# Assessment of Skeletal Muscle Fatigue in Men With Coronary Artery Disease Using Surface Electromyography During Isometric Contraction of Quadriceps Muscles

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ABSTRACT. Gayda M, Merzouk A, Choquet D, Ahmaidi S. Assessment of skeletal muscle fatigue in men with coronary artery disease using surface electromyography during isometric contraction of quadriceps muscles.Arch Phys Med Rehabil 2005;86:210-5.

**Objective:** To evaluate whether using surface electromyography to assess skeletal muscle fatigue during an isometric exercise has the potential to be clinically useful in patients with coronary artery disease (CAD).

**Design:** Double sample comparative study.

**Setting:** Cardiac rehabilitation service in France.

**Participants:** Sixteen men with documented CAD and 9 age-matched healthy men.

**Interventions:** Assessment of quadriceps skeletal muscle fatigue on an isokinetic apparatus with surface electromyography measurements and a symptom-limited exercise test in a laboratory.

**Main Outcome Measures:** The maximal voluntary isometric force (MVIF) of the quadriceps was quantified as a measure of muscle strength and isometric endurance was defined as the time required to sustain a contraction at 50% of MVIF until exhaustion. Surface electromyography signals were recorded from the vastus lateralis, rectus femoris, and vastus medialis during isometric endurance. The root mean square (RMS) and the median frequency (MF) were directly calculated on a computer and then normalized (as a percentage of the initial value).

**Results:** Muscle strength did not differ significantly between the patients with CAD and the healthy subjects (229±21N/m vs 228±52N/m), but isometric endurance was reduced (64±17s vs 90±7s, $P<.01$). The RMS values showed a significantly higher increase in the healthy subjects versus the patients with CAD for the vastus lateralis and vastus medialis ($P<.001$). The MF values were significantly lower for the vastus lateralis, rectus femoris ($P<.01$), and vastus medialis ($P<.05$) in patients with CAD compared with the healthy subjects.

**Conclusions:** Skeletal muscle fatigue occurs sooner in men with CAD relative to matched healthy men, despite similar muscle strength. This finding may be the result of an abnormality of skeletal muscle function and may play an important role in measuring functional capacity. In addition, it may be a useful tool to assess the efficacy of cardiac rehabilitation interventions.

**Key Words:** Coronary artery disease; Electromyography; Muscle fatigue; Rehabilitation.



Impaired exercise tolerance is a major problem in patients with coronary artery disease (CAD) and often results in functional disabilities.[1] Myocardial ischemia associated with CAD can lead to exertional dyspnea, which may limit exercise capacity.[1,2] Patients with CAD limit their physical activities because of exercise intolerance. This pattern results in a cycle of inactivity and physical deconditioning and, consequently, daily activities, and quality of life (QOL) are reduced.[1,3] Diminished muscle strength and perceived fatigue are frequently associated with exercise intolerance and may be responsible for these limitations.[1] However, skeletal muscle fatigue and its mechanisms remain poorly documented in CAD patients.

Surface electromyography is a noninvasive way to assess how the neuromuscular system is functioning.[4-6] By analyzing surface electromyography spectral parameters (root mean square [RMS], median frequency [MF]), one may evaluate how motor units are functioning and also evaluate skeletal muscle fatigue.[4,5] During isometric exercise, in healthy subjects, skeletal muscle fatigue is associated with an increase in the surface electromyographic signal amplitude (RMS) and with a shift of the surface electromyography spectrum (MF) toward lower frequencies.[4,5]

Despite the reproducibility of the surface electromyographic signal during isometric exercise,[5,6] this technique is seldom used in cardiac patients, probably because of technical difficulties.[7,8] The present study provides a new approach to the study of skeletal muscle function in this population, with an accurate assessment of skeletal muscle fatigue that associates surface electromyographic measurement and skeletal muscle tension development. To our knowledge, this approach has never been used in patients with CAD. We believe it may have significant clinical relevance in the assessment of functional capacity. We also believe that using surface electromyography to assess skeletal muscle fatigue may be useful for the evaluation of therapeutic interventions in CAD patients, including exercise training programs. The aim of the present study was, therefore, to establish the potential usefulness of this technique for CAD patients by assessing skeletal muscle fatigue of the quadriceps muscle in CAD patients compared with healthy control subjects, using surface electromyography during a submaximal isometric contraction.

