. The researchers performing the tests were not blinded to the proposed surgical group.

DASI and PRHS

The DASI is a self-reported questionnaire which scores daily activities and estimates peak VO_2 [20], whereas the PRHS is a visual analogue scale from 0 to 100% health status; here patients were asked to mark on the scale how well they felt on the day of CPET testing, 100% being in the best health state and 0% being the worst health they could imagine, as described [17].

Surgery

The majority (n=53) patients underwent infrarenal aneurysm repair, a small number had juxta-renal AAA repair (Open AAA group, n=4; EVAR group n=1) and one patient in each group had a suprarenal AAA repair (n=2). All patients received a general anaesthetic, arterial and intravenous lines, those for open repair also had a central line and an epidural for peri-operative analgesia. Peri-operative analgesia for patients undergoing EVAR was achieved using intravenous opiate in recovery as required and subsequently opiate and non-opiate oral analgesics. Non-steroidal anti-inflammatories were avoided in both groups. Patients could eat and drink and were supplemented with intravenous maintenance fluid. Patients were considered for discharge once they were cardiovascular stable, voiding consistently (>0.5ml/kg/min) with stable urea and electrolytes, tolerating food and fluids, and their pain was well controlled. They were routinely followed approximately 8 weeks post-operatively.

Statistical analyses

Statistical analysis was performed independently by the Applied Statistics Group of the University of the West of England. For an effect size of 0.67, or larger, (i.e. mid-point medium effect size), a sample size of n=20 would have in excess of 80% power to detect changes in AT (paired samples t-test, two sided, alpha = 0.05). Group comparisons were analysed using the independent t-test. Paired analyses were made using the paired sample t-test. Data is presented as mean ± standard deviation (± SD) or median (range). Two sided tests of statistical significance were used throughout and significance was taken as less than 5%. Proportions were compared using the Chi-Squared test.

Results

The demographic data for each group is shown in Table 1. There were no differences in the age, BMI, chronic disease status, pre-operative baseline blood results and activity and health status scores. In terms of cardiopulmonary function pre-operatively patients undergoing EVAR had a significantly lower AT and a tendency toward a lower VO_2 peak and to a higher VE/VCO_2 compared with patients undergoing open AAA repair (Table 1). Overall, the mean AT of the EVAR group was significantly less than the open AAA group and there were a higher proportion of patients undergoing EVAR with an AT < 11 ml/kg/min and who would be considered high risk for major surgery compared to the open AAA group (Table 1).

Patients in both the EVAR group (n=21) and the open AAA group (n=21) returned at 8 weeks post-operative for repeat CPET, DASI, PRHS and routine bloods. At 8 weeks post-operative there were significant reductions in peak VO_2, AT, O_2 pulse and Hb in both surgical groups, however there were no changes in basal oxygen uptake observed (Table 2). There was a small but significant fall in Hb post-operatively in both groups (EVAR group from 14.4 ± 1.3 to 12.6 ± 2 g/dl; open AAA group from 14.4 ± 1.9 to 11.9 ± 1.9 g/dl; p<0.01 paired t-test). The fall in VO_2 peak at 8 weeks post-operative was significantly greater following open AAA repair when compared to that in the EVAR group (VO_2 peak: 3.5 ± 2.7 vs 1.6 ± 1.8 ml/kg/min, p<0.05 independent t-test), a similar fall was also seen in AT which seemed to be greater in the AAA compared to the EVAR group (3.1 ± 1.8 vs 2.0 ± 1.7 ml/kg/min) however this just failed to reach statistical significance, (p=0.054 independent t-test) (Table 2). Conversely, a significant fall in the maximum heart rate (MHR) achieved during exercise was observed in the open AAA group but not in the EVAR group (AAA group:120 ± 16 bpm pre-operative vs 112 ± 15 bpm at 8 weeks post-operative (p<0.01, paired t-test) versus 119 ± 26 bpm and 121 ± 23 bpm in the EVAR group). There were no changes in the DASI or PRHS observed between any of the time points tested (0,8 and 16 weeks) in either of the surgical groups (Table 3).

