Electromyographic Response to Exercise in Cardiac Transplant Patients*

A New Method for Anaerobic Threshold Determination?

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The purpose of this study was to investigate the possible use of integrated surface electromyography (iEMG) in cardiac transplant patients (CTPs) as a new noninvasive determinant of the metabolic response to exercise by studying the relationship between the iEMG threshold (iEMGt) and other more conventional methods for anaerobic threshold (AT) determination, such as the lactate threshold (LT) and the ventilatory threshold (VT). Thirteen patients (age: 57±7 years, mean±SD; height: 163±7 cm; body mass: 70.5±8.6 kg; posttransplant time: 87±49 weeks) were selected as subjects. Each of them performed a ramp protocol on a cycle ergometer (starting at 0 W, the workload was increased in 10 W/min). During the tests, gas exchange data, blood lactate levels, and iEMG of the vastus lateralis were collected to determine VT, LT, and iEMGt, respectively. The results evidenced no significant difference between mean values of VT, LT, or iEMGt, when expressed either as oxygen uptake (11.1±2.4, 11.7±2.3, and 11.0±2.8 mL/kg/min, respectively) or as percent maximum oxygen uptake (61.6±7.5, 62.2±7.7, and 59.6±8.2%, respectively). In conclusion, our findings suggest that iEMG might be used as a complementary, noninvasive method for AT determination in CTPs. In addition, since the aerobic impairment of these patients is largely due to peripheral limitation, determination of iEMGt could be used to assess the effectiveness of an exercise rehabilitation program to improve muscle aerobic capacity in CTPs.

Key words: anaerobic threshold; cardiac transplantation; electromyography; exercise

Abbreviations: AT=anaerobic threshold; CTPs=cardiac transplant patients; EMG=electromyography; iEMG=integrated surface electromyography; iEMGt=electromyographic threshold; HR=heart rate; LT=lactate threshold; VO₂=Oxygen uptake; VO₂ peak=peak oxygen uptake; VT=ventilatory threshold

The high survival rates of patients after orthotopic heart transplantation have led many investigators to study the cardiorespiratory and metabolic responses to exercise of cardiac transplant patients (CTPs). In this regard, the anaerobic threshold (AT) has been used as an objective parameter for the determination of functional capacity in CTPs. It has been reported that in these patients, AT occurs at lower exercise intensities than expected when compared either with age-matched control groups of healthy individuals or with patients who had undergone other types of cardiac surgery.

On the other hand, since Wasserman and coworkers originally proposed the AT to predict aerobic endurance capacity, several methods have been reported for AT determination, based on the determination of different physiologic parameters such as expired gas, blood lactate and catecholamines, heart rate (HR), salivary composition, or the electromyographic (EMG) response of skeletal muscles to exercise. Concerning the latter method, it is known that surface EMG is available to quantify the total activity of working muscles and that integrated surface EMG (iEMG) is an acceptable method for estimating muscle fatigue noninvasively. Indeed, an increase in iEMG has been shown to reflect the recruitment of additional motor units and an increase in motor unit rate coding as the

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strength of a muscle contraction increases. In this line of thought, several studies have evidenced the existence of a nonlinear increase in iEMG during the aerobic-anerobic transition phase in ergometer cycling, indicating that iEMG could be used as a noninvasive method for AT determination.\textsuperscript{20,21,23,24} Indeed, an iEMG threshold (iEMG\textsubscript{r}) has been suggested to occur in the vastus lateralis,\textsuperscript{20,21,23,25} rectus femoris,\textsuperscript{23} and vastus medialis,\textsuperscript{23} during incremental tests in a cycle ergometer. Such threshold, in turn, would represent the point where there is an increased contribution from fast twitch motor units to maintain the required energy supply for muscle contraction.\textsuperscript{21,23} Other studies, however, have observed a linear relationship between iEMG and exercise intensity in ergometer cycling.\textsuperscript{26-29}

To our knowledge, no study has been reported regarding the iEMG response to exercise in CTPs. It was therefore the purpose of our investigation to analyze the iEMG response of leg muscles (vastus lateralis) of a group of CTPs during an incremental test in cycle ergometry. In addition, we aimed to investigate the possible use of iEMG in these patients as a noninvasive determinant of the metabolic response to exercise by studying the relationship between iEMG response (iEMG\textsubscript{r}) and that of more conventional methods for AT determination such as blood lactate levels (lactate threshold [LT]) and ventilatory parameters (ventilatory threshold [VT]).

