Comparison of oxygen uptake during arm or leg cardiopulmonary exercise testing in vascular surgery patients and control subjects

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Editor’s key points

- Cardiopulmonary exercise testing by cycle ergometry has limited utility as a preoperative assessment tool in patients with lower limb dysfunction.
- Leg ergometry was compared with arm ergometry in vascular surgery and healthy patients.
- Oxygen uptake using the two methods was correlated, but arm ergometry was a poor predictor of leg ergometry.
- Further study is required to establish the perioperative utility of arm ergometry.

Background. Cardiopulmonary exercise testing by cycle ergometry (CPETleg) is an established assessment tool of perioperative physical fitness. CPET utilizing arm ergometry (CPETarm) is an attractive alternative in patients with lower limb dysfunction. We aimed to determine whether oxygen uptake (VO2) obtained by CPETleg could be predicted by using CPETarm alone and whether CPETarm could be used in perioperative risk stratification.

Methods. Subjects underwent CPETarm and CPETleg. To evaluate the ability of VO2 obtained from CPETarm to predict VO2 from CPETleg, we calculated prediction intervals (PIs) at lactate threshold (AT) and peak exercise in both groups. Receiver operating characteristic (ROC) curves were used to risk stratify patients into high and low categories based on published criteria.

Results. We recruited 20 vascular surgery patients (17 males and three females) and 20 healthy volunteers (10 males and 10 females). In both groups, PIs for VO2 at AT and peak were wider than clinically acceptable (patient group—VO2 at AT CPETarm ranged from 55% to 108% of CPETleg and from 54% to 105% at peak; healthy volunteers—37–77% and 41–79%, respectively). The area under the ROC for CPETarm, VO2 in patients was 0.84 [95% confidence interval (CI): 0.66, 1.0] at AT, and 0.76 (95% CI: 0.54, 0.99) at peak.

Conclusions. Although a relationship exists between VO2 values for CPETarm and CPETleg, this is insufficient for accurate prediction using CPETarm alone. This however does not necessarily preclude the use of CPETarm in perioperative risk stratification.

Keywords: arm ergometry; cardiopulmonary exercise testing; cycle ergometry; preoperative assessment; vascular surgery

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Cardiopulmonary exercise testing (CPET) provides an integrated assessment and quantification of the cardiorespiratory system at rest and under stress of maximal exercise. CPET is gaining popularity as a physical fitness assessment tool before major elective surgery, including vascular, with evidence that variables such as oxygen uptake (VO2) at peak exercise and at estimated lactate threshold (AT) predict short- and long-term outcomes.1–5 Recently, CPET to maximal exercise has been suggested as identifying patients at risk of early perioperative death after elective abdominal aortic aneurysm (AAA) repair.6

CPET in the clinical setting is conducted on a cycle ergometer (CPETleg), but many vascular surgery patients are unable to perform this due to lower limb dysfunction such as joint arthrits, peripheral vascular disease, neurological disease, or previous amputations. CPET on an arm ergometer (CPETarm) is an attractive alternative as it provides data on physiological responses similar to those obtained by CPETleg. This has been validated in healthy subjects; however, it is currently not an accepted test in routine preoperative assessment. The maximum oxygen uptake obtained by arm ergometry is 60–80% of that measured by leg ergometry in healthy individuals,8–13 with a recent study suggesting 34% less VO2 at AT and VO2 at peak.14 The lower VO2 values obtained during CPETarm could be due to smaller muscle mass, distribution of fast twitch muscle fibres, recruitment pattern of motor units,13,15 and greater glycolytic enzyme activity.15 Literature around arm ergometry is mainly on healthy individuals11–13 with no literature available comparing arm and leg exercise testing in a patient population.

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The primary aim of this study was to determine whether oxygen uptake derived from CPETarm could be accurately predicted by using CPETarm alone in both healthy volunteers and perioperative patients. We considered an a priori predictive error for CPETarm of ±1.5 ml kg⁻¹ min⁻¹ for VO₂ at ˙uL and ±3.0 ml kg⁻¹ min⁻¹ for VO₂ at peak to be clinically acceptable. We also aimed to explore whether patients could be risk stratified using VO₂ obtained by CPETarm, in a similar fashion as for CPETleg (with known cut-off values of 10.2 ml kg⁻¹ min⁻¹ for VO₂ at ˙uL and 15 ml kg⁻¹ min⁻¹ for VO₂ at peak). Finally, we aimed to explore the validity of a previously published simple percentage proportionality relationship between VO₂ obtained from CPETarm and CPETleg.