Patients in both groups (Open n=12; EVAR n=11) returned at 16 weeks for a repeat CPET, DASI and PRHS (Tables 3 & 4). At this time, the fall in cardiopulmonary parameters observed at 8 weeks post-operative had resolved; VO_2 peak, AT, and O_2

pulse were no different to pre-operative values, (Table 4), DASI and PHRS values remained unchanged compared with values obtained at 8 or 16 weeks post-operative.

Discussion

This study examined the cardiopulmonary fitness and patient reported health and activity scores of patients undergoing open or endovascular aortic repair. Pre-operatively the demographics of each group were similar in terms of age, BMI, co-morbidities, baseline blood tests (Hb and eGFR) and reported health and activity scores (DASI and PRHS). However, there were differences with regard to their cardiopulmonary reserve in that patients selected for EVAR, overall, had a lower AT and contained a higher proportion of high risk individuals. This finding is reassuring in that it conforms to current NICE guidance [13] regarding the management of aortic aneurysms; this states that patients with a higher risk and significant co-morbidities should be considered for EVAR rather than open repair.

Post-operatively patients in both groups returned at 8 weeks for repeat cardiopulmonary exercise testing and patient reported outcome questionnaires. The study showed that at this time following either open or endovascular aortic repair there is a significant decline in cardiopulmonary reserve. This decline is characterised by a fall in AT, VO_2 peak, O_2 pulse and a relative anaemia compared with pre-operative Hb measurements. However, there was no significant change in the PRHS or DASI scores at 8 weeks post-operative. The reductions in the cardiopulmonary parameters of AT and VO_2 peak observed following both EVAR and open AAA are similar to those observed previously following live-related renal donation [17]. Here too a fall in AT, VO_2 and O_2 pulse was observed in the 7th post-operative week. Similar to the present study, the changes are unlikely to be wholly a result of a peri-operative fall in Hb since a change of 1g Hb is equivalent to only 0.39 - 0.97 ml/kg/min VO_2 [21,22]. Thus within 8 weeks of an EVAR or open AAA repair, or renal donation [17], both oxygen carrying capacity and delivery is impaired through a combination of anaemia and a process of deconditioning [1,17]. The magnitude of this response appears to be related to the surgical severity of the operative procedure since the change in VO_2 peak at 8 weeks post open AAA repair was significantly greater than that observed in the EVAR group and a similar trend was seen in AT at this time. Factors which may contribute to this difference between the groups are the degree of post-operative anaemia, which was slightly less in the EVAR group, and cardiovascular differences; no reduction in MHR was observed in the EVAR group. Although subtle, both of these factors will influence oxygen uptake and carrying capacity [2,3]. The deconditioning process observed in both groups is likely contributed and precipitated by elements of the surgical stress response [1] such as the activation of the hypothalamo-pituitary adrenal and immune axes which precipitate hypermetabolism and catabolism [1,4,5]. This may be further contributed by a perceived reduction in quality of life, and a delay in mental health and physical health recovery which occurs around this time post-operatively [24,25]. Previously we have demonstrated similar changes in peri-operative cardiopulmonary parameters following live donor nephrectomy which were accompanied by parallel changes in DASI and PRHS scores [17]. In the present study, whilst similar trends in these scores were noted significant changes were not found. This may suggest that patients are unaware of their peri-operative physiological status or merely reflect the diversity in reliability and validity that exists between different patient reported outcome techniques for AAA repair [26].