## METHODS

Sixteen male patients with CAD documented by prior myocardial infarction, prior coronary angiography or angioplasty, or myocardial ischemia on myocardial scintigraphy and 9 aged-

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**Table 1: Clinical Characteristics of the Patients With CAD**

| Characteristics | Values |
|---|---|
| Diagnosis | |
| Myocardial infarction | 4 |
| CABS | 7 |
| Angioplasty | 3 |
| NYHA classification | |
| I | 9 |
| II | 7 |
| Mean LVEF ± SD (%) | 52±9 |
| Treatment | |
| Calcium channel blockers | 10 |
| ACE inhibitors | 5 |
| Aspirin | 10 |
| Calcium inhibitors | 1 |
| Amiodarone | 1 |
| Statins | 10 |
| Diuretics | 1 |
| Oral antidiabetics | 1 |
| β-blockers | 11 |

NOTE. Values are number of patients are concerned or as indicated.
Abbreviations: ACE, angiotensin-converting enzyme; CABS, coronary artery bypass surgery; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; SD, standard deviation.

matched healthy men free of any cardiac pathology took part in this study. The healthy control subjects were free of any medications prescribed to treat CAD and its risk factors, including statins. The clinical characteristics of the CAD patients are in table 1. Anthropometric data (age, weight, height, fat mass, lean body mass, total volume of the lower limb, muscle volume of lower limb) were carried out before beginning the tests, with the measurement of skinfolds and the circumferences of the lower limb[9] (table 2). All subjects were randomly assigned to an evaluation of their skeletal muscle function. That evaluation was done on an isokinetic apparatus with surface electromyographic measurements. A medical doctor was present during the skeletal muscle function assessment. Patients were excluded from the study if the resting left ventricular ejection fraction (LVEF) was less than 35% or if they had severe exertional ischemia (>3mm ST-segment depression), severe exertional arrhythmias, or an exercise limitation due to a noncardiopulmonary cause (eg, arthritis). The resting LVEF was evaluated by using angioventriculography technique. All patients gave their written consent to participate in the study. The study was approved by the local ethics committee and complied with the ethical standards of the 1975 Declaration of Helsinki.

## Skeletal Muscle Function Assessment

Skeletal muscle fatigue was measured for the quadriceps on an isokinetic apparatus[a] by using a methodology previously described.[10] Previous work[10,11] in which no adverse effects on cardiovascular or musculoskeletal systems were noted showed the safety of isometric strength and endurance testing in male CAD patients. Subjects were seated and positioned at a knee and a hip angulation of 60° and 120°, respectively. They were strapped at chest and knee to maintain these angles. Skeletal muscle function was evaluated by measuring the maximal voluntary isometric force (MVIF) and the isometric endurance time at an intensity level of 50% of the MVIF. Subjects were allowed to become familiar with the apparatus before measurements. During MVIF measurement, each subject could visualize the production of his muscular force on a computer screen and encouragement was given to obtain the best MVIF. Subjects performed 3 sets of 5 repetitions, to develop a maximum force. Each repetition was separated by 20 seconds of recovery, and each set was separated by a 1-minute recovery period. The best values of each set were retained and averaged; this average value was considered as the MVIF. To measure their isometric endurance time, subjects were asked to maintain an isometric contraction at 50% of the MVIF for as long as possible. A visual reference mark corresponding to 50% of the MVIF was placed on the computer screen. Subjects were asked to look at it and control their contraction as best they could. They were asked to maintain this contraction intensity near the visual reference mark during the test. As soon as the produced force reached this reference mark, a stopwatch was started to measure isometric endurance time. The subjects were encouraged during isometric endurance time measurement, and elapsed time was regularly given to their subjects every 15 seconds. The isometric endurance test stopped when the subjects were unable to maintain the contraction intensity near the visual reference mark (when a 5% drop of the produced force occurred).