Methods

Subjects

We prospectively recruited two cohorts: (i) preoperative patients being assessed before elective abdominal aortic surgery (patient group), and (ii) healthy volunteers. We chose these two groups in order to uncover potential differences in response to arm and leg exercise in elderly patients in comparison with younger healthy subjects. After ethical approval (09/H1001/94) and written informed consent, preoperative patients were requested to undergo CPET twice: CPETleg as part of their normal preoperative assessment process, and a CPETarm, as part of this study. Healthy volunteers also underwent the same two tests using the protocols detailed below. Eligible patients were free of acute illness or clinically evident peripheral vascular disease, and did not have any disability precluding arm or leg exercise. Healthy volunteers were untrained and free from illness. CPET was reported by an experienced clinical scientist (S.J.) who was blinded to the mode of exercise testing.

Cardiopulmonary exercise testing

Symptom-limited CPET was conducted in accordance with American Thoracic Society/American College of Chest Physicians recommendations. CPET was performed on calibrated electromagnetically braked cycle and arm ergometers. Gas and flow calibration was performed before each test. Both leg and arm CPET were carried out using similar ramped protocols set to 10–25 W min⁻¹ based on a calculation described by Wasserman and colleagues using predicted VO₂ at unloaded pedaling, predicted VO₂ at peak exercise, height, and patient age. Both protocols consisted of 3 min of rest, followed by 3 min of unloaded exercise, then the loaded ramp increased until volitional termination. This was followed by 5 min of recovery. Subjects were monitored throughout each test using pulse oximetry, 12-lead electrocardiography, and non-invasive arterial pressure monitoring. Ventilation and gas exchange variables were measured using a metabolic cart (Geratherm Respiratory GmbH (Love Medical Ltd, UK) and a cycle ergometer (Love Medical Ltd, Ergoline) or arm ergometer (Love Medical Ltd, Ergoline). For CPETleg, seat height was adjusted to ensure that full knee extension was achieved when the pedal was in the down position and handlebars raised to maintain full weight supported exercise. Subjects were instructed to cycle at a speed of 55–65 RPM during the test. This was monitored by the participant through a light-emitting diode display. The test was ended if RPM decreased below 45 or symptoms were encountered. For CPETarm, the arm ergometer was adjusted to ensure that participants sat on the chair with their arms slightly flexed, and maintaining their feet flat on the floor. They were asked to grasp handles in front of them, and ‘pedal’ with their arms in a circular motion, maintaining 55–65 RPM during the test until they could no longer push against the resistance or if the RPM decreased below 45. Breath-by-breath data were collected through a face mask and flow sensor that were appropriately fitted to each participant.

Measurements

Subject characteristics, including age, gender, height, weight, and clinical details, were recorded. Before the first CPET, resting flow-volume loops were measured in the patient group to derive forced expiratory volume over 1 s (FEV₁) and forced vital capacity (FVC). CPET variables measured included: expired ventilatory volumes, VO₂, carbon dioxide output, tidal volume, minute ventilation, work rate, respiratory exchange ratio, and oxygen pulse. VO₂ (ml kg⁻¹ min⁻¹) at ˙uL and at peak exercise were the primary outcome variables recorded. ˙uL was estimated conventionally (breakpoint in the VCO₂ − VO₂ relationship), with increases in ventilatory equivalent for oxygen (Ve/VO₂) and end-tidal (PETO) oxygen but no increase in ventilatory equivalent for carbon dioxide (Ve/VCO₂) or decrease in PeCO₂ by an experienced, blinded, assessor. The peak VO₂ was averaged over the last 30 s of exercise.

Data analysis

Continuous variables are summarized using the median and inter-quartile range (IQR). Paired t-tests were used to compare CPETarm and CPETleg values within patient groups. Linear regression was used to assess whether CPETleg could be predicted using CPETarm alone by estimating 95% prediction intervals (PIs). The PIs should be interpreted as a measure of how accurate our prediction of CPETleg would be for a new patient given only a CPETarm measurement. In order to meet the assumptions of linear regression, it was necessary to natural log transform CPETleg. For the ease of interpretation, the linear regression results were presented on the original scale, with the consequence that the resulting PIs were asymmetric and non-constant. For simplicity, the predictive ability of CPETarm was evaluated against the predefined acceptable widths at the CPETleg sample mean. Arm and leg measurements were compared using paired t-tests. The assumption of normality for the mean of the paired differences was assessed using the Q−Q plots.