Previous studies have shown that in the early post-operative period the surgical stress response is associated with a 40-50% increase in basal VO_2 [2]. It is postulated that the ability to cope with this increase in VO_2 is critical to occurrence of major post-operative complications, consequently patients with a low pre-operative AT are at a much higher risk of major complications and death than those with a higher AT[8,11,12,14-16,19]. Indeed, this principle underlies the risk stratification of patients undergoing aortic surgery to open or endovascular repair [11-16]. In the present study we showed that basal VO_2 was not different to pre-operative values at 8 weeks post-operative, suggesting that the observed early post-operative increases in basal VO_2 [2] have normalised by this time post-operative. An overall fall of 20% in the AT was observed at 8 weeks, which if present immediately post-operative, raises the possibility that major complications after surgery arise not just because of a rise in tissue oxygen demand [2, 27], but also a parallel reduction in the ability to cope with that increased demand. This fall in AT after surgery also renders patients less capable of handling a second insult and its consequent rise in oxygen demand, such as a myocardial event, further surgical intervention or infection [2,3,28].

By 16 weeks after aortic surgery, (open or endovascular) the changes in cardiopulmonary parameters observed at 8 weeks had resolved to pre-operative values. These findings in peri-operative cardiopulmonary reserve are similar to those found following donor nephrectomy [17] and indeed, chemotherapy [29]. They add further understanding to the recovery processes following major surgery and have practical application in peri-operative counselling and setting expectations. This knowledge also helps with individual discharge planning and provides a more informed indication as to when they might be able to return to work which appears to be important to patients [30-32].

The findings of this and our previous study examining peri-operative cardiopulmonary reserve following nephrectomy [17] might also be helpful in decisions around post-operative shielding [33]. Recently it has been shown that 50% of patients contracting severe acute respiratory system coronavirus 2 (SARS-CoV-2) infection peri-operatively have pulmonary complications and a high mortality rate [34]. Numerous studies have shown that patients with poor cardiopulmonary reserve have higher complication and mortality rates[8,11,12,14-16,19]. In the present study we demonstrate that aortic surgery has a post-operative impact on cardiopulmonary reserve which is present at 8 weeks post-operative and resolves by 16 weeks. If we accept that risk is related to cardiopulmonary reserve then it follows that by virtue of the post-operative fall in cardiopulmonary parameters such as AT, VO_2 and O_2 pulse, patients have increased risk or vulnerability for a minimum of 8 weeks post-operative. The patient’s ability to cope with the metabolic demands of a SARS-Cov-2 infection during this time is likely to be significantly curtailed and may underlie the high complication and infection rates seen with post-operative SARS-Cov-2 infection [34]. For aortic surgery the current Royal College of Surgeons (England) guidance [33] suggests a post-operative shielding period of 2 weeks, however findings of the present study may indicate that a longer period of shielding might be safer.

There are obvious limitations to the present study. The stipulations of the ethics committee limited the recruitment to the local patient population, dictating the study design such that consecutive patients could not be recruited. This slowed the study progression and limited numbers recruited. In this study 30% (18/60) individuals dropped out of the study after the pre-operative evaluations. It is unlikely that this resulted in a cardiopulmonary fitness selection bias as their pre-operative CPET parameters were not different to those patients who went on to complete the study. However, there may have been some psychological differences with these individuals which may have influenced the PRHS and DASI scores. In this regard, the data presented may not be generalisable to wider patient populations. In retrospect, it would have been informative to have some indices of the activity of patients over the study period to correlate with their reported activity and the CPET parameters measured. However, it is encouraging that within each of the groups, individual recovery profiles showed similar patterns of change over time and showed internal consistency. Furthermore, the results concur with our previous study in live-related renal donors [17]. The study also benefits from a blind approach between measured variables and CPET reporting, and the use of an independent statistician.

In conclusion, recovery from aortic surgery is associated with a reduced cardiopulmonary reserve characterised by fall in AT, VO_2 peak and O_2 pulse at 8 weeks post-operatively and resolving by 16 weeks. The magnitude of the effect on AT appears to be linked to operative severity in that it is significantly smaller following EVAR. These data further characterise recovery from major aortic surgery and may be helpful in decisions regarding discharge planning and post-operative shielding.