## Surface Electromyographic Measurements and Analysis

During isometric endurance tests, the surface electromyographic activities were recorded for the vastus lateralis, the rectus femoris, and the vastus medialis muscles. Bipolar (20-mm interelectrode distance) surface electromyographic recordings were used. Surface electromyography electrodes (Ag-AgCl electrodes with 8-mm active diameter)[b] were placed according to previously described methodology.[11] For the vastus lateralis, electrodes were located 25% of the distance proximal to the lateral tibial condyle on a line connecting this patient and the anterior superior iliac spine (ASIS). For the rectus femoris, electrodes were placed at middistance along the line connecting the ASIS to the superior aspect of the patella. The electrodes were located over the vastus medialis at a position approximately 20% of the distance along a line connecting the medial gap of the knee to the ASIS. Before electrodes application, the skin was cleaned by abrasion and sponging with an alcohol-ether-acetone mixture to reduce interelectrode impedance below 2kΩ.

The myoelectric activities of the vastus lateralis, the rectus femoris, and the vastus medialis were amplified (differential amplifier) and were passed through upper (1kHz) and lower (1Hz) cutoff filters. The surface electromyographic signals were analyzed on-line by using acquisition and spectrum analyzer software[c] and data computing software.[12,13,c] The surface electromyographic signals were sampled at 1024Hz. The soft-

**Table 2: Anthropometric Data of the Healthy Subjects and the Patients With CAD**

| Characteristics | Healthy Subjects (n=9) | CAD Patients (n=16) |
|---|---|---|
| Age (y) | 58±8 | 55±8 |
| Weight (kg) | 74±6 | 85±12 |
| Height (cm) | 171±3 | 172±6 |
| Fat mass (%) | 23.27±1.85 | 27.92±3.12* |
| LBM (kg) | 56.96±4.00 | 61.57±6.93 |
| TVLL (L) | 12.46±0.59 | 12.39±1.60 |
| MVLL (L) | 9.37±0.42 | 8.49±1.21 |

NOTE. Values are mean ± SD.
Abbreviations: LBM, lean body mass; MVLL, muscle volume of lower limb; TVLL, total volume of lower limb.
*$P<.01$.

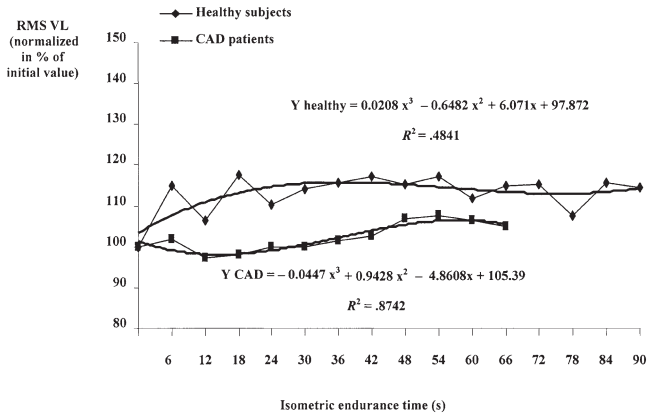


**Fig 1. RMS values for the vastus lateralis in both groups. Mean values fitted out with third-degree polynomial function. Abbreviation: VL, vastus lateralis.**