**Materials and Methods**

**Subjects**

Thirteen patients (10 male and three female) who had undergone orthotopic cardiac transplantation (age: 57±7 years, mean±SD; height: 163±7 cm; body mass: 70.5±8.6 kg) participated in this study. Written informed consent was given prior to participation in the experiments, in accordance with the institutional human subjects guidelines (Escuela de Medicina del Deporte de la Universidad Complutense de Madrid). At the time of evaluation, the mean posttransplant time of the subjects was 87±49 weeks (range, 13 to 180 weeks). All the patients were receiving immunosuppressive therapy consisting of cyclosporine, azathioprine, and prednisone, and had no signs of acute rejection.

**Study Protocol**

Prior to each exercise testing session, patients were familiarized with the equipment and procedures used in this investigation. All the subjects performed a bicycle ergometer test (Ergometrics 900; Ergo-line: Barcelona, Spain) in a thermally moderate environment (21 to 24°C, 45 to 55% relative humidity). Each of the tests consisted of a ramp protocol, starting at 0 W; the workload was increased in 10 W/min, and pedaling cadence was kept constant at 60 to 80 rpm. HRs (beats/min) were continuously monitored during the tests from modified 12-lead ECG tracings (EK56; Hellige; Freiburg, Germany). Exercise tests were terminated (1) voluntarily by the subjects, (2) when pedaling cadence could not be kept at least at 60 rpm, or (3) when established criteria of test termination were met.\textsuperscript{30}

**Expired Gas Analysis and Ventilatory Threshold Determination**

During the tests, gas exchange data were collected continuously using an automated breath-by-breath system (CPX; Medical Graphics; St. Paul, Minn), based on a method described elsewhere.\textsuperscript{31} The measuring instruments were calibrated before each test and the necessary environmental adjustments were made. The VT was determined using the criterion of an increase in both the ventilatory equivalent for oxygen and the end-tidal Po\textsubscript{2} with no increase of the ventilatory equivalent for carbon dioxide.\textsuperscript{14}

**Blood Lactate Concentration and LT Determination**

Capillary blood samples (50 μL) for the measurement of blood lactate (YSI 23L; Yellow Springs Instruments; Yellow Springs, Ohio) were taken from fingertips at rest, every 2 min during the test, and immediately after termination of exercise.

The LT was determined by examining the “lactate concentration-work load” relationship during the tests, using the method previously described by Weltman and coworkers.\textsuperscript{32} Thus the greatest work rate not associated with a rise in lactate concentration above the baseline was designated as the workload corresponding to LT.

Two independent observers detected LT and VT following the criteria previously described. If they did not agree, the opinion of a third investigator was included.

**Electrode Placement**

The EMGs were recorded from the vastus lateralis using a bipolar electrode configuration with an interelectrode distance of 20 mm. These electrodes were placed over the belly of the muscle approximately at the midpoint between the head of the greater trochanter and the lateral condyle of the femur.\textsuperscript{33} A reference electrode was placed equidistant with respect to the differential electrodes. Prior to electrode application, the skin was shaved and abraded using sandpaper to minimize the source impedance.

**EMG Instrumentation and Procedures**

Myoelectric signals during exercise tests were amplified with band-pass filtering (250 Hz) and recorded on a digital data recorder (ME3000P; Mega Electronics Ltd; Kuopio, Finland). Data were digitized at a sampling frequency of 1 kHz, and the iEMG was calculated at every 2-s interval by the use of a computer (486DX66; Inverstronica; Washington). In each subject, we obtained a graphic representation of the EMG recording, representing the increase in muscle electrical activity (iEMG, in microvolts) during the ramp test, as exercise intensity gradually increased with time. Figure 1 provides an example of the EMG response of one subject.

**iEMG\textsubscript{r} Determination**

The iEMG data against time during each exercise test were fitted mathematically to two straight lines by linear regression to determine the breakpoint (iEMG\textsubscript{r}) of the linear relationship between iEMG and time of exercise (that is to say, iEMG against work rate) (Fig 1).\textsuperscript{34} The exercise time (s) corresponding to the
iEMGT was therefore determined as the crossing point of the two lines.

