AN ABSTRACT OF THE THESIS OF

Todd C. Shoeppe for the degree of Master of Science in Human Performance presented on August 6, 2001, Title: Contractile Function of Single Muscle Fibers From Chronically Resistance Trained Humans.

Abstract approved: Jeffrey J. Widrick

Resistance training is widely prescribed for rehabilitation of injuries and as a method to improve athletic performance. It is accepted that resistance training increases the maximal force production of whole muscle and it has been suggested that the velocity of shortening can increase as well. However, little is known about the effects of resistance training at the cellular level. Therefore, we investigated morphology, force production, velocity, and force-velocity-power relationships of single chemically skinned muscle fibers from chronically resistance trained humans, including cross sectional area (CSA), peak Ca\textsuperscript{2+}-activated force production (P₀), specific tension (P₀/CSA), unloaded shortening velocity (V₀), and isotonic contractions. The untrained group (NT) group consisted of sedentary males (n = 6, age = 27 ± 2 yrs) while the chronically trained group (CHRT) group consisted of males with 7.7 ± 0.4 yrs resistance training experience (n = 6, 22 ± 1 yrs). Maximum voluntary isometric and isokinetic knee extensor strength were measured along with 6 repetition maximum (6RM) free weight bench press and leg press. Muscle biopsies were obtained from the vastus lateralis. Chemically skinned single muscle fibers were mounted between a force transducer and servo-controlled motor and subjected to slack tests to determine peak Ca\textsuperscript{2+}-activated force (P₀) and unloaded shortening velocity...
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CHRT groups are primarily due to differences in fiber CSA rather than differences in cross-bridge mechanisms of contraction. Supported by National Institute of Health grant R3AR46392A.
Contractile Function of Single Muscle Fibers From Chronically Resistance Trained Humans

by

Todd C. Shoepe

A THESIS

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Major Professor/Representing Human Performance

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Chair of Department of Exercise and Sport Science

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Todd C. Shoepe, Author
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CONTRIBUTION OF AUTHORS

Dr. Jeffrey J. Widrick was involved with every aspect of this project including design, data collection, analysis, and writing of the manuscript. Julian Stelzer and Dena Garner assisted in data collection. Dr. Jeffrey Mull performed the biopsies.
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DEDICATION

This project is dedicated to my family. Enough said.
Contractile Function of Single Muscle Fibers From Chronically Resistance Trained Humans

Shoepe, T.C., Stelzer, J.E., Garner, D.P., Mull, J., & Widrick, J.J.

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ABSTRACT

Resistance training is widely prescribed for rehabilitation of injuries and as a method to improve athletic performance. It is accepted that resistance training increases the maximal force production of whole muscle and it has been suggested that the velocity of shortening can increase as well. However, little is known about the effects of resistance training at the cellular level. Therefore, we investigated morphology, force production, velocity, and force-velocity-power relationships of single chemically skinned muscle fibers from chronically resistance trained humans, including cross sectional area (CSA), peak Ca^{2+}-activated force production (P_0), specific tension (P_0/CSA), unloaded shortening velocity (V_0), and isotonic contractions. The untrained group (NT) group consisted of sedentary males (n = 6, age = 27 ± 2 yrs) while the chronically trained group (CHRT) group consisted of males with 7.7 ± 0.4 yrs resistance training experience (n = 6, 22 ± 1 yrs). Maximum voluntary isometric and isokinetic knee extensor strength were measured along with 6 repetition maximum (6RM) free weight bench press and leg press. Muscle biopsies were obtained from the vastus lateralis. Chemically skinned single muscle fibers were mounted between a force transducer and servo-controlled motor and subjected to slack tests to determine peak Ca^{2+}-activated force (P_0) and unloaded shortening velocity (V_0). Isotonic load clamps were used to determine the force-velocity-power relationship. All fiber experiments were performed at 15° C. Fiber myosin heavy chain (MHC) content was determined by gel electrophoresis. The CHRT group was 119% and 81% stronger for 6RM leg press and bench press respectively. Peak
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INTRODUCTION

Resistance training has received much attention in terms of its ability to increase neuromuscular strength and power, changes that have been theorized to benefit athletic performance (59). Recently however, the interest in this form of exercise training has broadened due to evidence demonstrating the health and rehabilitative benefits of progressive resistance exercise. Used since World War II as a rehabilitative method for injured soldiers (11), the scope of resistance training prescription in rehabilitation has grown from injury rehabilitation to include attenuation of atrophy due to aging (31, 38), bedrest (2, 5), and most recently, spaceflight (4). Resistance training may also play a role in cardiac rehabilitation (55, 61, 62), treatment of insulin resistance (66), and the prevention of osteoporotic fracture (35, 36, 44, 51).

Adaptations to resistance training follow a time course where rapid, drastic increases in neuromuscular strength occur with short-term training. These changes in neuromuscular strength exceed muscular hypertrophy (1, 22, 30, 32, 50, 57, 65). Consequently, force per cross sectional area ($P_0/CSA$) increases. For example, Narici et al. (58) showed a 21% increase in isometric strength and only an 8.5% increase in muscle cross-sectional area (CSA) following 60 days of isokinetic training. This resulted in an 11% increase in $P_0/CSA$. The authors suggested that this increase in $P_0/CSA$ would occur in a linear fashion with continued training citing the work of Jones & Rutherford (32) who showed a 27% increase in $P_0/CSA$ following 84 days and Ikai & Fukunaga (30) who showed an increase of 59% following 100 days of
training (58). However, Alway et al. suggested that after initial increases in P₀/CSA, continued training would return P₀/CSA to normal levels (3). Jones & Rutherford (32) suggested that neural factors, increased angle of muscle pennation, preferential hypertrophy of fibers expressing intrinsically stronger fast myosin heavy chain (MHC) proteins, increased radiological density, and increased connective tissue attachments are possible mechanisms of increased P₀/CSA. It is widely accepted that neural adaptations such as increased agonist activation, decreased antagonist activity, and muscular coordination contribute the majority of the increase in P₀/CSA (8, 22, 25, 57). However, in studies where neural factors have been controlled, qualitative improvements in muscle function were still observed following resistance training (12, 32). To this point, it is still unknown how the documented increase in radiological density of the whole muscle after resistance training (9, 29, 32) affects single muscle fiber P₀. Furthermore, it is not known if greater force production of fast fibers (P₀) is maintained with resistance training and if they could contribute to increased P₀/CSA with as a result of preferential hypertrophy.

Force and velocity, the two contributing factors to power, were examined by Duchateau and Hainaut (12) utilizing direct external nerve stimulation. They demonstrated that factors intrinsic to the muscle were responsible for an 18% increase in the maximal shortening velocity (V_{max}) of the adductor pollicus after 12 weeks of light intensity resistance training (40% of max) utilizing fast dynamic contractions. This is in contrast to Jones & Rutherford (33) who, after reviewing the literature,
reported that it was unlikely that the intrinsic maximal shortening velocity could be altered with training.

One of the uncertainties concerning the qualitative changes in muscle as a result of resistance training is the influence of neural factors and excitation-contraction coupling. The isolated skinned fiber technique utilizes a saturating solution of $\text{Ca}^{2+}$ for the direct study of the mechanics of the myofilament lattice during contraction and therefore is useful in studying cellular adaptations in the absence of neural mechanisms.

We are unaware of any study examining the effects of resistance training on force-velocity-power relationship of single muscle fibers from young healthy subjects. Young, healthy subjects that have been engaged in chronic RT programs are therefore needed in order to provide a baseline of data for comparison to other studies investigating the cellular adaptations of resistance training. Therefore, we have chosen to examine chronically resistance trained vs. untrained subjects because they may show a greater adaptation than subjects undergoing short-term training. We investigated the force-velocity-power relationships of single chemically skinned muscle fibers from chronically resistance trained humans through description of cross-sectional area, peak $\text{Ca}^{2+}$-activated force production, $V_o$, and isotonic contractions.

