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Feasibility of Using Near Infrared Spectroscopy in Determining VO_2 for Preoperative Risk Assessment

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FEASIBILITY OF USING NEAR INFRARED SPECTROSCOPY IN DETERMINING VO_2 FOR PREOPERATIVE RISK ASSESSMENT

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ABSTRACT

Introduction: Cardiopulmonary exercise testing (CPX) has been used to identify elderly patients at high risk for mortality during major surgery; Older demonstrated that postoperative cardiovascular-related deaths were predicted by an anaerobic threshold (AT) < 11 ml/min/kg[1]. This methodology is limited by the uncomfortable and claustrophobic facemask used for standard CPX. During cycling, pulmonary-derived oxygen consumption (VO_2) is equivalent to twice muscle VO_2[2]. Our research group has developed novel methods of using near infrared spectroscopy (NIRS) to determine muscle oxygen saturation (SmO_2), muscle pH and hematocrit (Hct)[3]. **Hypothesis:** NIRS parameters, in combination with heart rate (HR) monitoring, may be used to estimate VO_2. **Methods:** Ten healthy subjects (5M/5F) performed CPX. Whole-body VO_2 was determined with a metabolic cart simultaneously with NIR spectra measures from the thigh. Muscle VO_2 was calculated using the Fick equation (VO_2 = SV x HR x C(a-v)O_2) where stroke volume was estimated from HR. Oxygen content difference was calculated from Hct and SmO_2 obtained with NIRS. VO_2 from pulmonary measures and NIRS VO_2 were compared by Bland-Altman analysis. AT was identified from spectrally determined pH[4]. **Results:** SV was gender specific and a mathematical equation was developed to calculate SV from HR during exercise. Using the gender specific equation for SV, NIRS VO_2 closely approximated whole-body VO_2 up to the AT. The mean bias between VO_2 from pulmonary measures and NIRS-derived VO_2 was -0.05 L/min, and the limits of agreement were -0.6 and +0.7 L/min (R^2 = 0.89). Larger errors were observed for VO_2 > AT. **Conclusion:** Our results demonstrate the feasibility of using NIRS-derived parameters and HR during exercise to estimate VO_2 for preoperative risk assessment.

INTRODUCTION

Postoperative morbidity and mortality may be reduced by identifying high risk individuals before surgery. Among the parameters identified by cardiopulmonary exercise testing (CPX) is the anaerobic threshold (AT), a point readily obtained by measuring oxygen consumption (VO_2). Older has shown that postoperative cardiovascular-related deaths are restricted to patients with an AT of <11 ml/kg/min[1]. He used these preoperative measurements as a means to appropriately triage patients postoperatively (i.e., ICU vs. ward admission). However, restrictive and claustrophobic masks during CPX VO_2 analysis may deter some patients.

Grassi has shown that the response of pulmonary-derived whole body and two times the invasively-measured muscle VO_2 during cycling exercise are similar[2]. Our group has used noninvasive near infrared spectroscopy (NIRS) to measure hemodynamic parameters such as pH, Hct, and capillary oxygen saturation (denoted SmO_2, as the sensor does not differentiate myoglobin and hemoglobin oxygen saturation)[3]. These NIRS-derived parameters may be used for screening of patients with low AT during exercise in a manner which is more comfortable to the subject.

HYPOTHESIS

Near infrared spectroscopy (NIRS), in combination with heart rate monitoring, may be used to determine VO_2 at the anaerobic threshold.

METHODS

Protocol

- 10 healthy subjects (5M, 5F)
- Graded cycle ergometry protocol which began at 50 W and increased 50 W per stage every 3 minutes until volitional fatigue
- Whole body VO_2 from pulmonary measures determined with standard metabolic cart (True One 2400, Parvo Medics, Salt Lake City, UT)
- NIRS sensor adhered to the skin over *vastus lateralis* muscle to measure pH, SmO_2, Hct
- HR measured with heart rate monitor (810S, Polar Electro Inc, Lake Success, NY)