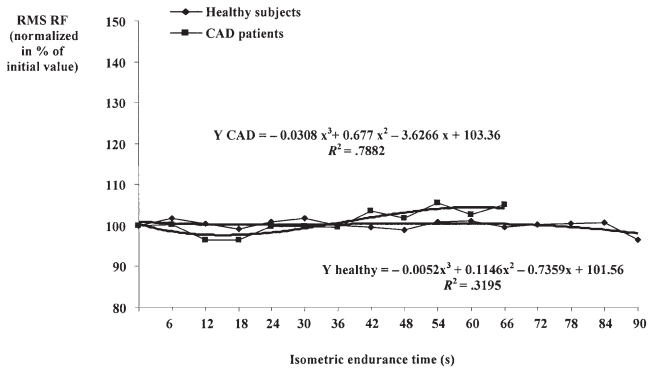


**Fig 2. RMS values for the rectus femoris in both groups. Mean values fitted out with third-degree polynomial function. Abbreviation: RF, rectus femoris.**

ware computed a mean power spectrum density by calculating the RMS values of 8 consecutive spectra obtained from 0.5-second time windows. The mean power spectrum density was defined by 256 points, on a 0- to 512-frequency band. The MF was defined as the frequency that divided the power spectrum density into 2 regions containing equal power. The RMS and MF of the power spectrum density were calculated in real time by computer analysis.[13] For both groups, the RMS and MF values were averaged for each muscle and normalized in percentage of initial values. The RMS changes with respect to time were fitted to a third-order polynomial function for each group.[13,14] The slope of decline of the MF was calculated as an index of muscle fatigability and to show percentage changes relative to the initial values.[4,12,15]

### Statistical Analysis

Data concerning skeletal muscle function and the surface electromyography of both groups were analyzed and compared by using a nonparametric test (Mann-Whitney *U* test) with StatView software.[d] Values are expressed as mean ± standard deviation (SD) unless otherwise indicated. The degree of significance was fixed at *P* less than .05. The normalized surface electromyographic data were analyzed and compared between groups by using the common isometric endurance time (64s).

## RESULTS

### Anthropometric Measurements

Fat mass was significantly higher in the CAD patients than in the healthy control subjects ($P<.001$), whereas the lean body mass (LBM), the total volume of the lower limb (TVLL), and the muscle volume of the lower limb (MVLL) did not differ between groups (see table 2).

### Skeletal Muscle Function Data

No difference was found for the quadriceps MVIF between the CAD patients and healthy subjects (228±21N/m vs 230±46N/m, $P=.95$). The CAD patients had a lower isometric endurance time than the healthy subjects (64±17s vs 90±7s, $P<.01$). No difference was observed between the CAD and control groups with respect to the MVIF normalized for LBM ($3.68\pm0.73 N\cdot m^{-1}\cdot kg^{-1}$ vs $3.98\pm0.3 N\cdot m^{-1}\cdot kg^{-1}$, $P=.12$), for TVLL ($18.19\pm3.08 N\cdot m^{-1}\cdot L^{-1}$ vs $18.7\pm1.97 N\cdot m^{-1}\cdot L^{-1}$, $P=.71$), and for MVLL ($26.76\pm4.22 N\cdot m^{-1}\cdot L^{-1}$ vs $24.53\pm1.76 N\cdot m^{-1}\cdot L^{-1}$, $P=.23$).

### Surface Electromyographic Data

The normalized RMS values were significantly lower for the CAD patients than in the healthy control group for the vastus lateralis (102.17%±3.46% vs 112.85%±5.11%, $P<.001$) and for the vastus medialis (100.89%±1.25% vs 133.28%±12.24%, $P<.001$), whereas no difference was found for the rectus femoris (100.84%±2.9% vs 100.28%±0.91%, $P=.52$) (figs 1–3). The normalized MF mean values were significantly lower for the CAD patients than in the healthy control group for the vastus lateralis (82.17%±7.22% vs 92.74%±2.84%, $P<.01$), the rectus femoris (90.94%±4.73% vs 97.98%±2.37%, $P<.01$), and the vastus medialis (85.90%±6.27% vs 91.68%±3.19%, $P<.05$) (figs 4–6). The slope of decline of the MF did not differ between the healthy controls and CAD patients for the vastus lateralis (−0.14±0.16Hz/s vs −0.63±1.2Hz/s, $P=.86$), rectus femoris (−0.08±0.14Hz/s vs −0.34±1.08Hz/s, $P=.70$), or vastus medialis (−0.15±0.21Hz/s vs −0.35±0.99Hz/s, $P=.78$).