METHODS

Subjects. Twelve healthy adult male subjects were recruited to participate in this study. Six college-aged subjects with $7.6 \pm 1.6$ years resistance-training
experience (CHRT group) were recruited from an on-campus exercise facility based on information about their training programs and observations of their exercise performance. Most of the subjects had been resistance training since high school. All CHRT subjects were currently engaged in periodized progressive resistance exercise and had been training without interruption (> 1 week) for at least three months prior to testing. Subjects were eliminated who had participated in chronic, frequent, or intense endurance training. None of the subjects reported using anabolic steroids and no medications were being used at the time of this study. Four subjects had used creatine at some point during their training. Six sedentary age and height-matched subjects were recruited and assigned to the non-trained group (NT). These subjects had no history of rigorous weight training and, with the exception of occasional recreational activities, had not trained aerobically in at least the past year. Anthropometric data of the subjects are shown in Table 1. This study was approved by the Institutional Review Board for the Protection of Human Subjects at Oregon State University and subjects signed a written informed consent before participation.

Experimental design. Percutaneous needle biopsies (6) were taken from the mid left vastus lateralis using suction as described by Evans et al. (15). For the CHRT, biopsies were obtained from subjects approximately five days following the last workout involving the quadriceps muscle. Immediately following the biopsy, body composition was assessed (see below). Neuromuscular strength (see below) for all subjects was measured three days later to allow for recovery from any muscle soreness due to the biopsy procedure.
Tissue preparation. Muscle biopsies were immediately placed in relaxing solution (for composition, see below) where they were dissected longitudinally into smaller bundles. The muscle bundles were chemically skinned at 4°C in a solution containing 50% relaxing solution (plus a protease inhibitor cocktail (Complete mini EGTA-free tablets, Boehringer Mannheim Corporation, Indianapolis, IND) and 50% glycerol. After 24 hours, samples were placed in fresh skinning solution and stored at −20°C. Fiber contractile analysis was performed over the next three weeks.

Relaxing and activating solutions. All procedures were similar to those previously described by Widrick et al. (79). The computer program described by Fabiato (16) was used to determine the final concentration of metals, ligands, and metal-ligand complexes in the experimental solutions. The stability constants used in these calculations (16) were adjusted for the experimental conditions of this project. The relaxing and activating solutions had a total free Ca\(^{2+}\) concentration of pCa\(^{2+}\) 9.0 and pCa\(^{2+}\) 4.5 respectively (where pCa\(^{2+}\) = -log [Ca\(^{2+}\)]) and contained 20.0 mM imidazole, 7.0 mM EGTA, 14.5 mM creatine phosphate, 15 U·ml\(^{-1}\) creatine kinase, 4 mM Mg\(^{2+}\)-ATP, and 1 mM free Mg\(^{2+}\). The pH of both solutions was adjusted to 7.0 with KOH and total ionic strength to 180 mM with KCl.

Body composition. Body composition of all subjects was assessed with an air displacement densitometry plethysmograph (Life Measurement Instruments, BOD POD; Concord, CA) with predicted thoracic gas volume (56). This technique uses Boyle’s Law (\(P_1V_1 = P_2V_2\)) to estimate body volume and has been validated in young
male football players of similar age and anthropometrics as the subjects in this study (10). In accordance with the guidelines for use, subjects had fasted a minimum of three hours before the assessments and were normally hydrated. Subjects had avoided exercise 12 hours prior to assessment, and wore only a small, tight-fitting bathing suit or boxer shorts with hair contained within a tight fitting swim cap. The Siri equation was used to estimate percent body fat (68).

Neuromuscular strength. Isometric and isokinetic strength testing were performed on an isokinetic dynamometer (Chattecx Corporation, KinCom III; Hixson, TN). Subjects sat upright against a backrest at 100°, restrained across the chest, lap, and above the knee with padded nylon straps. The lever arm of the dynamometer was attached to the ankle with the lowest portion of the pad ~2cm above the medial malleolus. Subjects were familiarized with the apparatus and given adequate warm-up and practice trials. During all testing, subjects kept the arms folded across their chest.

Isometric. Subjects completed three consecutive maximum voluntary isometric contractions (MVC) of the knee extensors of five seconds duration at 60° of knee flexion. Subjects were encouraged to maximally contract throughout the duration of the 5-second test even though only peak values were used in analysis. A minimum of one-minute rest separated each set of trials.

Isokinetic. Maximum voluntary concentric knee extension torque was determined at angular velocities of 30°, 60°, 120°, 180°, and 240° per second through a range of motion of 90° -25° of knee flexion. At least three trials were performed at each
velocity. Peak voluntary torque was defined as the greatest force achieved during each contraction and occurred between $90^\circ$-$60^\circ$ of knee flexion. A minimum of one-minute rest separated each set of velocity trials.

**Isotonic neuromuscular strength as determined with free weights.** Six repetition maximums (6RM) were established for each subject for leg press and bench press. For the leg press, subjects were required to lower the weight to $>90^\circ$ of knee flexion. For BP, subjects were required to maintain foot contact with the floor, hip contact with the bench, and to contact the chest with the bar during the lift. A successful 6RM lift for both exercises was defined as six complete range-of-motion repetitions performed with good form in the absence of spotter aid. At least three minutes rest was provided between sets to allow for recovery. Although difficult with the NT group, where little knowledge of strength performance was available prior to testing, an effort was made to reach 6RM within three sets in order to avoid fatigue.

**Skinned fiber analysis.** Single fibers (~4-5 mm in length) were isolated from the muscle bundles in relaxing solution. The fiber ends were attached to stainless steel troughs using 4.0 monofilament posts and 10.0 suture. The troughs were cut from 28-gauge hypodermic needle tubing. One trough was connected to an isometric force transducer (Aurora Scientific, Model 400; Aurora, Ontario) while the other was attached to a direct-current position motor (Aurora Scientific, Model 308B; Aurora, Ontario). Motor position was specified by a servocontroller (Positron Development, Model 300-FC1; Engelwood, CA) operating in either position (slack tests) or force (isotonic contractions) mode. The fiber was suspended in one of several small
chambers milled into a stainless steel dip-plate. The fiber could be moved from chamber to chamber by depressing and translating the stainless steel plate. The mounted fiber was viewed under an inverted microscope at 600X (Olympus Optical Co., Model IX70; Melville, NY). Sarcomere length was adjusted to 2.5 μm using a calibrated eyepiece micrometer and 3-axis micromanipulators mounted to the motor and force transducer. Fiber diameter was measured as the fiber was briefly suspended in air. Fiber CSA was calculated from the diameter measurement assuming the fiber in air forms a cylinder. The mean of three measurements made along the length of the fiber was used in determining fiber CSA. Fiber length was determined using a digital micrometer (resolution = 10μm) mounted to the microscope stage. All experiments were performed at 15°C. Temperature was continuously monitored by a type-T thermocouple inserted into the chamber and positioned 2 mm to the side of the fiber. The thermocouple was arranged so that it moved from chamber to chamber with the fiber. Temperature was maintained by use of a refrigerated water bath that circulated through a radiator in contact with the experimental plate. Fine temperature adjustment was accomplished by thermoelectric cells sandwiched between the radiator and plate. Fibers were bathed in a relaxing solution containing 0.05% Triton X-100 prior to measurements.