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Table 1: Pre-operative base line demographics, cardiopulmonary parameters and biochemistry for patients undergoing open (Open AAA) and endovascular (EVAR) abdominal aortic aneurysm repair

Demographics, CPET parameters and biochemistry	**Open AAA (n=30)**	**EVAR (n=30)**
Median age (± range)	70 (60-86)	72 (61-83)
Male : female	28 : 2	28 : 2
BMI *(±SD)*	28.3 (5.9)	26.9 (4.5)
Hypertension	73%	83%
Diabetes	10%	13%
Active smoking status	30%	27%
Beta blockers	19%	13%
ASA 2/ ASA 3 (n)	25/5	23/7
Basal O_2 uptake (ml/kg/min (±SD))	4.56 (1.0)	4.4 (1.3)
AT (ml/kg/min (±SD))	12.6 (1.7)***	11.1 (2.0)
Proportion with AT<11	3/30 (10%)$^{\Psi}$	15/30 (50%)
High risk individuals[1]	14/30 (47%) $^{\Psi\Psi\Psi}$	26/30 (87%)
VE/VCO_2 (±SD)	31.1 (3.6)	32.7 (5.0)
VE/VO_2 (±SD)	34.4 (5.9)	35.4 (5.7)
Max Heart Rate (bpm (±SD))	122 (16)	119 (24)
VO_2 Peak (ml/kg/min(±SD))	16.2 (2.6)	15.5 (3.2)
O_2 Pulse (ml/beat (±SD))	13.4 (5.9)	13.5 (4.5)
eGFR (ml/min/1.73m^2 (±SD))	71 (17)	69 (14)
Hb (g/l (±SD))	14.4 (1.8)	14.2 (1.5)
DASI (±SD)	28.6 (6.0)	27.7 (5.9)
PRHS (±SD)	77.3 (17.1)	81.0 (11.9)

[1]High risk defined as a CPET profile with one or more of VO_2 <16 ml/kg/min, AT<11 ml/kg/min, VE/VCO2 ≥ 34 [17].
*Comparing means between AAA and EVAR groups; ***P<0.005 Independent t-test.*
Comparing proportions between groups; $^{\Psi\Psi\Psi}$ P<0.005 Chi-squared test.

Table 2. Changes (mean ± SD) in cardiopulmonary parameters at 8 weeks following aneurysm repair (n =42) by open (n=21) or endovascular (n=21) approach.

	Basal Oxygen Uptake (ml/kg/min)	**AT (ml/kg/min)**	**VO_2 Peak (ml/kg/min)**	**O_2 Pulse (ml/beat)**	**VE/VCO_2**
All patients (n=42)					
Pre-operative	4.5 ± 1.2	12.2 ± 1.9	16.6 ± 3.0	14.0 ± 3.7	32.6 ± 4.7
8 wk Post-operative	4.0 ± 0.9	9.7 ± 1.8***	13.9 ± 3.0***	12.0 ± 3.0***	33.7 ± 5.3
EVARs (n=21)					
Pre-operative	4.5 ± 1.3	11.8 ± 1.9	16.3 ± 3.2	14.1 ± 4.5	32.5 ± 5.6
8 wk Post-operative	3.9 ± 0.9	9.7 ± 1.6***	14.5 ± 2.9***	12.3 ± 3.4**	33.4 ± 5.5
Open AAA (n=21)					
Pre-operative	4.6 ± 1.0	12.7 ± 1.9	16.9 ± 3.0	14.1 ± 2.7	32.3 ± 3.2
8 wk Post-operative	4.1 ± 0.9	9.5 ± 2.2***	13.4 ± 3.1***	11.9 ± 2.8***	33.6 ± 5.2

AT, anaerobic threshold; VO_2 peak, peak oxygen uptake; VE/VCO_2, ventilatory equivalent for carbon dioxide; O_2 pulse, oxygen pulse; Hb, haemoglobin. P value refer to paired t-test (,P<0.05; **, P<0.01, ***p<0.005) .*

Table 3. Changes (mean ± SD) in patient reported health (PRHS) and activity (DASI) status at 8 weeks and 16 weeks following aneurysm repair by open or endovascular approach.