## DISCUSSION

Although perceived muscle fatigue is frequently associated with exercise intolerance in CAD populations[1]; no studies to

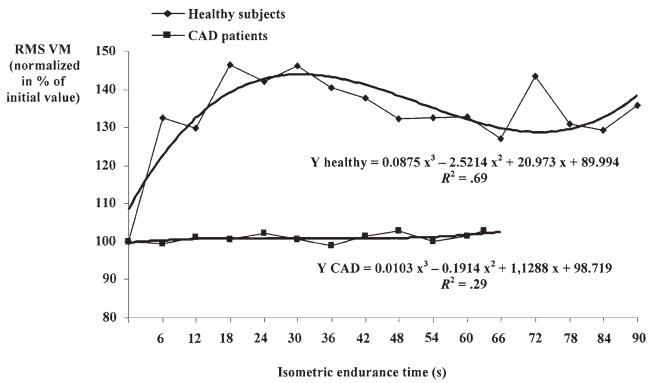


**Fig 3. RMS values for the vastus medialis in the healthy subjects and patients with CAD. Mean values fitted out with third-degree polynomial function. Abbreviation: VM, vastus medialis.**

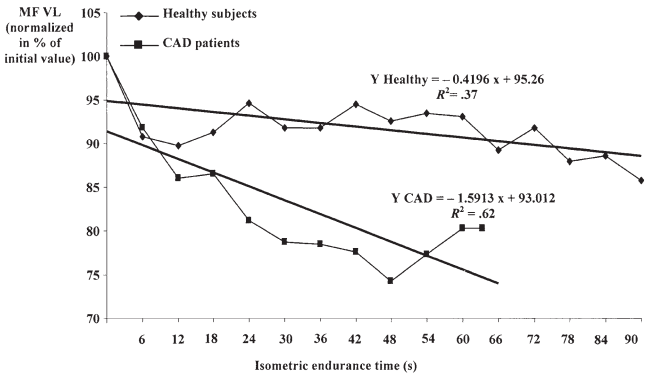


**Fig 4. MF values for the vastus lateralis in both groups. Mean values fitted out with a linear regression.**

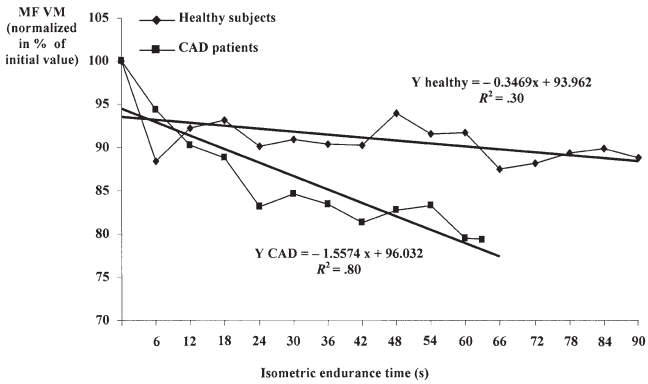


**Fig 6. MF values for the vastus medialis in both groups. Mean values fitted out with linear regression.**

date have directly evaluated skeletal muscle fatigue in this population. The present study was performed to accurately assess skeletal muscle fatigue using surface electromyography and skeletal muscle tension measurements. This approach is considered the most accurate for the measure of skeletal muscle fatigue in healthy subjects and in chronic heart failure patients.[5-8]

We believe that skeletal muscle fatigue in CAD patients may have important consequences for their QOL and daily physical activities. Some daily activities require isometric contractions that are not adequately reflected by cardiopulmonary exercise testing, which is generally used to assess exercise tolerance.[8] Cardiopulmonary exercise testing does not directly measure muscle fatigability.[8] This new approach, therefore, appears to permit a more complete evaluation of functional capacity. Additionally, it could be used to follow the effects of therapeutic interventions on functional capacity and QOL.