Force and position outputs were amplified (Positron Development, Model 300-DIF2H; Engelwood, CA), digitized at 5 kHz and interfaced to a computer via a data acquisition board (National Instruments, Model AT-MIO-16E; Austin, TX). Display, analysis, and storage of data were performed using custom software written in our laboratory (National Instruments, LabView; Austin, TX).
Experimental procedures.

Peak Ca\(^{2+}\) - activated force production (P\(o\)). P\(o\) was determined by the difference between the force generated in relaxing solution (pCa\(^{2+}\) 9.0) and the force generated in activating (pCa\(^{2+}\) 4.5) solution (Figure 1). Specific tension (P\(o\) / CSA) was calculated by dividing peak isometric force by CSA.

![Graph showing force vs. time for NT and CHRT groups.](image)

Figure 1 – Peak Ca\(^{2+}\)-activated force measurement (force vs. time). Original peak Ca\(^{2+}\) -activated force tracings of a type I - MHC fiber from each group. The cross sectional areas and P\(o\) of the two fibers areas were 6246 and 7370 µm\(^2\) and 113 and 122 kN/m\(^2\) for the NT and CHRT fibers respectively. The tracing above begins as the fiber is situated in relaxing solution (pCa\(^{2+}\) 9.0). The fiber is then moved into activating solution (pCa\(^{2+}\) 4.5) where it rapidly begins to develop tension. Force increases until maximal tension is achieved. At this point, the fiber is returned to relaxing solution and the force returns to baseline. Peak isometric force is measured as the difference between maximal force production and baseline. The tracings occur over the course of 30-40 seconds. (Note: rapid oscillations at each end of the tracing represent movement artifact as the fiber is moved between the two solution chambers.)

\(mN\) = millinewtons; NT = untrained control group; CHRT = chronically resistance trained group

Unloaded shortening velocity (V\(o\)). V\(o\) was determined using the slack test method (13, 82). The fiber was moved into activating solution and allowed to come to peak
force. The fiber was rapidly "slacked" by displacing the position motor a given distance in the longitudinal orientation of the fiber. Force dropped to baseline as the fiber was slacked. The activated fiber shortened under no-load until it had taken up the imposed slack. At that instant, there was a rapid re-development of force. The time required for re-development of tension, measured from the imposition of the slack step until the re-development of force, was measured and recorded. The fiber was relaxed, re-extended to its original fiber length, and the procedure was repeated until a minimum of five different slack steps had been imposed (Figure 2A–2B).

A first-ordered least squares regression (Figure 2C) was applied to time versus slack distance. \( V_0 \) was calculated as the slope of the line. This velocity was expressed as fiber lengths per second (fl/s) in order to account for varying fiber lengths and thus the additive effect of the number of sarcomeres in series on velocity. Fiber experiments in which correlation coefficients of time of unloaded shortening vs. slack distance were < 0.98 or compliance values > 5% of fiber length (y-intercept of slack test plot taken as compliance) were not included in data analysis.
Figure 2 – *Determination of unloaded shortening velocity* ($V_0$). *(A)* Illustrates superimposed force records of a single fiber subjected to 5 different slack steps. Peak Ca$^{2+}$-activated force is represented by the plateau in force in the upper left of the figure. The fiber (experiment 1519 – CHRT type I MHC) was slacked a known distance, relaxed in relaxing solution, re-extended to its original length, and subjected to another activation-slack cycle. *(B)* Expanded view of the area within box in *A*. The arrows represent the time at which force redeveloped for each of five slack distances (200, 250, 300, 350, and 396 μm). Below each arrow is the measured time to tension redevelopment in milliseconds. Slack lengths never exceeded 20% of fiber length. *(C)* Regression lines were plotted from the slack tests of three different fibers. The calculated slope of each line after length normalization is the maximal unloaded shortening velocity. The fibers plotted above had velocities of (●) 0.67, (▼) 2.18, and (○) 4.15 fiber lengths/second. Subsequent gel electrophoresis identified these fibers expressing type I, IIA, and IIX MHC respectively. mN = millinewtons; ms = milliseconds; μm = micrometers.
Force-velocity relationship. Force-velocity-power relationships were determined from a series of isotonic load clamps using previously described techniques (81). After attaining peak force, the fiber was then subjected to a series of three isotonic contractions. Fiber shortening was controlled via the servo-controlled position motor so that force remained constant at every step. Each isotonic step was 30-100 milliseconds in duration. Total shortening across all three contractions never exceeded 20% of fiber length. Following the last step, the fiber was slacked and force dropped to baseline. This force baseline was used when determining the peak force and the relative force at each isotonic step. The velocity at each step was calculated as the slope of the length change. Force and velocity were determined over the final portion of each step after velocity and force had stabilized. Nine data points were obtained for the majority of fibers. A representative force-velocity test is shown in Fig. 3. The Hill equation, \( PV = bP(P_0-P)/(P+a) \) was used to construct force-velocity curves from the original data (27). \( V_{max}, a/P_0, \) and \( P_0 \) were obtained from the curves and used to calculate peak power. Fiber type and group composite force-velocity and power curves were constructed using the average values of \( V_{max}, a/P_0, \) and \( P_0 \) from the single fiber experiments.
Figure 3 – Isotonic load clamps. Illustrated is a force-velocity recording of a single fiber subjected to 3 isotonic load clamps. (A) Peak Ca\(^{2+}\) - activated force is represented by the plateau in force in the upper left of the figure (100% \(P_0\)). The fiber was then allowed to shorten at three predetermined forces for 100 ms each before the fiber was slacked and force dropped to baseline. It was then re-extended to its original length, and subjected to another activation-contraction cycle. 100% peak tension is calculated as the difference between baseline and peak tension development. Above each step is the percentage of \(P_0\) the fiber produced during shortening. (B) This tracing represents the motor position during the corresponding 100 ms load clamp. The slope of the position record over the last portion of each step was used to determine shortening velocity. Above each step is the measured shortening velocity.

**Myosin heavy chain analysis.** After contractile analysis, each fiber was solubilized in 30 \(\mu\)l of an SDS sample buffer containing 62.5 mM tris(hydroxymethyl)aminomethane (adjusted to pH 6.8), 2% SDS, 0.01% bromphenol blue, 10% glycerol, and 5% \(\beta\)-mercaptoethanol. The fiber was denatured for 4 minutes at 95° C and then stored at -80° C until MHC analysis. A polyacrylamide gel composed of a 7% separating gel and a 3.5% stacking gel was prepared as described.
Electrophoresis was carried out on a Mini-Protean 3 Cell electrophoresis gel system (BIO-RAD, Hercules, CA) at 4°C for 22-26 hours at a constant 70 volts (BIO-RAD, Power Pac 300; Hercules, CA). Gels were silver stained (67) and each fiber characterized as expressing type I, IIa, IIx, MHC or multiple MHC isoforms, (i.e. hybrid fibers IIa/IIa, IIa/IIx) using a human myosin protein standard prepared in our laboratory. The IIx classification was used instead of the commonly used IIb due to the finding that this MHC is homologous with the rat IIx rather than the rat IIb MHC isoform (14, 69). An example of a 7% gel and MHC isoform identification is shown in Fig. 4.

Figure 4 – 7% polyacrylamide gel electrophoresis for fiber MHC identification. Lane 5 is a human myosin standard showing the migration of each of the three adult myosin isoforms present in skeletal muscle. For the standard, the band at the bottom represents type I MHC, the middle band is type IIa, and the top is type IIx. All other lanes contain a single fiber segment run after functional analysis. (Lane 1: type I, Lane 2: IIa, Lane 3: type IIa, Lane 4: type IIa, Lane 6: type I, Lane 7: type IIa/IIa, Lane 8: type IIa/IIx, Lane 9: type I/IIa, Lane 10: type IIa/IIx.)