Fick Equation

VO_2 = SV x HR x C(a-v)O_2

C(a-v)O_2 = (97-SvO_2)/100 x 1.34 x [Hb] x 10 + ~~(0.003 x PO_2)~~

Obtained with NIRS

Stroke Volume

- Research shows that SV progressively increases to VO_2 max in trained and untrained subjects, and SV found to be related to HR[5,6]
- Therefore, stroke volume was estimated from HR based upon population models of SV response during exercise (Krip et al[6])
- Using the average of three subjects' resting seated stroke volumes from echocardiographic measures, predicted percent change at each HR interval during exercise was used to determine SV values during graded exercise protocol
- Stroke volume estimates for three subjects were plotted versus HR and the resulting best fit equation was obtained
- Equation was modified for gender and applied to remaining subjects

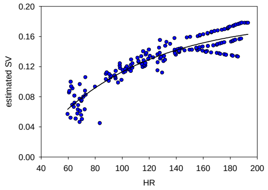
Determination of AT

- Identified by NIRS-measured change in pH (denoted the H^+ threshold, which is shown to be highly correlated with classic metabolic indicators of AT)[4]

Data Analysis

- NIRS-measured muscle VO_2 plotted versus pulmonary VO_2 up to AT
- The two methods of measurement compared with Bland-Altman analysis and correlation coefficient.

RESULTS

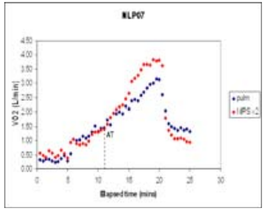


$$SV = C(1 - e^{-0.0132(HR-27.45)})$$

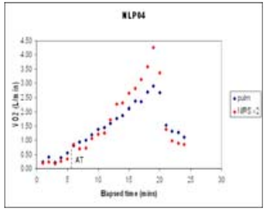
- The best fit equation to estimate SV was found to be an exponential with offset multiplier. The multiplier 'C' is effectively the stroke volume at maximum VO_2 for the test.
- The equation was applied to all subjects, and C was varied until the best fit was obtained for each subject.
- C was found to have one value for male and a different value for female subjects:

  Males: C = 0.154 ± 0.035

  Females: C = 0.096 ± 0.018

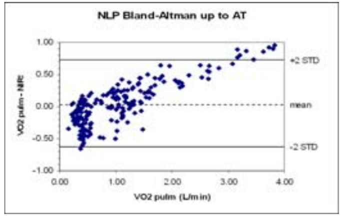


Typical male subject plot



Typical female subject plot

- Pulmonary-derived VO_2 and NIRS-derived muscle VO_2 are well-correlated up to the AT (R^2 = 0.89).
- Larger differences between the two measurements are seen after the AT.



•Bias = 0.046

•Limits of agreement:
-0.64, +0.73

•Discordant values of pulmonary VO_2 above 2.5 L/min attributed to one subject, an elite athlete who did not fit the general model

DISCUSSION

- NIRS-derived muscle VO_2 and whole body VO_2 are strongly correlated for exercise up to the AT.
- After the AT, larger errors may be attributed to differences between SmO_2 and SvO_2.
- The Fick equation assumes we measure SvO_2, but for VO_2 > AT, myoglobin desaturation may contribute substantially to SmO_2, thereby overestimating VO_2 with the NIRS method.
- Additional work is required to determine whether the limits of agreement between the two methods of measuring VO_2 are small enough to be of clinical value.

Limitations

- This study utilized a small sample of young, healthy subjects, whose responses may not be representative of the elderly population who might benefit most from preoperative risk assessment.
- The SV values were estimated based on HR response for three subjects, and this model may not be accurate for all individuals.

CONCLUSIONS

- Using NIRS is a feasible method of measuring VO_2 up to the AT in young active subjects, but this method must be validated in the target population.
- The accuracy of this technique might be improved if myoglobin desaturation is accounted for and better estimates of SV during exercise are obtained (work on-going).
- Ultimately, NIRS monitoring may prove to be useful alternative to the more involved and potentially uncomfortable technique of measuring VO_2 using a metabolic cart.

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REFERENCES

1. Older et al. *Chest.* 1999, 116:355-362
2. Grassi et al. *J Appl Physiol.* 1996, 80:988-998
3. Yang et al. *Optics Express*. 2007, 15:13715-13730
4. Soller et al. *J Appl Pysiol.* In revision
5. Vella et al. *Br J Sports Med.* 2005, 39:190-195
6. Krip et al. *Med Sci Sports Exerc.* 1997, 29:1469-1476