The first major finding of our study was that the maximal voluntary isometric strength of the quadriceps muscle was preserved in the CAD group compared with the healthy control group. However, quadriceps isometric endurance was markedly reduced in the CAD patients, resulting in enhanced skeletal muscle fatigue. The second major result is that, for the same level of isometric force, the level of motor unit recruitment was greater in the CAD patients than in the controls for the vastus lateralis and medialis muscles. The mean MF was lower in all muscles in the patients with CAD compared with the healthy subjects, confirming an enhanced skeletal muscle fatigue—probably because of abnormalities of skeletal muscle function.

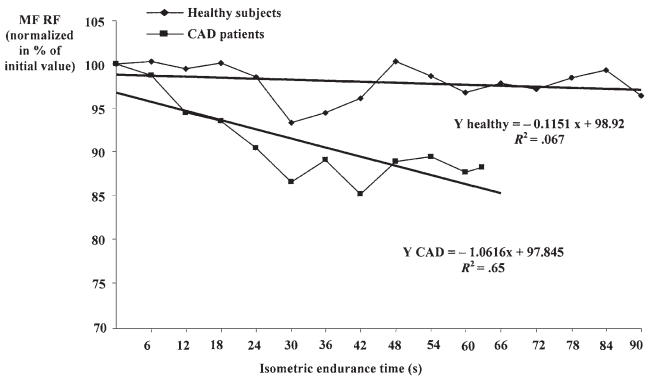


**Fig 5. MF values for the rectus femoris in both groups. Mean values fitted out with linear regression.**

The CAD patients had the same MVIF as the healthy subjects. It is well known that the MVIF decreases with age and depends on muscle size and recruitment of motor units.[16,17] The anthropometric data indicate that our CAD patients were more obese than the controls; however, this difference did not influence the results of quadriceps testing, because muscle mass was identical between the 2 groups. Our findings for MVLL and those of other studies[10,18-20] suggest no alterations in the muscle characteristics of patients with CAD (volume, myotypology). The results obtained on MVIF showed that the capacity of CAD patients to develop a maximal force was still preserved. This has previously been shown in CAD patients for the quadriceps muscle[10] and also in heart failure patients for the quadriceps and tibialis anterior muscles.[17,21,22]

In the present study, our CAD patients had a quadriceps isometric endurance time that was lower relative to the healthy controls, indicating more pronounced skeletal muscle fatigue in the CAD patients. Skeletal muscle fatigue is often attributed to intracellular lactate accumulation,[23] acidosis, or to an increase in inorganic phosphate or its protonated form ($H_2PO^{4-}$).[24-27] Studies using nuclear magnetic resonance spectroscopy showed a lower intracellular pH and a faster accumulation of inorganic phosphate and $H_2PO^{4-}$ in the forearm muscles of chronic heart failure patients compared with control subjects for the same level of work.[28,29] We believe the impaired isometric endurance time observed in our CAD patients was probably due to perturbations of muscular energy metabolism.[10] We previously showed reduced quadriceps isometric endurance time in men with CAD.[10] This same phenomenon has been shown in chronic heart failure patients leg muscles.[21,22,25]

In our present study's healthy subjects, the RMS profiles of the vastus lateralis and medialis muscles were similar to those found in the literature,[4,5] with an important increase in the RMS amplitude. A common finding is an increase in surface electromyographic amplitude during a submaximal isometric exercise with prolonged duration.[4,5,30] Several factors are responsible for this increase: (1) recruitment of additional motor units, (2) changes of firing frequency characteristics of individual motor units, and (3) synchronization of motor unit firing patterns, and (4) changes in muscle fiber conduction velocity and/or in the electromyographic power density spectrum.[4,5] The RMS profiles of the vastus lateralis and medialis were significantly higher in our control subjects during the first 24 seconds, probably because of the recruitment of type 2 fibers