Densitometry. Relative hybrid MHC composition was assessed using laser-scanning densitometry (Molecular Dynamics, ImageQuaNT 5.0, Sunnyvale, CA.).
Gels were scanned for 100-micron pixel size and area integration was performed to
determine relative density of each MHC band for all hybrid fibers.

*Statistical analysis.* A two way ANOVA, with main effects of training status
and subjects nested within training status, was used to evaluate intra-group differences
in fiber contractile properties. Error terms were adjusted for unequal sample sizes.
Separate analyses were conducted on each fiber type. Two tailed t-tests were used
for anthropometric and whole muscle strength analysis. Statistical significance was
accepted as p< .05. All statistics were performed using SAS version 8.0.

**RESULTS**

*Anthropometrics.* The NT group was not significantly different from the
CHRT group in age or height. The CHRT group weighed significantly more (16%),
had a lower percentage of body fat (55%) and, thus had greater lean mass (31%) than
the NT group. All anthropometric data is shown in Table 1.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
<th>% Body Fat</th>
<th>Lean Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT</td>
<td>6</td>
<td>27 ± 2.5</td>
<td>178 ± 2</td>
<td>82.3 ± 4</td>
<td>22 ± 4</td>
<td>63.7 ± 3</td>
</tr>
<tr>
<td>CHRT</td>
<td>6</td>
<td>22 ± 0.7</td>
<td>180 ± 4</td>
<td>95.4 ± 3*</td>
<td>12 ± 2*</td>
<td>83.7 ± 2*</td>
</tr>
</tbody>
</table>

Table 1 - *Subject anthropometrics.* Values are presented as means ± SE.
* Denotes significantly different from NT (p < .05). n = number of subjects;
cm = centimeters; kg = kilograms; NT = untrained control group; CHRT =
chronically resistance trained group.
Neuromuscular strength. As shown in Table 2, the CHRT group was significantly stronger than the NT group for both the bench press (81%) and the leg press (120%). The CHRT group produced significantly greater isometric torque (28%) and greater isokinetic torque at all isokinetic velocities tested (Figure 5). However, when neuromuscular strength was normalized per kilogram of lean body mass, the groups were approximately equal as there was no difference in isometric or isokinetic torque.

<table>
<thead>
<tr>
<th>Group</th>
<th>Bench Press (kg)</th>
<th>Leg Press (kg)</th>
<th>Bench Press /lean mass</th>
<th>Leg Press /lean mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT</td>
<td>62.5 ± 7</td>
<td>155.3 ± 10</td>
<td>0.98 ± .11</td>
<td>2.44 ± .16</td>
</tr>
<tr>
<td>CHRT</td>
<td>112.9 ± 3*</td>
<td>340.9 ± 9*</td>
<td>1.34 ± .04*</td>
<td>4.07 ± .11*</td>
</tr>
</tbody>
</table>

Table 2 – Neuromuscular strength for each group. Data are presented as means ± SE. * Denotes statistically different from NT (p< .05). kg = kilogram; NT = untrained control group; CHRT = chronically resistance trained group
Fig. 5 – Isokinetic strength and power curves. A and B are mean isokinetic strength and power curves for the (●) NT and (○) CHRT groups. C and D are mean isokinetic strength and power curves after normalization to body mass. E and F are isokinetic strength and power curves after normalization for lean body mass. Points are shown as means ± SE bars. * Denotes statistically different from NT (p<.05). Nm = Newton meters.
**Skinned fiber analysis.** In total, 449 (236 NT; 213 CHRT) fibers from the twelve subjects were analyzed. Mean data for the fibers expressing solely type I, IIa, or IIx MHC are shown in Table 3. Significant differences in CSA were observed between the NT and CHRT groups for all fiber types. CHRT fibers expressing type I MHC were 39% larger and produced 41% greater peak Ca\(^{2+}\)-activated force production. CHRT fibers expressing type IIa MHC were 50% larger and produced 55% more peak Ca\(^{2+}\)-activated force. CHRT fibers expressing type IIx fibers were 64% larger and produced 66% more peak Ca\(^{2+}\)-activated force. When peak force was normalized to fiber CSA, there was no difference in peak Ca\(^{2+}\)-activated force production for NT vs. CHRT for any fiber types.

<table>
<thead>
<tr>
<th>MHC</th>
<th>Group</th>
<th>n</th>
<th>%</th>
<th>CSA (μm(^2))</th>
<th>P(_0) (mN)</th>
<th>P(_0)/CSA (kN/m(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>NT</td>
<td>98</td>
<td>42</td>
<td>5433 ± 147</td>
<td>0.61 ± .02</td>
<td>113 ± 2</td>
</tr>
<tr>
<td></td>
<td>CHRT</td>
<td>77</td>
<td>35</td>
<td>7552 ± 221*</td>
<td>0.86 ± .02*</td>
<td>115 ± 2</td>
</tr>
<tr>
<td>IIa</td>
<td>NT</td>
<td>76</td>
<td>32</td>
<td>6739 ± 171</td>
<td>0.88 ± .02</td>
<td>133 ± 3</td>
</tr>
<tr>
<td></td>
<td>CHRT</td>
<td>110</td>
<td>50</td>
<td>10074 ± 208*</td>
<td>1.36 ± .03*</td>
<td>136 ± 2</td>
</tr>
<tr>
<td>IIx</td>
<td>NT</td>
<td>6</td>
<td>3</td>
<td>6995 ± 566</td>
<td>1.00 ± .02</td>
<td>142 ± 10</td>
</tr>
<tr>
<td></td>
<td>CHRT</td>
<td>1</td>
<td>0</td>
<td>11468*</td>
<td>1.66</td>
<td>144</td>
</tr>
</tbody>
</table>

Table 3 — **CSA and peak Ca\(^{2+}\)-activated force properties for fibers expressing only one myosin heavy chain isoform.** Data are presented as means ± SE. * Denotes statistically different from NT (p< .05). % indicates the percentage of total fibers analyzed. n = number of fibers tested; μm\(^2\) = square micrometers; mN = millinewtons; kN/m\(^2\) = kilonewton/square meter; NT = untrained control group; CHRT = chronically resistance trained group.
Data for hybrid fibers are presented in Table 4. CHRT fibers expressing type I/IIa MHC were 66% larger and produced 47% more force than those from the NT. Type IIa/IIX fibers were 33% larger and produced 35% more force in the CHRT group. The observed difference between groups for I/IIa fibers in P₀/CSA (128 kN/m² CHRT; 140 kN/m² NT) was not significant.

Figure 6 shows the relationship between CSA and peak Ca²⁺-activated force for all type I, IIa, and IIa/IIX fibers. We chose to graphically exclude type I/IIa fibers based on the relatively few data points collected for these fiber types.

