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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 ($CPET_{leg}$) is an established assessment tool of perioperative physical fitness. CPET utilizing arm ergometry ($CPET_{arm}$) is an attractive alternative in patients with lower limb dysfunction. We aimed to determine whether oxygen uptake ($\dot{V}o_2$) obtained by $CPET_{leg}$ could be predicted by using $CPET_{arm}$ alone and whether $CPET_{arm}$ could be used in perioperative risk stratification.

Methods. Subjects underwent $CPET_{arm}$ and $CPET_{leg}$. To evaluate the ability of $\dot{V}o_2$ obtained from $CPET_{arm}$ to predict $\dot{V}o_2$ from $CPET_{leg}$, we calculated prediction intervals (PIs) at lactate threshold ($\hat{\theta}_L$) 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 $\dot{V}o_2$ at $\hat{\theta}_L$ and peak were wider than clinically acceptable (patient group—$\dot{V}o_2$ at $\hat{\theta}_L$ $CPET_{arm}$ ranged from 55% to 108% of $CPET_{leg}$ and from 54% to 105% at peak; healthy volunteers—37–77% and 41–79%, respectively). The area under the ROC for $CPET_{arm}$ $\dot{V}o_2$ in patients was 0.84 [95% confidence interval (CI): 0.66, 1.0] at $\hat{\theta}_L$, and 0.76 (95% CI: 0.54, 0.99) at peak.

Conclusions. Although a relationship exists between $\dot{V}o_2$ values for $CPET_{arm}$ and $CPET_{leg}$, this is insufficient for accurate prediction using $CPET_{arm}$ alone. This however does not necessarily preclude the use of $CPET_{arm}$ 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 ($\dot{V}o_2$) at peak exercise and at estimated lactate threshold ($\hat{\theta}_L$) 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 ($CPET_{leg}$), but many vascular surgery patients are unable to perform this due to lower limb dysfunction such as joint arthritis, peripheral vascular disease, neurological disease, or previous amputations. CPET on an arm ergometer ($CPET_{arm}$) is an attractive alternative as it provides data on physiological responses similar to those obtained by $CPET_{leg}$. This has been validated in healthy subjects;[7] 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 $\dot{V}o_2$ at $\hat{\theta}_L$ and $\dot{V}o_2$ at peak.[14] The lower $\dot{V}o_2$ values obtained during $CPET_{arm}$ 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 individuals[11–13] with no literature available comparing arm and leg exercise testing in a patient population.

The primary aim of this study was to determine whether oxygen uptake derived from $CPET_{leg}$ could be accurately predicted by using $CPET_{arm}$ alone in both healthy volunteers and perioperative patients. We considered an *a priori* predictive error for $CPET_{arm}$ of ± 1.5 ml kg^{-1} min^{-1} for $\dot{V}o_2$ at $\hat{\theta}_L$ and ± 3.0 ml kg^{-1} min^{-1} for $\dot{V}o_2$ at peak to be clinically acceptable. We also aimed to explore whether patients could be risk stratified using $\dot{V}o_2$ obtained by $CPET_{arm}$ in a similar fashion as for $CPET_{leg}$ (with known cut-off values of 10.2 ml kg^{-1} min^{-1} for $\dot{V}o_2$ at $\hat{\theta}_L$ and 15 ml kg^{-1} min^{-1} for $\dot{V}o_2$ at peak).[6] Finally, we aimed to explore the validity of a previously published simple percentage proportionality relationship between $\dot{V}o_2$ obtained from $CPET_{arm}$ and $CPET_{leg}$.[8–11]

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: $CPET_{leg}$, as part of their normal preoperative assessment process, and a $CPET_{arm}$, 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.[16 17] 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[18] using predicted $\dot{V}o_2$ at unloaded pedalling, predicted $\dot{V}o_2$ 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 $CPET_{leg}$, 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 $CPET_{arm}$, 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 (FEV_1) and forced vital capacity (FVC). CPET variables measured included: expired ventilatory volumes, $\dot{V}o_2$, carbon dioxide output, tidal volume, minute ventilation, work rate, respiratory exchange ratio, and oxygen pulse. $\dot{V}o_2$ (ml kg^{-1} min^{-1}) at $\hat{\theta}_L$ and at peak exercise were the primary outcome variables recorded. $\hat{\theta}_L$ was estimated conventionally (breakpoint in the $\dot{V}co_2 - \dot{V}o_2$ relationship), with increases in ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}o_2$) and end-tidal ($P_{E'}$) oxygen but no increase in ventilatory equivalent for carbon dioxide ($\dot{V}_E/\dot{V}co_2$) or decrease in $P_{E'_{CO_2}}$[19] by an experienced, blinded, assessor.[18] The peak $\dot{V}o_2$ 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 $CPET_{arm}$ and $CPET_{leg}$ values within patient groups. Linear regression was used to assess whether $CPET_{leg}$ could be predicted using $CPET_{arm}$ alone by estimating 95% prediction intervals (PIs). The PIs should be interpreted as a measure of how accurate our prediction of $CPET_{leg}$ would be for a new patient given only a $CPET_{arm}$ measurement. In order to meet the assumptions of linear regression, it was necessary to natural log transform $CPET_{leg}$. 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 $CPET_{arm}$ was evaluated against the predefined acceptable widths at the $CPET_{leg}$ 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 $CPET_{leg}$ *vs* $CPET_{arm}$ were constructed and boundaries representing $CPET_{arm}$ as a percentage of $CPET_{leg}$ were added. The purpose of these plots was to establish whether a simple relative relationship rule such as '$CPET_{arm}$ is typically *x*–*y*% of $CPET_{leg}$' could be advised. Finally, non-parametric receiver operating characteristic (ROC) curves were used to determine whether $CPET_{arm}$ could discriminate