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REDUCED KNEE EXTENSOR FUNCTION IN HEART FAILURE IS NOT EXPLAINED BY INACTIVITY

Michael J. Toth, Ph.D., Anthony O. Shaw, P.T., Mark S. Miller, Ph.D., Peter VanBuren, M.D., Martin M. LeWinter, M.D., David W. Maughan, Ph.D., and Philip A. Ades, M.D.

Departments of Medicine and Molecular Physiology and Biophysics, University of Vermont, College of Medicine Burlington, VT

Abstract

Background—The goal of this study was to determine if heart failure alters knee extensor muscle torque, power production or contractile velocity.

Methods—Heart failure patients (n=11; 70.4 ± 4.3 yrs) and controls (n=11; 70.3 ± 3.4 yrs) matched for age and sex were evaluated for knee extensor contractile performance under isometric and isokinetic conditions and body composition by dual energy x-ray absorptiometry. Additionally, we recruited sedentary to minimally active elderly controls to match heart failure patients for habitual physical activity and assessed activity levels using accelerometry.

Results—Groups did not differ for total or regional body composition or average daily physical activity level. Despite similar muscle size and use, heart failure patients exhibited 21-29% lower (P<0.05 to P<0.01) isometric knee extensor torque throughout a range of knee angles, 15-33% lower (P=0.05 to P<0.01) peak concentric torque measured at various isokinetic speeds and corresponding reductions (P=0.05 to P<0.01) in peak power output. Expression of peak isokinetic torque data relative to isometric torque eliminated group differences, suggesting that impaired contractile function under dynamic conditions is explained by deficits in the force generating capacity of muscle. No group differences were found in the time required to reach target velocity during isokinetic contractions, an index of contractile velocity.

Conclusion—Because group differences in muscle torque were independent of age, sex, physical activity level and muscle size, our results suggest that muscle contractile dysfunction in these patients is likely attributable to the heart failure syndrome.

Keywords

muscle strength; physical activity; cardiac cachexia; disability

INTRODUCTION

Exercise intolerance is a hallmark symptom of chronic heart failure. Although cardiac pump dysfunction contributes to diminished physical work capacity, a considerable body of research suggests a role for alterations in skeletal muscle [1, 2]. Most studies have focused on diminished muscle endurance (ie, oxidative capacity) as the primary mechanism of

Correspondence to: Michael J. Toth, Ph.D. Health Science Research Facility 126B 149 Beaumont Ave University of Vermont Burlington, VT 05405 michael.toth@uvm.edu Tele: (802)656-7989 Fax: (802)656-0747.

CONFLICTS OF INTEREST

The authors recognize no conflicts of interest.

impaired functional capacity [1, 2]. In contrast, few studies have explored the role of alterations in skeletal muscle mechanical properties.

Most studies examining the effect of heart failure on muscle contractile performance have measured knee extensor isometric torque, an index of the force generating capacity of muscle. Results of these investigations have been inconsistent, with some showing reduced isometric force/torque [3-7], while others have found similar values in patients and controls [8-10]. These data are difficult to interpret, however, because heart failure is often accompanied by muscle atrophy [5, 11], which reduces overall muscle function. Adjusting force/torque data for muscle size does not resolve discrepancies among these studies, however, as some have found reduced isometric torque per unit muscle size in heart failure patients [5, 6], whereas others have not [3, 7]. Presently, it is unclear whether heart failure alters the force generating capacity of skeletal muscle.

Although isometric torque is a useful index of contractile function, this type of static muscle contraction is rarely encountered in activities of daily living. Instead, muscles normally contract against a load at some velocity. Measurements performed under dynamic conditions, therefore, should provide functional indices that better reflect muscle performance during normal activities. The effect of heart failure on contractile function measured under dynamic conditions, however, is equally ambiguous as assessments under static conditions, with some studies showing reduced muscle torque [4, 6] and others finding no difference [7]. Adjusting muscle torque data for muscle size does not resolve differing results among studies [6, 7]. Therefore, the effect of heart failure on muscle torque and power production has not been clearly defined.