<table>
<thead>
<tr>
<th>MHC</th>
<th>Group</th>
<th>n</th>
<th>%</th>
<th>CSA (µm²)</th>
<th>P₀ (mN)</th>
<th>P₀/CSA (kN/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I/IIa</td>
<td>NT</td>
<td>10</td>
<td>4</td>
<td>6604 ± 304</td>
<td>0.93 ± 0.08</td>
<td>140 ± 9</td>
</tr>
<tr>
<td></td>
<td>CHRT</td>
<td>3</td>
<td>1</td>
<td>10934 ± 1483*</td>
<td>1.37 ± 0.15*</td>
<td>128 ± 15</td>
</tr>
<tr>
<td>IIa/IIX</td>
<td>NT</td>
<td>46</td>
<td>19</td>
<td>6674 ± 226</td>
<td>0.96 ± 0.03</td>
<td>145 ± 3</td>
</tr>
<tr>
<td></td>
<td>CHRT</td>
<td>22</td>
<td>10</td>
<td>8873 ± 490*</td>
<td>1.30 ± 0.07*</td>
<td>148 ± 4</td>
</tr>
</tbody>
</table>

Table 4 — CSA and peak Ca²⁺-activated force properties for all fibers expressing multiple myosin isoforms. Data are presented as means ± SE. * Denotes statistically different from NT (p < .05). % indicates the percentage of total fibers analyzed. n = number of fibers; µm² = square micrometers; mN = millinewtons; kN/m² = kilonewton/square meter; NT = untrained control group; CHRT = chronically resistance trained group.
Figure 6 – *Relationship of $P_0$ vs. CSA*. First order least squares regressions of fiber peak $\text{Ca}^{2+}$-activated force vs. CSA. NT fibers are plotted in the top row. CHRT fibers are plotted in the middle row. The pooled fibers from both groups plotted with a new regression line in the bottom row. Included in the bottom row are the regression lines from each of the previous relationships. Presented at the bottom right of each figure are the r-values for the regression line. NT = untrained control group; CHRT = chronically resistance trained group. Dashed = NT; dotted = CHRT; solid = CHRT and NT; mN = millinewtons; $\mu$m$^2$ = square micrometers; $P_0$ = peak $\text{Ca}^{2+}$-activated force; CSA = cross-sectional area.
Slack test data are shown in Table 5. No differences in $V_0$ were seen between NT and CHRT for fibers expressing type I and type IIa MHC. The 15% faster $V_0$ of the CHRT was not statistically different for fibers expressing type IIa/IIx MHC. Type I/IIa hybrids showed a difference between groups for $V_0$ but only two observations were made from the CHRT group. The percentages of MHC isoform for each hybrid vs. $V_0$ are plotted in Figure 7.

<table>
<thead>
<tr>
<th>MHC</th>
<th>Group</th>
<th>n</th>
<th>$V_0$ (fl/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>NT</td>
<td>82</td>
<td>0.58 ± 0.016</td>
</tr>
<tr>
<td></td>
<td>CHRT</td>
<td>70</td>
<td>0.58 ± 0.017</td>
</tr>
<tr>
<td>I/IIa</td>
<td>NT</td>
<td>7</td>
<td>1.28 ± 0.158</td>
</tr>
<tr>
<td></td>
<td>CHRT</td>
<td>2</td>
<td>3.84 ± 0.583*</td>
</tr>
<tr>
<td>IIa</td>
<td>NT</td>
<td>64</td>
<td>3.20 ± 0.197</td>
</tr>
<tr>
<td></td>
<td>CHRT</td>
<td>86</td>
<td>3.13 ± 0.118</td>
</tr>
<tr>
<td>IIa/IIx</td>
<td>NT</td>
<td>40</td>
<td>3.70 ± 0.210</td>
</tr>
<tr>
<td></td>
<td>CHRT</td>
<td>21</td>
<td>4.27 ± 0.257</td>
</tr>
<tr>
<td>IIx</td>
<td>NT</td>
<td>4</td>
<td>4.42 ± 0.714</td>
</tr>
<tr>
<td></td>
<td>CHRT</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 5 – *Unloaded shortening velocity of all fiber types.* Data are presented as means ± SE. * Denotes statistically different from NT (p< .05). n = number of fibers analyzed; fl/s = fiber lengths/second; NT = untrained control group; CHRT = chronically resistance trained group.
Figure 7 – Percentage hybrid vs. $V_o$ for the (○) NT and (□) CHRT. A is the relationship between the percentage of IIx MHC and $V_o$ for fibers co-expressing IIa and IIx MHC. B is the relationship between the percentage of IIa MHC and $V_o$ for fibers co-expressing I and IIa MHC. fl/s = fiber lengths/second

Force-velocity curve data are presented in Table 6. Significant differences were seen between groups in maximal $P_o$ for all fiber types. Only fiber expressing purely fast MHC showed differences in $a/P_o$ with only type IIa/IIx from the CHRT being different from NT for $V_{max}$.

Power data are displayed in Table 7. For all fiber types, the CHRT displayed greater peak absolute power than the NT group. CHRT fibers expressing type I, I/IIa, IIa, and IIa/IIx fibers had 27%, 73%, 59%, 35% greater absolute power respectively than the NT group. After normalization for fiber volume (normalized power), only type I from the CHRT was different (8% lower) than the NT. Despite the decreased trends in the percentage of $P_o$ at which absolute power was attained, absolute $P_o$ was
greater for all fiber types except type IIa/IIx where the p value (p = .09) approached significance. Although not statistically significant, all fiber types displayed trends for greater velocity at absolute power except type I, which was significantly (11%) lower (Table 8). Force-power curves are presented in Figure 8 which graphically shows the difference in power for the type I, IIa, and IIa/IIx fibers.

<table>
<thead>
<tr>
<th>MHC Group</th>
<th>N</th>
<th>V_max (fl/s)</th>
<th>P_0 (mN)</th>
<th>a/P_0</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>NT 80</td>
<td>0.78 ± .04</td>
<td>0.60 ± .02</td>
<td>.030 ± .002</td>
</tr>
<tr>
<td></td>
<td>CHRT 68</td>
<td>0.73 ± .04</td>
<td>0.86 ± .03*</td>
<td>.026 ± .001</td>
</tr>
<tr>
<td>IIa</td>
<td>NT 8</td>
<td>1.52 ± .26</td>
<td>0.85 ± .06</td>
<td>.045 ± .007</td>
</tr>
<tr>
<td></td>
<td>CHRT 3</td>
<td>1.97 ± .73</td>
<td>1.37 ± .15*</td>
<td>.041 ± .012</td>
</tr>
<tr>
<td>I/IIa</td>
<td>NT 58</td>
<td>1.59 ± .10</td>
<td>0.90 ± .02</td>
<td>.063 ± .004</td>
</tr>
<tr>
<td></td>
<td>CHRT 85</td>
<td>1.83 ± .08</td>
<td>1.33 ± .04*</td>
<td>.052 ± .002*</td>
</tr>
<tr>
<td>IIa/IIx</td>
<td>NT 31</td>
<td>1.76 ± .09</td>
<td>0.96 ± .03</td>
<td>.088 ± .009</td>
</tr>
<tr>
<td></td>
<td>CHRT 22</td>
<td>2.24 ± .13*</td>
<td>1.28 ± .07*</td>
<td>.058 ± .005*</td>
</tr>
<tr>
<td>IIx</td>
<td>NT 2</td>
<td>2.45 ± .40</td>
<td>1.24 ± .07</td>
<td>.078 ± .011</td>
</tr>
<tr>
<td></td>
<td>CHRT 0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 6 – Force-velocity relationship parameters derived from isotonic contractions. Data are presented as means ± SE. * Denotes statistically different from NT (p< .05). n = number of fibers analyzed; fl/s = fiber lengths/second; mN = millinewtons; V_max is the y-intercept from Hill plots (27); P_0 is peak Ca^{2+} - activated force; a/P_0 is a unit-less ratio describing the slope of the velocity curve where a/P_0 = 1 is a straight line.
<table>
<thead>
<tr>
<th>MHC Group</th>
<th>Peak Power (μN·fl/s)</th>
<th>Peak Power (kN/m²·fl/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I NT</td>
<td>8.3 ± .3</td>
<td>1.52 ± 0.04</td>
</tr>
<tr>
<td>CHRT</td>
<td>10.5 ± .4*</td>
<td>1.40 ± 0.004*</td>
</tr>
<tr>
<td>I/IIa NT</td>
<td>34.1 ± 5.2</td>
<td>5.54 ± 0.95</td>
</tr>
<tr>
<td>CHRT</td>
<td>59.0 ± 7.8*</td>
<td>5.62 ± 1.09</td>
</tr>
<tr>
<td>IIa NT</td>
<td>46.5 ± 1.3</td>
<td>7.01 ± 0.21</td>
</tr>
<tr>
<td>CHRT</td>
<td>73.8 ± 2.9*</td>
<td>7.53 ± 0.27</td>
</tr>
<tr>
<td>IIa/IIx NT</td>
<td>71.5 ± 3.4</td>
<td>11.37 ± 0.56</td>
</tr>
<tr>
<td>CHRT</td>
<td>96.4 ± 8.0*</td>
<td>11.42 ± 1.00</td>
</tr>
<tr>
<td>IIX NT</td>
<td>131.9 ± 17.6</td>
<td>17.51 ± 3.21</td>
</tr>
<tr>
<td>CHRT</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 7 – Power curve data from load clamps. Data are presented as means ± SE. * Denotes statistically different from NT (p< .05). μN·fl/s = micronewtons · fiber lengths/second; kN/m²·fl/s = kilonewtons/square meter · fiber lengths/second; NT = untrained control group; CHRT = chronically trained group.