Scatter plots of CPETleg vs CPETarm were constructed and boundaries representing CPETarm as a percentage of CPETleg were added. The purpose of these plots was to establish whether a simple relative relationship rule such as ‘CPETarm is typically x−y% of CPETleg’ could be advised. Finally, non-parametric receiver operating characteristic (ROC) curves were used to determine whether CPETarm could discriminate...
between high- and low-risk patients and hence become a useful perioperative risk stratification tool. Risk groups (high/low) were established by dichotomizing CPET\textsubscript{leg} at 10.2 ml kg\textsuperscript{-1} min\textsuperscript{-1} for \(\dot{V}\text{O}_2\) at \(\dot{t}\) and 15 ml kg\textsuperscript{-1} min\textsuperscript{-1} for \(\dot{V}\text{O}_2\) at peak based on published cut-off points (≥ cut-off—low risk and < cut-off—high risk).\textsuperscript{6}

All results were considered as statistically significant at the 5% level. All statistical analyses were carried out using Stata version 12.1 (StataCorp, 2011. Stata Statistical Software: Release 12, College Station, TX, USA).

Results

We prospectively screened 26 and recruited 23 (19 men, four women) vascular surgery patients. Three patients dropped out due to withdrawal of consent, aneurysmal rupture, and expedited elective surgery. Twenty patients were included with the median (IQR) age of 74 (70–77) yr and with body mass index of 27 (25–29) kg m\textsuperscript{-2}. Baseline pulmonary function tests showed a generalized mild–moderate obstructive pattern [according to GOLD spirometric criteria for chronic obstructive pulmonary disease (COPD) severity] with a median (IQR) FEV\textsubscript{1} of 93% (75.5–105.3), FVC 110% (97.8–128.5), and FEV\textsubscript{1}/FVC ratio of 63.5 (59–69) of their predicted values. Seventeen out of 20 patients had a median FEV\textsubscript{1}/FVC ratio of 61 (59–69); of which, six had an FEV\textsubscript{1} of < 80%. Patients were undergoing preoperative evaluation before elective AAA repair (n=16), elective thoraco-abdominal aortic aneurysm repair (n=1), combined AAA repair and cancer resection (n=2), and elective aorto-mesenteric bypass (n=1). Twenty healthy volunteers (10 men and 10 women) were also recruited, median (IQR) age of 31 (24–42) yr and median (IQR) body mass index of 27 (25–29) kg m\textsuperscript{-2}. The order of the CPET was not randomized. Arm and leg CPET was not carried out on the same visit and not more than 14 days apart [median 7 (range 6–14) days].

For both patients and healthy volunteers, \(\dot{V}\text{O}_2\) and workload values were lower during CPET\textsubscript{arm} compared with CPET\textsubscript{leg} (P<0.0001; Table 1). One patient experienced chest pain with electrocardiographic changes during CPET\textsubscript{leg}, but no signs or symptoms were reported during CPET\textsubscript{arm}, while another experienced significant oxygen desaturation (to 85%) during CPET\textsubscript{leg}, but not CPET\textsubscript{arm}.