Operation (n)	**Week Post-operative**	**Health Status**	**DASI**
All patients (n=42)	Pre-op	80.1 ± 14.9	28.9 ± 5.5
	8 wk Post-operative	77.3 ± 15.2	26.4 ± 6.2
EVAR (n=21)	Pre-operative	81.6 ± 12.3	29.4 ± 5.5
	8 wk Post-operative	78.4 ± 15.6	27.5 ± 6.4
Open AAA (n=21)	Pre-operative	77.9 ± 17.4	28.6 ± 5.6
	8 wk Post-operative	76.0 ± 14.9	25.1 ± 5.6
All Patients (n=23)	Pre-operative	83.3 ± 10.3	30.9 ± 3.9
	8 wk Post-operative	80.2 ± 15.0	28.2 ± 5.6
	16 wk Post-operative	89.1 ± 14.5	31.1 ± 3.8
EVAR (n=11)	Pre-operative	84.8 ± 9.8	32.5 ± 3.4
	8 wk Post-operative	81.7 ± 16.3	30.7 ± 4.8
	16 wk Post-operative	94.0 ± 7.9	31.8 ± 3.2
Open AAA (n=12)	Pre-operative	81.5 ± 11.0	29.1 ± 3.7
	8 wk Post-operative	78.5 ± 13.9	25.5 ± 5.3
	16 wk Post-operative	81.7 ± 19.6	30.1 ± 4.6

Table 4. Changes (mean ± SD) in cardiopulmonary parameters at 8 weeks and 16 weeks following aneurysm repair (n =23) by open (n=12) or endovascular (n=11) approach.

	Basal Oxygen Uptake	AT (ml/kg/min)	VO_2 peak (ml/kg/min)	O_2 Pulse (ml/beat)	VE/VCO_2
All patients (n=23)					
Pre-operative	4.4 ± 1.0	12.6 ± 1.8	17.7 ± 2.8	14.5 ± 3.8	32.2 ± 4.8
8 wk Post-operative	3.9 ± 0.8	9.9 ± 1.6**	14.7 ± 2.9***	12.7 ± 3.2	33.9 ± 5.8
16 wk Post-operative	4.0 ± 0.9	12.0 ± 2.1	16.8 ± 3.6	14.7 ± 3.9	33.0 ± 4.7
EVAR (n=11)					
Pre-operative	4.6 ± 1.2	12.4 ± 1.5	16.9 ± 2.6	14.4 ± 5.0	32.0 ± 5.9
8 wk Post-operative	4.1 ± 0.7	10.1 ± 1.6***	15.6 ± 2.8*	13.2 ± 3.5	32.9 ± 5.2
16 wk Post-operative	4.2 ± 1.0	12.8 ± 1.8	17.9 ± 3.6	16.0 ± 4.8	33.0 ± 5.4
Open AAA (n=12)					
Pre-operative	4.1 ± 0.9	12.8 ± 2.2	18.0 ± 3.1	14.6 ± 2.1	32.5 ± 3.5
8 wk Post-operative	3.8 ± 1.0	9.7 ± 1.8***	13.7 ± 2.8**	12.2 ± 3.0**	34.9 ± 6.4
16wk Post-operative	3.7 ± 1.0	11.1 ± 2.1	15.6 ± 3.5	13.4 ± 2.2	33.0 ± 4.1

AT, anaerobic threshold; VO_2 peak, peak oxygen uptake; VE/VCO_2, ventilatory equivalent for carbon dioxide; O_2 pulse, oxygen pulse; Hb, haemoglobin. P value refer to paired t-test (,P<0.05; **, P<0.01, ***p<0.005) .*