during isometric contraction. A different RMS profile was found for the rectus femoris in healthy subjects, with only a weak increase. This may be explained by the alternation strategies in the quadriceps agonist muscles shown in different studies[30-33] for other muscles. When alternations are present, the occurrence of muscle fatigue can be delayed and analysis of the surface electromyography of a single muscle may not be sufficient to characterize the behavior of a muscle group.[30,33] Another explanation may be because of the knee joint angle, the rectus femoris being potentially less active when the contraction is performed at 60°. At this angle, the vastus lateralis and medialis were probably more activated, as suggested by the RMS profile. In our patients, the RMS values for each muscle showed a weak increase. The recruitment of the motor unit is dependent on the force level and increases with exercise intensity.[34] Moreover, when the intensity of a contraction reaches 75% of maximal voluntary contraction, all motor units are recruited for most muscles.[35] We believe that, compared with the healthy subjects, our CAD patients recruited more motor units for an equivalent isometric contraction intensity. Thus, men with CAD would have a higher motor unit recruitment threshold to maintain the same force level during isometric endurance testing, and an additional motor unit recruitment might not be able to compensate for muscle fiber fatigue. Our finding conforms with the study by Wilson et al[7] of chronic heart failure patients. They showed that for an equivalent work load during a maximal bicycle exercise, chronic heart failure patients had higher RMS values for the vastus lateralis muscle compared with healthy control subjects during a maximal bicycle exercise. They concluded that heart failure patients had lower neuromuscular efficiency associated with enhanced muscle fatigue.[7]

In our male patients with CAD, the MF values were lower for each muscle compared with healthy subjects. However, the slope of decline of the MF did not differ between groups for all muscles studied. This lack of significant difference in slopes was probably because of the low number of control subjects ($n=9$): the MF slope of decline would have been different with a greater number of controls subjects. Our results indicate greater skeletal muscle fatigue in men with CAD compared with healthy subjects—regardless of the muscle studied—and that fatigue was associated with an impaired isometric endurance time. These results are also consistent with Wilson's data.[7] The Wilson study showed that the mean MF of the vastus lateralis was lower ($P<.03$) in heart failure patients during a maximal cycling test than in healthy subjects. Skeletal muscle fatigue is often associated with a shift of the power density spectrum toward lower frequencies and with a diminution of the MF during submaximal isometric contraction.[4,5,12,30] Two major mechanisms have been given to explain this shift: a decrease of the muscle fiber conduction velocity and the changing statistics of the motor units patterns.[4,5] The decrease of the muscle fiber conduction velocity and the spectral parameters (eg, mean power frequency or MF) have been associated with an accumulation of byproducts of anaerobic metabolism (eg, lactate),[36,37] protons and $H_2PO^{4-}$,[15] and other ions such as $H^+$, potassium, or ammonium.[38-40] The lower MF values in our CAD patients probably occurred because they required a higher motor unit recruitment to develop and maintain the submaximal force level (as suggested by the RMS data for the vastus lateralis and medialis muscles). In CAD patients, this higher motor unit recruitment level probably led to an earlier accumulation of byproducts of anaerobic metabolism in the muscle with an earlier recruitment of fast motor units.

## CONCLUSIONS

Men with CAD showed a preserved maximal isometric strength of the quadriceps muscle relative to an age- and sex-matched healthy control population. However, isometric endurance time was markedly reduced in CAD patients, showing a higher muscle fatigue that was probably caused by abnormalities of skeletal muscle function. The surface electromyographic data suggest that men with CAD require a higher motor unit recruitment threshold in order to maintain the same force level during isometric endurance testing. Moreover, because the mean MF values were lower in the men with CAD for each muscle, this probably led to an earlier accumulation of metabolites in the muscle, which therefore enhanced muscle fatigue. These results indicate that surface electromyography can be used to assess skeletal muscle fatigue in men with CAD. In addition, this technique could potentially be used to the response to therapeutic interventions such as cardiac rehabilitation in this population.

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**Suppliers**

a. Cybex Norm II; Cybex, division of Lumex Inc, 2100 Smithtown Ave, Ronkonkoma, NY 11779-0903.
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