In both groups, there was a strong correlation between \(\dot{V}\text{O}_2\) measured by the two tests, at \(\dot{t}\) (patient group—r=0.72, P=0.0003; healthy volunteers—r=0.64, P=0.0024) and at peak exercise (patient group—r=0.75, P=0.0001; healthy volunteers—r=0.77, P=0.0001), with \(\dot{V}\text{O}_2\) CPET\textsubscript{arm} being systematically lower than \(\dot{V}\text{O}_2\) CPET\textsubscript{leg}. After fitting a simple linear regression model, at the mean CPET\textsubscript{leg} \(\dot{V}\text{O}_2\) at \(\dot{t}\) of 11.1 ml kg\textsuperscript{-1} min\textsuperscript{-1} for the patient group, the PI’s width was 8.0 (4.0) ml kg\textsuperscript{-1} min\textsuperscript{-1} (Fig. 1a). For \(\dot{V}\text{O}_2\) at peak, the total width of the PI was 14.0 ml kg\textsuperscript{-1} min\textsuperscript{-1} at the mean of 16.6 ml kg\textsuperscript{-1} min\textsuperscript{-1}, approximately ± 7.0 ml kg\textsuperscript{-1} min\textsuperscript{-1} (Fig. 1a). In the healthy volunteer group, at the mean \(\dot{V}\text{O}_2\) at \(\dot{t}\) of 21.7 ml kg\textsuperscript{-1} min\textsuperscript{-1}, the total PI width was 19.9 (10.0) ml kg\textsuperscript{-1} min\textsuperscript{-1}. For \(\dot{V}\text{O}_2\) at peak, the total width of the PI was 25.3 ml kg\textsuperscript{-1} min\textsuperscript{-1} at the mean of 35.8 ml kg\textsuperscript{-1} min\textsuperscript{-1}, approximately ± 12.5 ml kg\textsuperscript{-1} min\textsuperscript{-1} (Fig. 2a and b).

The scatter plots in Figures 3 and 4 depict the relationship between \(\dot{V}\text{O}_2\) at \(\dot{t}\) and \(\dot{V}\text{O}_2\) at peak for CPET\textsubscript{arm} and CPET\textsubscript{leg} with overlaid percentage boundaries for CPET\textsubscript{arm} as a proportion of CPET\textsubscript{leg}. In the patient group, \(\dot{V}\text{O}_2\) at \(\dot{t}\) values ranged from 55% to 108% (median 79%) and \(\dot{V}\text{O}_2\) at peak values ranged from 54% to 105% (median 80%). In the healthy volunteer group, \(\dot{V}\text{O}_2\) at \(\dot{t}\), the range was 37–77% (median 56%) and for \(\dot{V}\text{O}_2\) at peak, the range was 41–79% (median 64%). We used ROC curve analysis to test the ability of CPET\textsubscript{arm} to discriminate between high- and low-risk patients by dichotomizing \(\dot{V}\text{O}_2\) at \(\dot{t}\) at 10.2 ml kg\textsuperscript{-1} min\textsuperscript{-1} and \(\dot{V}\text{O}_2\) at peak at 15 ml kg\textsuperscript{-1} min\textsuperscript{-1} as obtained from CPET\textsubscript{leg} (Fig. 5). The area under the ROC (AUROC) for \(\dot{V}\text{O}_2\) at \(\dot{t}\) in the patient group was 0.84 [95% confidence interval (CI): 0.66, 1.0], while for \(\dot{V}\text{O}_2\) at peak, the AUROC was 0.76 (95% CI: 0.54, 0.99).

Discussion

This study clearly showed that it is not possible to predict \(\dot{V}\text{O}_2\) obtained by CPET\textsubscript{leg} from CPET\textsubscript{arm}, in patients or healthy volunteers. The PIs for both \(\dot{V}\text{O}_2\) at \(\dot{t}\) and peak were unacceptable wide. We also found that CPET\textsubscript{arm} has a discrete ability to predict CPET\textsubscript{leg} when dichotomizing \(\dot{V}\text{O}_2\) obtained by CPET\textsubscript{leg} at the cut-off points described by Hartley and colleagues,\textsuperscript{6} however, it must be emphasized that in the proposed model, the \(\dot{V}\text{O}_2\) at \(\dot{t}\) cut-off was not used in isolation but as part of a more complex risk prediction model. Furthermore, we must also emphasize that although this might be deemed useful in perioperative risk stratification (especially when extremes of \(\dot{V}\text{O}_2\) are obtained by CPET\textsubscript{arm}), we are unable to justify the use of CPET by arm ergometry in this setting without further robust studies. Finally, when exploring the proportionality relationship between \(\dot{V}\text{O}_2\) obtained from CPET\textsubscript{arm} and CPET\textsubscript{leg}, we found very high variability in the \(\dot{V}\text{O}_2\) values of CPET\textsubscript{arm}, as a proportion of CPET\textsubscript{leg} such that any linear relationship would appear to be overly simplistic and would not accurately reflect the relative relationship between the two measurements.