Between groups differences in fiber power are illustrated in Figure 9. For all fiber types, absolute power was greater in the CHRT vs. the NT. We have chosen to graphically display absolute power differences due to the finding that no difference existed between training groups after normalizations for fiber volume.
<table>
<thead>
<tr>
<th>MHC</th>
<th>Group</th>
<th>%P₀ at peak power</th>
<th>P at peak power (mN)</th>
<th>V at peak power (fl/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>NT</td>
<td>14.0 ± .003</td>
<td>.085 ± .003</td>
<td>.101 ± .002</td>
</tr>
<tr>
<td></td>
<td>CHRT</td>
<td>13.4 ± .003</td>
<td>.115 ± .003*</td>
<td>.093 ± .002*</td>
</tr>
<tr>
<td>I/Ila</td>
<td>NT</td>
<td>16.7 ± .012</td>
<td>.141 ± .014</td>
<td>.240 ± .033</td>
</tr>
<tr>
<td></td>
<td>CHRT</td>
<td>16.1 ± .022</td>
<td>.227 ± .051*</td>
<td>.285 ± .061</td>
</tr>
<tr>
<td>Ila</td>
<td>NT</td>
<td>19.1 ± .002</td>
<td>.171 ± .005</td>
<td>.282 ± .009</td>
</tr>
<tr>
<td></td>
<td>CHRT</td>
<td>17.8 ± .003*</td>
<td>.238 ± .008*</td>
<td>.312 ± .009</td>
</tr>
<tr>
<td>Ila/Ilx</td>
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<td>21.2 ± .007</td>
<td>.199 ± .007</td>
<td>.360 ± .014</td>
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<td>CHRT</td>
<td>18.5 ± .007*</td>
<td>.235 ± .015</td>
<td>.409 ± .023</td>
</tr>
<tr>
<td>Ix</td>
<td>NT</td>
<td>21.1 ± .012</td>
<td>.260 ± .000</td>
<td>.506 ± .066</td>
</tr>
<tr>
<td></td>
<td>CHRT</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 8 — %P₀, P₀, and V at peak power. Data are presented as means ± SE. * Denotes statistically different from NT (p< .05). n = number of fibers analyzed; fl/s = fiber lengths/second; mN = millinewtons.
Figure 8 - Power curves for type I, IIa, and IIa/IIx fibers for NT and CHRT. A is the NT group and B is the CHRT group. For both A and B, power for fibers expressing type I MHC are represented by a solid line, type IIa fibers are dotted, and type IIa/IIx are shown as dashed. mN = millinewtons; μN · fl/s = micronewtons · fiber lengths/second
Figure 9 – Force-velocity and force-power curves for NT (dotted) and CHRT (solid) groups. A Type I, B Type I/Ila, C Type Ila D Type IId/IIX. Each graph is plotted with absolute force on the x-axis. In D, type IIX fibers (dashed) from the NT group are included for comparison to the Ila/IIX fibers from both groups. fl/s = fiber length/second; mN = millinewtons; µN • fl/s = micronewtons • fiber lengths/second

DISCUSSION

Anthropometrics. Long-term resistance training is most likely responsible for the greater body mass, lower percent body fat, and greater lean mass of the CHRT vs.
NT groups. Similar differences in these variables have been reported in both short-term longitudinal studies (22, 24, 25) and cross sectional studies comparing elite athletes to sedentary subjects (3, 23, 37, 47).

Neuromuscular strength. As expected, the CHRT group displayed greater neuromuscular strength than the NT for both complex and simple motor tasks. The 119% greater strength of the CHRT vs. NT in the leg press was much greater than the 28% greater isometric force production of the knee extensors. The great discrepancy between the bench press and leg press vs. isokinetic results can be explained by specificity. The resistance-trained subjects used the bench press and leg press regularly in their training. In contrast, the isokinetic testing was unique. Thus, differences could be explained by training status and would reflect a greater learning effect with more complex movement patterns (32, 65). Muscular adaptations due to resistance training have been characterized as being highly specific to the type of training the muscle is subjected to with larger discrepancies found where testing modality and training protocol differed (for review see (33)). For instance, Rutherford et al. (64) demonstrated that 12 weeks of dynamic leg extension training produced a 160% increase in training resistance but only a 20% increase in maximal isometric strength. The greater differences seen in isotonic movements are related to the specificity of training as our subjects regularly incorporated multi-joint exercises such as the leg press and squat as part of their training and had never included maximal isometric contractions into their training programs.
Observed maximal isometric knee extensor strength of 883 N or 282 Nm for the NT are similar to the 730 N (52), 750 N (58), 760 N (8), and 282 Nm (1) previously reported from untrained subjects. Investigating well-trained physical education students, Tesch & Karlsson (70) reported a maximal isometric value of 1160 N, which is very similar to the 1095 N for our CHRT group. Studies of short-term (8-14 weeks) dynamic resistance training have shown a 16-24% increase in maximum isometric strength, which is slightly less than the 28% greater isometric strength of the CHRT (1, 22, 58).

**CSA.** Our data demonstrate that fibers from chronically resistance-trained subjects are larger in CSA than then fibers from untrained subjects across all fiber types. The greatest relative differences existed in fibers expressing type IIa MHC. These data suggest that prolonged resistance training induces hypertrophy of all fiber types with greater hypertrophy occurring in fibers expressing type IIa and type IIa/IIX MHC fibers. In agreement, previous studies have demonstrated preferential hypertrophy of fast fibers with both short-term (39, 54) and long-term training (34, 37, 71, 72).
Table 9 - CSA comparison to previous studies. For this comparison, our data at the top has been reduced 20% to account for fiber swelling during skinning. CSAs are shown as means. Following each set of means is the difference between groups shown as a percentage. We have maintained the original fiber type terminology as used by the original authors. However, type IIb is analogous to MHC type IIX. # Denotes that no distinction was given as to IIa vs. IIX fibers of fast hybrids. The CSA therefore represents the mean of all fast fibers. † Six out of seven subjects in the elite group had reported using anabolic steroids. All CSAs are given in µm² = square micrometers.
Our data are presented without correction for the approximate 20% swelling of individual fiber diameter that occurs as a result of the disruption of the sarcolemma due to the chemical skinning process (21). However, in Table 9, our values have been reduced by 44% for comparison to previous histochemical studies measuring CSA. The absolute fiber CSA values for NT are similar to fibers from previously reported college-aged male control groups (39, 46, 54) and the fiber CSAs of the CHRT are very similar to previous cross sectional studies (34, 37) (see Table 9). The CSA differences between the NT and CHRT demonstrated here are much greater than those shown with 6 weeks (46) and 12 weeks (54) of training and are slightly less than those shown for elite powerlifters (34) and elite bodybuilders (37). Studies with elite lifters have shown much greater hypertrophy (48), but how much of this might be explained by the possible use of anabolic steroids is unknown.