The primary goal of the present study was to examine the effect of heart failure on skeletal muscle contractile function by assessing knee extensor torque under isometric conditions at a variety of joint angles and peak torque and contractile velocity under isokinetic conditions at a range of speeds. Examination of the effect of heart failure on muscle function, however, is hindered by the fact that the condition is accompanied by physiological and pathophysiological changes that complicate comparisons between patients and non-diseased controls. One of the most important differences is that heart failure patients are profoundly inactive [12]. Disuse can impair muscle function by promoting atrophy, but can also impair contractile function per unit muscle size [13]. Thus, to insure that group differences in muscle function reflect the effect of heart failure, we recruited controls to match patients for physical activity level. In addition, we matched controls for age, gender and HMG CoA reductase inhibitor (ie, statin) use to further control for other confounding physiological and pharmacological factors. We hypothesized that, independent of group differences in muscle size, heart failure patients would exhibit reduced isometric torque and downward shifts in torque-velocity and power-velocity curves; whereas, the time to reach target velocity during isokinetic contractions, an index of contractile velocity, would be increased in patients, owing to a shift in fiber type towards a more fast-twitch phenotype [14-16].

METHODS

Subjects

Eleven patients (7 men, 4 women) with physician-diagnosed, chronic heart failure were recruited from the Heart Failure Clinic of the Cardiology Unit at the University of Vermont. Seven patients were characterized as having systolic failure (left ventricular ejection fraction <40%) and four as having heart failure with preserved systolic function (signs and symptoms of failure with ejection fraction >40%). The average ejection fraction was $25.9 \pm 2.3\%$ (range: 17-35%) in those with systolic failure and $46.8 \pm 1.8\%$ (range: 45-52%) in those with preserved systolic function. The average New York Heart Association (NYHA)

functional class was 2.27 ± 0.19 , with one class I patient, six class II patients and four class III patients. Peak oxygen consumption expressed relative to body mass, an index of disease severity [17], averaged $14.1 \pm 1.5 \text{ ml/kg}\cdot\text{min}^{-1}$ ($n=9$; range: $10\text{--}25 \text{ ml/kg}\cdot\text{min}^{-1}$). The etiology of heart failure was ischemic in 3 and non-ischemic in 8 volunteers. In addition, 5 patients had Type II diabetes mellitus. All patients were clinically stable and had not been hospitalized for 6 months prior to testing. None had signs or symptoms of severe hepatic or renal disease (plasma creatinine >3), peripheral vascular disease or an active neoplastic process and none were smokers. All patients were on stable doses of heart failure medications, including angiotensin-converting enzyme (ACE) inhibitors/receptor blockers (100%), β -blockers (91%) and diuretics (73%). In addition, 3 patients were taking HMG CoA reductase inhibitors (statins) and one female patient was on a stable regimen of levothyroxine for hypothyroidism. To verify that statins were not impacting skeletal muscle, we confirmed that all volunteers (statin users and non-users) had creatine kinase levels less than 3 times the upper limit of normal (ULN). No patient was taking hormone replacement therapy (estrogen or estrogen/progestin therapy in women or testosterone in men).

Controls were recruited to match the heart failure patients for age and sex. Additionally, volunteers were recruited who self-reported being sedentary to minimally physically active (2 sessions of 30 min of exercise per week) and not currently participating in any organized exercise training or weight loss programs in an effort to match heart failure patients for habitual activity levels. Controls were required to be non-smokers and have a stable body weight ($\pm 2 \text{ kg}$) for 6 months prior to testing. They had no signs or symptoms of heart failure, coronary heart disease or diabetes (fasting blood glucose $>112 \text{ mg/dL}$), normal left ventricular function by echocardiography (ejection fraction $>55\%$), normal blood counts and biochemistry values and were not taking hormone replacement therapy (estrogen or estrogen/progestin therapy in women or testosterone in men). Four controls had a history of hypertension. Three of these were receiving diuretics and one an angiotensin-converting enzyme inhibitor. All were normotensive at the time of testing. To frequency match heart failure patients for statin use to account for the potential effects on muscle function [18-20], we included three control volunteers who were taking statins to treat hyperlipidemia. In all control volunteers (statin users and non-users), creatine kinase levels were less than 3 times the ULN. Finally, one female control on a stable regimen of levothyroxine for hypothyroidism was included to match the hypothyroidic woman in the heart failure group. Written consent was obtained from each volunteer and the protocol was approved by the Committee on Human Research at the University of Vermont.