It is not uncommon, in our practice, to encounter patients who are unsuitable for CPET on a cycle ergometer due to co-morbidity affecting the lower limbs. In these patients, arm ergometry is, intuitively, a potential alternative which, however, has not yet been clinically validated. We decided to test our hypothesis in two different groups of subjects (patients and healthy volunteers) because we suspected that elderly vascular patients could show a higher degree of variability between the two tests due to subclinical co-morbidity (e.g. mild joint arthritis in shoulder/hip/knee or COPD). In general, we found a strong correlation between \(\dot{V}\text{O}_2\) measured by the two tests, at \(\dot{t}\) and at peak exercise, with CPET\textsubscript{arm} being systematically lower than CPET\textsubscript{leg}. Although our findings in patients were mirrored by those in volunteers, it was notable that, in all volunteers, \(\dot{V}\text{O}_2\) at \(\dot{t}\) during CPET\textsubscript{arm} was never measured at more than three-quarters of the value recorded during CPET\textsubscript{leg}, while in patients, higher proportional values were seen...
Table 1  Oxygen uptake (\(\dot{V}O_2\)) and workload during CPET at estimated lactate threshold (\(\hat{u}_L\)) and peak exercise (\(\dot{V}O_2\) peak). Data presented as median (IQR)

<table>
<thead>
<tr>
<th>Patients</th>
<th>Arm</th>
<th>Leg</th>
<th>P-value</th>
<th>Healthy</th>
<th>Arm</th>
<th>Leg</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\dot{V}O_2) at (\hat{u}_L) (ml kg(^{-1}) min(^{-1}))</td>
<td>8.9 (6.9–9.6)</td>
<td>10.9 (8.9–12.8)</td>
<td>&lt;0.00005</td>
<td>11.5 (10.7–13.6)</td>
<td>20.8 (18.2–27.9)</td>
<td>&lt;0.00005</td>
<td></td>
</tr>
<tr>
<td>(\dot{V}O_2) at peak (ml kg(^{-1}) min(^{-1}))</td>
<td>12.1 (11.1–14.7)</td>
<td>16.2 (12.5–20.6)</td>
<td>&lt;0.00005</td>
<td>20.6 (19.9–24.2)</td>
<td>34.5 (29.4–40.7)</td>
<td>&lt;0.00005</td>
<td></td>
</tr>
<tr>
<td>Workload at (\hat{u}_L) (W)</td>
<td>42.0 (32–52)</td>
<td>50.0 (46–66)</td>
<td>0.0001</td>
<td>58.0 (50–68)</td>
<td>121 (100–155)</td>
<td>&lt;0.00005</td>
<td></td>
</tr>
<tr>
<td>Workload at peak (W)</td>
<td>73.0 (52–89)</td>
<td>92.0 (69–117)</td>
<td>0.0001</td>
<td>101 (86–137)</td>
<td>214 (188–256)</td>
<td>&lt;0.00005</td>
<td></td>
</tr>
</tbody>
</table>

Fig 1  Linear regression modelling of the relationship between CPET\(_{arm}\) and CPET\(_{leg}\) for the vascular surgery patient group. The curvature in the linear fits and PIs is a result of fitting a linear regression model to the log-transformed CPET\(_{leg}\). The limits of the 95% PIs give an indication of our uncertainty in predicting CPET\(_{leg}\) using CPET\(_{arm}\).
in half of the cases, with one even showing marginally higher $\dot{V}O_2$ during CPET$_{arm}$.

When evaluating the ability of $\dot{V}O_2$ obtained from CPET$_{arm}$ to predict $\dot{V}O_2$ obtained from CPET$_{leg}$ using the width of the estimated PIs at the CPET$_{leg}$ sample mean, we have shown that in both groups PIs for $\dot{V}O_2$ at $\hat{\eta}L$ and peak were prohibitively wide. This coupled with a lack of proportionality relationship indicates that CPET$_{arm}$ should not be used to determine $\dot{V}O_2$ obtained from CPET$_{leg}$.

Although CPET$_{arm}$ is unable to substitute CPET$_{leg}$ in perioperative risk stratification, it might still be a useful adjunct in risk assessment. Estimated AUROCs indicated that CPET$_{arm}$ may be useful in discriminating between low- and high-risk patients (since they both exceed 0.75); however, the CIs are wide, suggesting that a larger study is needed to confirm our findings. CPET$_{arm}$ may be useful in identifying patients at low risk of developing postoperative complication when patients attain high $\dot{V}O_2$ values. Furthermore, it also has the ability to detect subclinical co-morbidity (ECG changes, cardiac or ventilatory limitation) which might only become apparent when the cardiorespiratory system is stressed, albeit to a lesser degree than by using CPET$_{leg}$.