\( P_o \) and \( P_o/\text{CSA} \). Accompanying the greater CSA of all fiber types (except type I/IIa) in the CHRT vs. the NT was a greater absolute \( P_o \). After normalization for fiber CSA, there was no significant differences in \( P_o/\text{CSA} \) between groups. Thus, the large differences in peak \( \text{Ca}^{2+} \)-activated force production of all fiber types appear mostly to be a result of their larger CSA.

The greater \( P_o/\text{CSA} \) for type IIa/IIX fibers vs. type IIa (9%) and type IIa vs. type I (18%) fibers for the NT group is in agreement with previous data from sedentary males (7, 20, 26, 42, 82). Fibers from the CHRT group exhibited the same relative differences between fiber types as the NT subjects (type IIa/IIX vs. type IIa 9%; type IIa vs. type I 18%). Our data is consistent with Hoppeler (28) who showed
that fibers expressing faster isoforms contain higher percentages of myofibrils compared to type I and Tikunov et al. (74) who demonstrated a higher concentration of MHC in faster fiber isoforms. This has been suggested to be due to a sort of competition of myofibrils, mitochondria, and sarcoplasmic reticulum for cellular space related to fiber function (63). Our data indicate no change in $P_0/\text{CSA}$ in fibers from chronically resistance trained individuals. The most direct explanation is that the ratio of myofibrils to noncontractile components is unaltered by years of resistance training. In the untrained state, 85%-90% of the cellular volume is occupied by myofibrils, approximately 3-5% mitochondria, and 9-15% sarcoplasm (28).

With the greater $P_0/\text{CSA}$ shown for fast fibers vs. slow, independent of group, force production at the whole muscle level is not simply dependant upon fiber hypertrophy but is also affected by the proportion of slow to fast fibers. Additionally, the differences we note in our preparation will likely be accentuated in vivo since slow fibers have higher levels of inorganic phosphate ($P_i$) at rest (41) and $P_i$ has been shown to depress fiber force. While some have attempted to describe this relationship of whole muscle strength and CSA (52, 53, 83), future studies relating the increases in muscle force to fiber hypertrophy need to be aware of this.

The small trend towards higher $P_0/\text{CSA}$ for all fiber types in the CHRT suggests that should cellular function be altered it could be masked by lack of statistical power or the cross sectional design of this study. However, the overall contribution of increased cellular $P_0/\text{CSA}$ to increased whole muscle $P_0/\text{CSA}$ is probably small at best with long-term training. Finally, with no differences between
groups for mean $P_o$/CSA (Tables 3 and 4), investigation into the relationship between $P_o$ and CSA (Figure 6) also produced no differences between groups.

It has been repeatedly shown that force increases disproportionately to whole muscle CSA with short-term training in pennate muscle where changes in physiological CSA are often underestimated by measuring anatomical CSA (1, 22, 32, 46, 50, 65) and fusiform muscle where physiological CSA is more reliably estimated (30, 57). Comparing duration of training and degree of hypertrophy Alway et al. (3) reported that whole muscle $P_o$/CSA was lower in elite bodybuilders than recreationally trained controls. The authors suggested that $P_o$/CSA could be elevated in short-term training and as hypertrophy continued, this would decrease back to a more normal level. Jones and Rutherford (32) suggested that the increased whole muscle $P_o$/CSA due to short term training could be in part due to the reported increases in radiological density of muscle (9, 29, 32). Furthermore, this increased radiological density (a measure of whole muscle density) could occur as a result of decreased muscular fat content, increased connective tissue attachments, or increased contractile element packing (32). Both increased myofibrillar packing (measured as volume density) and myofilament packing (measured as distance between filaments) are ways in which alterations in the packing of the contractile elements could increase $P_o$/CSA. However, although previous studies have shown absolute increases in myofibrillar volume, these were equal to the increased CSA and thus, no changes were seen in myofibrillar density in men (46, 49) and women (77). Refuting the earlier work of Penman (60) who showed an increased myofilament packing density with training, Claassen et al. cited methodological flaws in Penman’s earlier work and
demonstrated no change in myofilament packing density (9). Our data support the later finding, that there is no alteration in myofibrillar or myofilament packing density with long-term training significant enough to affect $P_0$/CSA.

**Unloaded shortening velocity.** Our reported NT values of 3.20 and 0.58 fl/s for type IIa and type I fibers represent a 5.5:1 ratio of type IIa:I shortening velocity. Although some discrepancy exists between studies as to the absolute velocity of shortening our data fall within the range of previously reported human data showing type IIa:I velocity ratio between 3.3-5.6 (18, 26, 40, 42, 43, 80, 82). The reported shortening velocity $Q_{10}$ of 5.88 for skeletal muscle fibers in the range of 12-17°C (7) explains much of the difference between the studies of Larsson et al. 1996, Larsson et al. 1997, and Harridge et al. 1998 (26, 42, 43) which were performed at 12°C and the studies of Fitts et al. 1989 (18), Widrick et al. 1996 (82), Widrick et al. 2001 (80), and Krivickas et al. 2001 (40) which were performed at 15°C.

Our data show that fibers expressing pure MHC from chronically resistance-trained subjects have the same unloaded shortening velocities as fibers from untrained subjects. Although fibers expressing type IIa/IIx MHC were slightly faster in the CHRT, this difference was not significant. Further, as no differences were seen in plots of the percentage of IIx MHC vs. $V_0$ (Figure 8), their higher velocity could reflect changes in myosin light chain (MLC) content, which were not examined in the present study.

These data suggest that $V_0$ of single chemically skinned muscle fibers appears to be unaltered as a result of long-term resistance training. Trappe recently showed
that fiber $V_0$ of type I and IIa fibers obtained from male subjects increased 75% and 45% respectively after 12 weeks of heavy resistance training (76). However, the same resistance training protocol in older women induced no changes in fiber $V_0$ for any fiber type (75). The authors studied 74 year olds and it is unclear whether the increased $V_0$ seen in older males represents a specific effect of resistance training or simply a reversal of the age-related declines in fiber $V_0$ shown to occur in rats (45, 73) and humans (40, 42). Our data suggest no influence of resistance training on fiber $V_0$ in either slow or fast fibers independent of age. Furthermore, our data support the conclusion reached by Jones and Rutherford (33). These authors reviewed the literature and based on whole muscle responses, concluded that resistance training has no effect on fiber shortening velocity. Finally, sprint training, a form of high intensity exercise producing similar metabolic demands on muscle as resistance training was shown to produce no change in shortening velocity of either type I or type IIa fibers with a subject group similar to the present NT group (26).

The increased maximal velocity of contraction as a result of light resistance/high velocity training as reported by Duchateau & Hainaut (12) could be explained as a result of the light resistance utilized, possibly causing adaptation similar to endurance training. Other possibilities include: their technique for $V_{\text{max}}$ extrapolation (from the Hill equation)(27), fiber type shifts, or calcium kinetics related to EC-coupling. A final possibility to explain the increased $V_{\text{max}}$ seen by Duchateau & Hainaut is that in describing the force-velocity relationship, they included only five data points of only one subject after training.
The compromised adaptations involved with concurrent endurance and resistance-training exercise (39) are partially explained by the differential adaptations seen at the single fiber level. Whereas resistance training produces hypertrophy of all fiber types, endurance training produces either no change or a slight decrease in fiber CSA (18, 39, 78). Furthermore endurance training studies with single fibers have shown that $V_o$ of type I fibers is increased (18, 19, 82) and decreased in type IIa fibers (18). Therefore, with apparently opposite outcomes of either exercise regime, concurrent training would produce a conflict in the development of exercise specific adaptation.