Body composition

Body mass was measured on a digital scale (ScaleTronix, Wheaton, IL). Total and regional fat mass, fat-free mass and bone mass were measured by dual energy x-ray absorptiometry using a GE Lunar Prodigy densitometer (GE Lunar, Madison, WI). Bone mineral mass data are not reported. Appendicular skeletal muscle mass was measured as described by Heymsfield et al. [21].

Peak oxygen consumption (peak VO_2)

Peak VO_2 was determined using the Naughton protocol [22], and was defined as the highest 30 sec average VO_2 value during the final 2 minutes of the test. Peak VO_2 data are presented on an absolute basis, adjusted for fat-free tissue mass via simple division and statistical adjustment for fat-free tissue mass via regression techniques [23]. Because of logistical problems, tests were not conducted on $n=2$ heart failure patients and $n=1$ control.

Accelerometry

Free-living physical activity energy expenditure was estimated using a single-plane (vertical) accelerometer (Caltrac; Muscle Dynamics Fitness Network, Torrance, CA) in a sub-group of patients (n=9/group). Each patient's age, weight, height and sex was programmed into the accelerometer to allow calculation of caloric content of physical activity. Volunteers were instructed to wear the accelerometer on their waistline during waking hours for as many days as possible over a 10 day period. Participants recorded the number of calories on the accelerometer at the start and end of each day.

Knee extensor muscle function

Knee extensor torque production was measured under isometric and isokinetic conditions using a multi-joint dynamometer (HUMAC/NORM, Computer Sports Medicine Inc., Stoughton, MA), with data collected at a frequency of 100 Hz. The right leg was tested in all volunteers. The hip was fixed at an angle of 90° flexion and secured with straps across the waist, thorax and lower thigh. The lever arm of the dynamometer was attached just proximal to the lateral malleolus and the axis of rotation aligned with the knee joint at the lateral epicondyle of the femur. The range of motion was determined separately for each individual prior to testing.

Isometric measurements—Peak torque of knee extensor muscles was measured under isometric conditions at various joint angles (90°, 70°, 50° and 30° knee flexion relative to full knee extension) throughout the range of motion. Following instructions and the performance of a sub-maximal practice contraction at 90°, two trials (each contraction held for minimum of 4 sec) were performed at each knee angle starting at 90° and progressing through the range of motion. Each trial was separated by two minutes of rest. The peak torques for each angle were averaged. Torque data were adjusted statistically for leg fat-free tissue mass prior to comparison between groups. Curvilinear regression analysis was used to fit the data for each individual volunteer's isometric torque-knee angle curve. The equation of this regression analysis was then used to calculate isometric torque for at the knee angle that peak isokinetic torque was obtained in the studies described below. This allows expression of isokinetic torque relative to isometric torque at the same joint angle, as detailed below.

Isokinetic measurements—Isokinetic measurements were conducted at 60°/s, 120°/s, 180°/s, 240°/s and 300°/s knee extension in a randomized fashion. The flexion speed was 180°/s for all speeds to minimize leg muscle fatigue over the entire testing session. Practice trials were performed at each speed to familiarize volunteers with each speed. Thereafter, volunteers performed one trial of four consecutive repetitions at each speed, with each trial separated by 2 min of rest. For all speeds, data were reviewed to assure that the target velocity was obtained in at least 3 of the 4 repetitions. The data of volunteers who did not meet this requirement were excluded from analysis. The peak torque value and the knee angle at which peak torque occurred were recorded for each repetition that reached the target velocity and the average value for each calculated at each speed. Additionally, the time to reach the target velocity was recorded for the knee extension portion of each repetition as the time interval between the point where velocity increased above zero to the time that it reached target. This measurement was used as a proxy of muscle contractile velocity. Peak muscle power (W) was calculated as the product of peak isokinetic torque (Nm) and the angular velocity (rad) and was averaged across repetitions. Finally, peak torque values were expressed as a percentage of isometric torque. To accomplish this, the isometric torque at the angle at which peak isokinetic torque occurred was calculated from the regression equation derived from each individual's isometric torque-knee angle relationship, as described above. Isokinetic torque was then expressed as a percentage of the calculated

isometric torque at that specific knee angle. Expression of data in this manner normalizes isokinetic data for the absolute force generating capacity of the muscle (ie, isometric torque). Moreover, this method of data expression further controls for any variation between groups in the moment arm or the angle at which peak isokinetic torque may occur.