Comparison Among VT, LT, and iEMGT

Each individual value of VT, LT, and iEMGT corresponded to a certain time point (work rate) during the tests, which in turn elicited a certain value of Vo2. Therefore, to compare the exercise intensity at which all three thresholds occurred, mean values of VT, LT, and iEMGT were expressed both in oxygen uptake (Vo2) (in mL/kg/min) and in percent peak oxygen uptake (Vo2 peak).

Data Analysis

Results were expressed as mean±SD. Repeated measures of analysis of variance were used to determine if there was a significant difference (p<0.05) among mean values of VT, LT, and iEMGT when expressed in Vo2 (mL/kg/min) and in percent Vo2 peak. In addition, the relationship among VT, LT, and iEMGT was assessed using the Pearson correlation coefficient at the 0.05 level of significance.

Results

Exercise Termination

All patients voluntarily terminated the exercise tests due to either leg or general fatigue, or dyspnea, and not because of altered hemodynamic responses (ie, ECG abnormalities). The average duration of tests was of 491±115 s.

Peak Values

Peak values of Vo2, respiratory exchange ratio, minute ventilation, HR, and lactate averaged 18.3±4.8 mL/kg/min, 1.06±0.1, 53.3±25.4 L/min, 125±17 beats/min, and 4.7±1.7 mmol/L, respectively. The subjects reached an average value of peak work of 87.0±44.2 W (range: 46 to 227 W) at the end of exercise.

Comparison Among LT, VT, and iEMGT

Using the methods described above, VT and LT could be detected in 100% (n=13) and 85% (n=10) of subjects, respectively. Average values of LT occurred at a blood lactate concentration of 1.5±0.5 mmol/L. However, an EMG threshold response was identified in 100% of the subjects.

Mean values of VT, LT, and iEMGT expressed in Vo2 (mL/kg/min) and in percent of Vo2 peak are expressed in Table 1. No significant differences (p<0.05) were found among mean values of VT, LT, or iEMGT when expressed either as Vo2 or as %Vo2 peak.

Finally, all three parameters were significantly correlated (p<0.05) when expressed as Vo2 or as %Vo2 peak (Table 2).

Figure 1. Example of EMG response in one subject. Each data point represents a value of iEMG, recorded at every 2-s interval. The iEMG data against time were fitted mathematically to two straight lines by linear regression.
Table 1—Mean Values of VT, LT, and iEMGr*

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<th>(\text{Vo}_2 ) mL/kg/min</th>
<th>%(\text{Vo}_2) Peak</th>
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<tbody>
<tr>
<td>VT</td>
<td>11.1 ± 2.4</td>
<td>61.6 ± 7.5</td>
</tr>
<tr>
<td>LT</td>
<td>11.7 ± 2.3</td>
<td>62.2 ± 7.7</td>
</tr>
<tr>
<td>iEMGr</td>
<td>11.0 ± 2.8</td>
<td>59.6 ± 8.2</td>
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*All the results are expressed as mean±SD. No significant differences existed between means (p<0.05).

Figure 2 shows an example of determination of VT, LT, and iEMGr, respectively, in the same subject.

Discussion

Peak Values

The low values of \(\text{Vo}_2\) peak (18.3 ± 4.8 mL/kg/min) obtained in our investigation are in agreement with those reported for CTPs in previous studies, at about two-thirds of those of age-matched control subjects.\(^1\),\(^6\) Lactate levels at peak exercise, on the other hand, were also similar to those reported by other authors.\(^1\),\(^5\),\(^6\) Finally, mean values of peak HRs (125 ± 17 beats/min) were similar to those reported in other studies.\(^7\),\(^8\) Some authors, however, have reported higher values of \(\text{Vo}_2\) peak and peak HR in younger CTPs (mean age younger than 50 years).\(^2\),\(^3\),\(^9\) In addition, our protocol did not include a warm-up period. During warm-up periods, indeed, circulating catecholamine levels might increase before the beginning of testing, leading to higher HRs during a test.\(^9\)