Cycle ergometry has been used in perioperative risk stratification since the late 1990s. Findings by Older and colleagues\textsuperscript{20} in elderly patients undergoing major intra-abdominal surgery suggest that preoperative $\dot{V}O_2$ at $\hat{\eta}_L < 11.0$ ml kg$^{-1}$ min$^{-1}$

\begin{figure}
\centering
\includegraphics[width=\textwidth]{Fig2.png}
\caption{Linear regression modelling of the relationship between CPET$_{arm}$ and CPET$_{leg}$ for the healthy volunteer group. The curvature in the linear fits and PIs is a result of fitting a linear regression model to the log-transformed CPET$_{leg}$. The limits of the 95\% PIs give an indication of our uncertainty in predicting CPET$_{leg}$ using CPET$_{arm}$.}
\end{figure}
was associated with increased cardiovascular mortality. In a later study and review,21 22 Older investigated the effects of triaging patients having a $\dot{V}o_2$ at $\hat{u}_L$, 11 ml kg$^{-1}$ min$^{-1}$ and concludes that using a small number of important variables obtained from CPET$\text{leg}$, we can accurately predict future response to perioperative stress. This was then replicated in various observational studies,1 –62 3 which conclude that variables derived from CPET$\text{leg}$ can be used in accurate risk prediction modelling with reasonable accuracy.

To date, CPET using arm ergometry in a perioperative setting has mainly focused on the ability of detecting ECG changes in patients with coronary artery disease.24 25 Arm exercise testing has also been utilized to determine physical fitness of vascular amputee patients before commencement of rehabilitation programmes.26 Traditionally, it has been suggested that if a person is healthy and has not undergone specific upper extremity training, the peak $\dot{V}o_2$ for arm cycling will be ≈50–70% of that for leg cycling.9 13 27 We have now demonstrated that the relationship between the two tests is too weak for such a rule. In healthy subjects, lower $\dot{V}o_2$ values during arm exercise are expected due to a smaller muscle mass of the arms compared with the legs and the lack of experience with rhythmic arm exercise which can result in fatiguing sooner.13 However, more recently, the interaction between limb blood flow and cardiac output (which limits the maximum rate in a given muscle group), the amount of work done, and its ATP cost, together with the ancillary work done by other muscles which contribute to the $\dot{V}o_2$ measured at the mouth, also need to be considered when accounting for arm-to-leg differences.28 29 This difference is also apparent in COPD patients, where other reasons are suggested for the lower $\dot{V}o_2$ values.30 Interestingly, baseline pulmonary function

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**Fig 3** Percentage plots for the vascular surgery patient group $\dot{V}o_2$ at $\hat{u}_L$ (A) and $\dot{V}o_2$ at peak (B).
tests in our vascular patient group presented with a generalized obstructive pattern.

Strengths of this study include the homogeneous nature of the study population, the blinded reporting of objectively measured CPET variables, and the prospective nature of the study. An inherent limitation is that we used the width of PIs as a measure of the predictive ability of CPETarm since this width is partly determined by the sample size (i.e. a larger sample size would result in a reduced width). However, the width of a PI does not approach zero as the sample size increases. Using our results, the PI widths were re-estimated for a large (infinite) sample size (results not shown), but the reduction in PI widths was only modest and still remained prohibitively wide. Another limitation of our study is that perhaps CPETleg could be more accurately predicted if other variables, alongside CPETarm, were considered as part of a multivariable model; however, this was beyond the scope of this project.

In conclusion, although a relationship exists between \( \dot{V}O_2 \) values for CPETarm and CPETleg, this was insufficient for \( \dot{V}O_2 \) obtained from CPETleg to be accurately predicted using CPETarm alone. Similarly, any relative or absolute relationship rule between the two tests would be overly simplistic and not encouraged. While these results do not necessarily preclude the use of high or low \( \dot{V}O_2 \) values, subclinical ECG changes, or the discovery of cardiac or ventilatory limitation in the perioperative risk stratification of patients with lower limb dysfunction, further evaluation of CPETarm as a perioperative risk assessment tool is necessary.
Authors’ contributions


Declaration of interest

None declared.

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Oxygen uptake in arm or leg ergometry

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