Statistics

All data are reported as mean $\pm$ SEM. Unpaired Student *t* tests were used to compare groups. Analysis of covariance was used to compare muscle function data between groups after adjusting for differences in leg muscle mass. All analyses were conducted with SPSS software version 15 (SPSS Inc, Chicago, IL).

RESULTS

Physical characteristics for heart failure patients and controls are shown in Table 1. Groups were similar for age, body size and both whole body and regional tissue composition (range of P-values: 0.434 to 0.998). Although the difference was not statistically significance, heart failure patients had a leg fat-free tissue mass that was nearly 1 kg less than controls (P=0.638). Because of the strong dependence of contractile performance on muscle size [5], we opted to adjust isometric and isokinetic torque and power production data for leg fat-free tissue mass to insure that group differences were not related to variation in muscle size.

Peak VO_2 and average daily physical activity data are shown in Table 2. Peak VO_2 , expressed on an absolute basis and relative to fat-free tissue mass using mathematical and statistical approaches, was lower in heart failure patients compared to controls (P 0.01 for all approaches). Physical activity levels were measured by accelerometry for an average of 7.7 ± 0.5 and 7.3 ± 0.7 days (P=0.720) in patients and controls, respectively. No difference was observed between patients and controls in average daily physical activity level (P=0.788).

Knee extensor peak isometric torque data at various knee angles adjusted statistically for leg fat-free tissue mass are shown in Figure 1. Isometric muscle torque at all angles was lower in heart failure patients compared to controls (90° : 129 ± 9 vs. 163 ± 9 Nm, P<0.02; 70° : 138 ± 12 vs. 188 ± 12 Nm, P<0.01; 50° : 129 ± 9 vs. 178 ± 9 Nm, P<0.01; 30° : 101 ± 7 vs. 141 ± 7 Nm, P<0.01). The best fit equations for the average isokinetic-knee angle data are: $y = 3.219x + (-0.02306x^2) + 25.56$ for heart failure patients ($r^2=0.999$) and $y = 5.042x + (-0.03885x^2) + 24.52$ for controls ($r^2=0.997$).

Knee extensor peak isokinetic torque at various speeds is shown in Figure 2. Data are presented: 1) as absolute torque (Nm) statistically adjusted for leg fat-free tissue mass (Panel A) and 2) relative to isometric torque at the knee angle at which peak isokinetic torque occurred (Panel B). For the $240^\circ/\text{s}$ speed, only 7 volunteers in each group were able to achieve the target velocity for 3 out of the 4 repetitions and no volunteer in either group was able to achieve the target velocity at $300^\circ/\text{s}$. Because of this, data are only shown for speeds of 60 through $240^\circ/\text{s}$. Absolute peak torque (Panel A) was consistently lower in heart failure patients compared to controls ($60^\circ/\text{s}$: 115 ± 10 vs. 146 ± 10 Nm, P<0.05; $120^\circ/\text{s}$: 97 ± 6 vs. 114 ± 6 Nm, P=0.05; $180^\circ/\text{s}$: 80 ± 5 vs. 103 ± 5 , P<0.01; $240^\circ/\text{s}$: 65 ± 4 vs. 91 ± 4 Nm, P<0.01). The angle at which peak torque occurred demonstrated a tendency towards being greater in heart failure patients at $180^\circ/\text{s}$ (55 ± 2 vs. $50 \pm 2^\circ$; P=0.09) and was significantly greater at $120^\circ/\text{s}$ (59 ± 2 vs. $51 \pm 2^\circ$; P<0.02), but did not differ at 60 and $240^\circ/\text{s}$ (62 ± 3 vs. $56 \pm 3^\circ$ and 50 ± 1 vs. $50 \pm 2^\circ$; P=0.130 and 0.957, respectively). Isokinetic torque, expressed relative to the isometric torque at the knee angle at which peak torque occurred (Panel B), did not differ between patients and controls at any speed examined ($60^\circ/\text{s}$: 83 ± 6 vs. $83 \pm 5\%$, P=0.987; $120^\circ/\text{s}$: 70 ± 5 vs. $67 \pm 5\%$, P=0.657; $180^\circ/\text{s}$: 58 ± 4 vs. $59 \pm 5\%$,

$P=0.937$; $240^{\circ}/s$: 46 ± 2 vs. $48 \pm 2\%$, $P=0.484$). During isokinetic contractions, the time required to reach the target velocity, a proxy of contractile velocity, did not differ between heart failure patients and controls (Table 3; range of P-values: 0.423 to 0.667), although a trend ($P=0.06$) towards a slower time to target velocity in patients was observed at $60^{\circ}/s$.