Ventilatory and Lactate Thresholds

In our investigation, the %\(\text{Vo}_2\) peak corresponding to the VT and to the LT (approximately 62%) was higher than the values reported in previous studies,\(^1\),\(^5\) in the range of 50 to 60% \(\text{Vo}_2\) peak. Such difference, in turn, might be partly explained by the ramp protocol used in our study. During such types of protocols, indeed, the blood lactate response to exercise might be delayed.\(^35\) In addition, our subjects (mean, 57 years) were, in general, older than those selected in previous research with CTPs. In this regard, it has been suggested that the pattern of recruitment of fast glycolytic fibers might be altered with aging, resulting in a delayed lactate response during exercise.\(^36\) In a study recently reported by us, indeed, the LT of a group of CTPs with similar characteristics occurred at 64% \(\text{Vo}_2\) peak.\(^7\)

However, no significant differences were noted between VT and LT, in accordance with the original work conducted by Wasserman\(^37\) and with the findings of previous research with CTPs.\(^1\)

EMG Response and AT

To our knowledge, this is the first report to analyze the EMG response of CTPs during incremental cycle ergometry. Previous studies with healthy individuals have evidenced the occurrence of a point (the "iEMGr") where the increase of iEMG of quadriceps muscles becomes nonlinear during such type of exercise.\(^20\),\(^23\),\(^34\) This iEMGr, in turn, has been shown to occur during the transition from aerobic to anaerobic metabolism, at similar exercise intensities to that of the AT.\(^20\),\(^23\),\(^24\) Indeed, the iEMGr might occur as a result of a change in the pattern of motor unit recruitment from predominantly fast-twitch motor units to fast-twitch motor units, which could contribute to the accumulation of circulating lactate during exercise.\(^20\),\(^21\),\(^23\),\(^24\) The iEMGr has therefore been suggested as an alternative, noninvasive method for AT determination.\(^20\),\(^24\)

Our results are in agreement with those of previous studies with healthy subjects, since no significant differences were evidenced between the exercise intensity corresponding to the iEMGr and that corresponding to the AT (determined both with ventilatory parameters and blood lactate concentration). It follows that iEMG might represent a complementary, noninvasive method for AT determination in this population group. Furthermore, this method might be used to study the metabolic response of CTPs to exercise. A major limitation of our findings, however, comes from the fact that we did not study the test-retest reliability of AT determination with iEMG in CTPs. Thus, new research is still needed in this regard to further assess the validity of iEMG for AT determination.

Clinical Implications

Peripheral limitation is one of the factors responsible for the aerobic impairment of CTPs.\(^10\) In this perspective, determination of iEMGr might represent a valuable tool for assessing the effectiveness of an exercise rehabilitation program to improve muscle capacity in CTPs. A shift of iEMGr to a higher percentage of \(\text{Vo}_2\) peak, indeed, should be expected.

Table 2—Correlation Coefficients Among VT, LT, and iEMGr, Expressed as \(\text{Vo}_2\) (mL/kg/min) or as %\(\text{Vo}_2\) Peak*

<table>
<thead>
<tr>
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<th>VT</th>
<th>LT</th>
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<tr>
<td>VT</td>
<td>—</td>
<td>0.96 ((\text{Vo}_2))</td>
</tr>
<tr>
<td>LT</td>
<td>0.59 ((\text{Vo}_2))</td>
<td>0.88 (%(\text{Vo}_2) peak)</td>
</tr>
<tr>
<td>iEMGr</td>
<td>0.76 (%%(\text{Vo}_2) peak)</td>
<td>0.74 (%(\text{Vo}_2) peak)</td>
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*p<0.05 for all correlations.
with a successful exercise program, reflecting an improvement in muscle utilization of aerobic metabolism and an attenuation of peripheral limitations.

In conclusion, our results suggest that iEMG represents a valid, noninvasive method for AT determination in CTPs, and thus a complementary tool for assessing the overall functional capacity of these patients. Further research, however, is necessary to evaluate the practical implications of our findings.

**REFERENCES**


Moritani T, de Vries HA. Anaerobic threshold determination by surface electromyography: re-examination of the relationship between the surface integrated electromyogram (iEMG) and force of isometric contraction. Am J Phys Fitness 1978; 57:263-77