Knee extensor peak power output data, adjusted statistically for leg fat-free tissue mass, are shown at various speeds in Figure 3. Heart failure patients showed reduced muscle power output at all speeds ($60^{\circ}/s$: 120 ± 10 vs. 153 ± 10 W, $P<0.05$; $120^{\circ}/s$: 203 ± 12 vs. 238 ± 12 W, $P=0.05$; $180^{\circ}/s$: 252 ± 17 vs. 322 ± 17 W, $P<0.01$; $240^{\circ}/s$: 271 ± 15 vs. 380 ± 15 W, $P<0.01$).

DISCUSSION

Numerous studies have shown that heart failure adversely affects skeletal muscle function and that these changes, in turn, contribute to exercise intolerance. The effect of heart failure on muscle contractile properties, however, remains unclear. To test for alterations in muscle performance, the present study compared knee extensor contractile function between heart failure patients and controls matched for age, sex, physical activity level and medications that could alter muscle function. Our results show that heart failure patients exhibit lower peak isometric and isokinetic knee extensor torque independent of variation in muscle mass. Accordingly, there was a downward shift in the peak power-velocity curve in heart failure patients, indicating reduced power production at a variety of contractile speeds. Expression of isokinetic torque data relative to isometric torque, however, eliminated group differences, suggesting that impaired function under dynamic conditions is explained by deficits in the absolute force generating capacity of muscle. Under isokinetic conditions, the time to reach target velocity, an index of contractile velocity, was similar between groups. Collectively, these results suggest that heart failure impairs knee extensor contractile function under both static and dynamic conditions.

An important strength of the current study is our attempt to account for factors that confound comparisons between patients and controls. The most important factor considered is physical activity level, which is greatly reduced in heart failure patients [12] and could diminish skeletal muscle function independent of the disease process [13]. To date, no study that has examined skeletal muscle contractile function has controlled for the effect of muscle disuse in heart failure patients [3, 4, 6-10]. To address the physical inactivity of heart failure patients, we recruited controls that reported being sedentary to minimally physically active and verified similar daily activity levels in the patients and controls by measuring physical activity level by accelerometry over a 7 d period (Table 2). Although the uniaxial accelerometer worn at the waist is limited in its ability to assess the caloric cost of daily activities that are generally static in nature (eg, activities performed while seated or standing in place) and that involve complex movement patterns, it does provide reasonable estimates of weight bearing-type activities (eg, walking) that involve lower extremity musculature [24]. Moreover, because groups were, on average, nearly identical for age, weight, height and sex (Table 1), the calorie counts from the accelerometer essentially reflect activity counts. In this context, we conclude that patients and controls had similar levels of use of their lower extremity musculature. Inasmuch as our physical activity measurement reflects habitual activity patterns, differences in contractile function in our study should be independent of muscle disuse.

In addition to matching for physical activity level, we attempted to account for the confounding influence of medications that may alter muscle function. It would be impossible to match patients and controls for all medications. Instead, we focused on those medications that might influence muscle function. Because of their reputation for deleterious

effects on muscle function in rare instances [19], we frequency matched groups (3 of 11 volunteers in each group) for statin use. Importantly, in both groups, no patient had any clinical evidence or history of any statin-induced myopathy. Whether statin use alters muscle performance is still an open question. Studies have found detrimental [19], beneficial [18] and no [20] effects on muscle function. While our study was not designed to identify what effects statins might have, any effect of statin use should be equally distributed between our two populations. The only other class of medications common to heart failure patients that might alter muscle function is the ACE inhibitors/receptor blockers. However, based on available data, ACE inhibitor/receptor blocker use would likely enhance, not reduce, muscle strength in patients [25, 26], which would minimize group differences in muscle function. Taken together with efforts to account for the confounding effects of muscle disuse, age and sex, these experimental design considerations permit us to ascribe differences in skeletal muscle contractile function primarily to the heart failure syndrome.

Knee extensor isometric torque was reduced in heart failure patients at a variety of angles after statistical control for muscle size (Figure 1). Our results agree with studies that have found reduced isometric torque in heart failure patients [3-7] and, in particular, with those showing reduced isometric strength after controlling for muscle size [5, 6]. Some investigators, however, have not observed differences in isometric torque between patients and controls [10], and others have shown that deficits in isometric torque do not persist after adjustment for muscle size [3, 7]. The reasons for divergent results among studies are not readily apparent. Our study adds to this literature by showing that heart failure is associated with skeletal muscle weakness under isometric conditions when compared to a carefully-selected, control population that was matched for physical activity and other physiological and pharmacological factors that could confound group comparisons of muscle function.

Dynamic knee extensor torque was also impaired in heart failure patients. Using measurements of torque production at various isokinetic speeds, we found a downward shift in the torque-velocity curve (Figure 2) in heart failure patients after controlling for differences in muscle size. Our results agree with prior work from our laboratory [6] and others [4] that examined peak isokinetic torque at a single speed (30 and 90°/s, respectively), but differ from one study that measured torque at multiple speeds (30, 90 and 180°/s; ref. [7]). Two of these studies adjusted isokinetic torque data for muscle size [6, 7], with one finding reduced strength in patients [6] and the other finding no difference [7]. Here again, the reason for differing results is not clear.

The result of reduced isokinetic torque in heart failure patients is a downward shift in the peak power-velocity curve (Figure 3), which indicates a reduced capacity for muscle power production throughout the range of contractile speeds. Muscle power is the product of torque and velocity. Under isokinetic conditions, because contractile speed is fixed, the primary factor contributing to reduced power production should be decreased muscle torque production. Thus, reduced muscle power output (ie, isokinetic torque) may be related to an intrinsic deficit in muscle force production in heart failure patients, as revealed under isometric conditions (Figure 1). To test whether this was the case, we expressed peak isokinetic torque data relative to isometric torque at a comparable joint angle, which adjusts isokinetic torque data for group differences in the absolute force producing capacity of the knee extensors. After expressing isokinetic data relative to isometric torque, the isokinetic peak torque-velocity curve was nearly identical in patients and controls (Figure 2B), suggesting that reductions in isokinetic peak torque in patients--and accordingly peak power--are indeed attributable primarily to impairments in the ability of muscle to generate force.

Finally, we found no difference between the groups in the time to reach target velocity during isokinetic studies, a rough index of contractile velocity. This result was somewhat unexpected. Considering the shift in fiber type distribution in knee extensor muscles of patients towards a more fast-twitch phenotype [14, 15], we predicted that heart failure patients would display a shorter time to target velocity (ie, greater contractile velocity). However, in accord with our results, studies examining the time to peak isometric tension of knee extensor muscles in response to electrical stimulation have similarly showed no difference between patients and controls [8, 9]. Thus, while the fiber type distribution of knee extensor muscles may change with heart failure, this does not appear to alter the contractile velocity of the whole muscle.

Several caveats of our study deserve discussion. First, because we measured volitional contractile function, we cannot dismiss the possibility that variation in neural drive/activation may have contributed to group differences. This is unlikely to account completely for group differences, however, as no deficits in central motor drive or neuromuscular transmission have been observed in heart failure patients during volitional knee extensor testing [27] and the largest study to date (n=100 patients and 31 controls) to examine muscle strength in heart failure patients found reduced isometric muscle strength per unit cross-sectional area despite imposition of electrical stimulation during maximal voluntary contraction to insure full activation [5]. Second, we evaluated only a small number of patients and controls. This was partly necessitated by the rigorous matching procedures employed in this study. In this context, the variation in muscle function between patients and controls should be reduced considerably, diminishing the need for larger samples sizes. Third, because studies in animal models suggest that heart failure impairs excitation-contraction coupling in skeletal muscle [28, 29]--although these findings are not unanimous [30]--deficits in contractile function may be explained by a diminished Ca^{2+} signal. While assessments of excitation-contraction coupling have not been conducted in humans because of methodological limitations, changes in Ca^{2+} regulatory proteins that may contribute to defects in excitation-contraction coupling [31, 32] are not observed in humans [33]. Moreover, studies in chemically-skinned human single muscle fibers, a preparation that eliminates the excitation-contraction coupling system, show reduced force production in heart failure patients [34], suggesting alterations in the intrinsic mechanical properties of skeletal muscle in heart failure patients.

In summary, heart failure patients displayed reduced peak torque and power production, but similar time to reach target velocity, compared to controls. Because patients and controls were well-matched for age, sex, physical activity level and medications that might affect muscle performance, we ascribe these differences in muscle contractile function to the heart failure syndrome, not to muscle disuse or other confounding factors. Considering that muscle power production is a key determinant of functional capacity in the elderly [35-37], our results provide evidence that impaired skeletal muscle contractile function may contribute to the primary symptom of heart failure--reduced physical work capacity.

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Figure 1.

Isometric knee extensor torque-knee angle curves for heart failure patients (closed squares; n=11) and controls (open squares; n=11). All data were statistically adjusted for leg fat-free tissue mass using analysis of covariance. The equations describing the best fit lines are provided in the *Results* section. Data are mean $\pm$ SE. *, P<0.05; **, P<0.01.

Figure 2.

Isokinetic knee extensor peak torque-velocity curves for heart failure patients (closed squares) and controls (open squares) with data expressed on an absolute (Nm; Panel A) and relative (% of isometric torque at the joint angle at which peak isokinetic torque was reached; Panel B) basis. Absolute peak torque data were statistically adjusted for leg fat-free tissue mass using analysis of covariance. For 240°/s, n=7 patients and n=7 controls. All other speeds reflect n=11 per group. Data are mean $\pm$ SE. *, $P<0.05$; †, $P=0.05$; **, $P<0.01$.

Figure 3.

Knee extensor peak power-velocity curve for heart failure patients (closed squares) and controls (open squares). Data were statistically adjusted for leg fat-free tissue mass using analysis of covariance. For 240°/s, n=7 patients and n=7 controls. All other speeds are n=11 per group. Data are mean $\pm$ SE. *, $P<0.05$; †, $P=0.05$; **, $P<0.01$.

Table 1

Physical characteristics and body composition data.

	Heart failure	Controls
<i>n</i> (male/female)	7/4	7/4
Age (yrs)	70.4 ± 4.3	70.3 ± 3.4
Height (cm)	168.2 ± 2.9	168.6 ± 3.0
Body mass (kg)	86.1 ± 7.6	85.6 ± 4.1
Fat mass (kg)	32.5 ± 4.3	31.5 ± 1.9
Fat-free mass (kg)	51.3 ± 4.3	51.3 ± 3.4
Body fat (%)	37.5 ± 2.8	38.4 ± 2.3
Arm fat-free mass (kg)	5.10 ± 0.50	5.68 ± 0.53
Leg fat-free mass (kg)	15.4 ± 1.5	16.3 ± 1.2

Data are mean ± SE.

Table 2

Peak oxygen consumption and physical activity levels in heart failure patients and controls.

	Heart failure	Controls
Peak oxygen consumption (L/min)	1.242 ± 0.180	1.933 ± 0.165 *
Peak oxygen consumption (mL/kg FFM•min⁻¹)	23.5 ± 2.3	38.7 ± 1.4 *
Peak oxygen consumption (L/min)[‡]	1.198 ± 0.102	1.972 ± 0.097 *
Daily physical activity level (kcal/d)	228 ± 52	211 ± 34

Data are mean ± SE.

Data represent n=9 heart failure patients and n=10 controls for peak oxygen consumption and n=9/group for daily physical activity level.

* P 0.01.

[‡] peak oxygen consumption data were adjusted for fat-free tissue mass (FFM) using analysis of covariance.

Table 3

Time to reach target velocity during isokinetic contractions.

<i>Isokinetic speed</i>	Heart failure	Controls
60°/s (ms)	308 ± 18	269 ± 7
120°/s (ms)	318 ± 11	304 ± 13
180°/s (ms)	352 ± 16	364 ± 23
240°/s (ms)	372 ± 19	344 ± 22

Data are mean ± SE. Data for 240°/s represent n=7 heart failure patients and n=7 controls. All other data are n=11 per group.