**Power.** We have chosen to graphically display absolute power differences (Figure 9) due to the finding that no difference existed between training groups after normalizations for fiber volume. The drastic difference within fiber types between groups after training shows very clearly the importance of force, and thus fiber CSA, to power production. Absolute power was much greater in the CHRT group. With no differences in $V_{max}$ for all but the type IIa/IIx fibers, the large difference in maximal $P_o$ was responsible for the larger power in the CHRT group. Interestingly, the type IIa power curves for the CHRT group had greater peak power than IIa/IIx curves from the NT group.

Our data show that fibers from chronically trained subjects reached peak power at a lower percentage of $P_o$ for all fiber types (Table 8). However, as a result of the greater $P_o$ after training, peak power occurred at higher absolute forces in all fiber types and higher absolute velocities in all fiber types except type I fibers. Here, the
difference was slightly lower (Table 8). Practically speaking, this adaptation would have profound implications for all movements and in particular athletics. If after training, hypertrophy has allowed for greater force producing capability of the musculature, one would be able to move a resistance at a faster velocity than an untrained individual would be able to move that same resistance. This occurs as a result of the rightward shift in force-velocity curves in the absence of maximal velocity changes.

Our data suggests that even after years of training, subjects maintain a subpopulation of fibers expressing some portion of type IIx MHC. Therefore it appears that although the absolute percentage of IIx isoform decreases, fibers expressing some type IIx MHC may contribute significantly to high power contractions. Furthermore, the IIx to IIa transition, often viewed as a disadvantage due to the loss of high velocity/high power motor units, is possibly the opposite due to the possibility that fibers gain fatigue resistance. The advantage to this shift could be that even though the fastest, most powerful fibers are reduced in number, the slower fibers have hypertrophied and thus have a greater absolute power production after training. Thus one may gain greater fatigue resistance at a small cost of power. While the IIa/IIx hybrids decrease from 20% to 10% of all fiber types, a substantial amount of IIx isoform remains. The omission of the importance of this fiber type after training is therefore unwarranted as is seen oftentimes with histochemical fiber typing often demonstrating ~1% IIx isoform prevalence after training. However, the relative contribution to whole muscle performance is still unknown.
Conclusion. This methodology and design of this study have some limitations. Most obvious, is the *in vitro* cellular preparation. In order to control for numerous factors such as angle of pennation, fiber type prevalence, biochemistry, neurological mechanisms, and psychological issues (related to motivation or learning), the skinned fiber preparation does not allow for direct extrapolation to *in vivo* conditions. The concentration and content of solutions, although estimated to mimic the internal milieu, combined with a lower experimental temperature, to *in vivo* conditions. Secondly, the cross-sectional design of this study does not take into account possible genetic differences and training history of the subjects that could be better controlled in a longitudinal training study. Nonetheless, the carefully controlled and reliable techniques used here provide evidence that despite years of resistance training no qualitative differences were seen in force production and unloaded shortening velocity of all fiber types. Larger differences in absolute force and peak absolute power production are caused as a result of the greater cross-sectional area of fibers and result in peak power occurring at higher velocities and higher forces.
REFERENCES


APPENDICES
APPENDIX A

APPLICATION FOR INSTITUTIONAL REVIEW BOARD APPROVAL
Contractile function of single muscle fibers from chronically resistance-trained humans

1. Brief description of the project.

Resistance-training is currently prescribed for injury rehabilitation, disease prevention, enhanced athletic performance, and increased functional mobility. While the effects of resistance training on muscular strength are well established, very little is known about how resistance training produces these effects. Currently, our laboratory is investigating how 12 weeks of resistance training exercise alters the contractile properties (peak force, shortening velocity, power) of human muscle fibers. Longer periods of training, i.e. years of training, may induce greater changes than those that occur in 12 weeks. Therefore, the purpose of this study is to examine the contractile properties of muscle fibers obtained from individuals who have been participating in a resistance-training program for at least 3 years.

2. Description of the methods and procedures.

The purpose, procedures, risks, and benefits associated with the study will be explained to all potential subjects. Subjects will be encouraged to ask questions and their questions will be answered by the principal investigator. Each potential subject will sign an informed consent document before being allowed to participate in any aspect of the study. A copy of the informed consent will be given to all subjects.
a. Subject recruitment

Advertisements will be used to recruit male and female subjects from the University and surrounding communities. The advertisement is included in the Appendix. A total of 16 subjects will be recruited, approximately equal numbers of males and females. Potential subjects will complete a training history and health questionnaire (see Appendix). Inclusion of a potential subject into the study will be based on the criteria in section 4.

b. Testing procedures

Testing procedures will consist of the following. Session 1 (day 1): determination of physical characteristics and muscle biopsy of the vastus lateralis (thigh muscle). Session 2 (day 7): assessment of muscular strength. Session 3 (day 10): repeat assessment of muscular strength.

i. Physical characteristics. Subjects will report to the Human Performance Laboratory. Their height and mass will be recorded. Body composition will be assessed in a “BodPod”. This apparatus utilizes air displacement for estimation of body density and body composition determination. This technique requires the subject to wear a swimsuit and to sit motionless in a small chamber for ~1 minute.

ii. Muscle biopsy. Subjects will report to the Human Performance Lab where Jeffrey Mull, M.D., (Student Health Services) will extract a small muscle sample using the percutaneous needle muscle biopsy procedure. Subjects will be advised to abstain from using aspirin or ibuprofen products for three days prior to the biopsy procedure. The muscle sample will be obtained from the side of the thigh (vastus lateralis). The skin near the biopsy site is sterilized and draped with a sterile field. An anesthetic is injected subcutaneously into the thigh at the biopsy site. An incision (~ 3/8” inch) is made through the skin and the connective tissue of the muscle. A biopsy “needle” (~2/10 of an inch in diameter) is inserted through the incision and into the muscle in order to obtain a small sample of tissue (0.002-0.004 oz.). The incision is closed, dressed, and covered with a compression bandage.

Subjects are given verbal and written instructions (see Appendix) on how to care for the incision. Subjects will be contacted by phone 24-48 hours after the biopsy to check on their status and see if they have any further questions concerning the incision.

iii. Strength testing – isokinetic dynamometry. Approximately 7 and 10 days following the muscle biopsy, subjects will report to the Sports Medicine Lab. A KinCom dynamometer will be used to determine isometric and isokinetic strength of the left and right knee extensors and flexors.
After a warm-up consisting of stretching and light aerobic exercise, the subject will be positioned in a seated position on the dynamometer. The subject is restrained at the chest, waist, and thigh. The ankle is attached to a lever arm using Velcro straps. Subjects will be instructed in how to perform the test and will be given adequate time for learning and familiarization with the testing procedure.

Isometric strength will be determined by having the subject maximally extend the knee against the stationary lever arm (30 degrees from horizontal). Subjects will perform 3 trials. Strength will be determined by having subjects perform maximal extensions and flexions against the lever arm at velocities of, 30, 60, 90, 120, 180, and 240 degrees/second. Each velocity will be tested three times.

iv. **Strength testing – free weights.** Following both dynamometry sessions, subjects will report to the Langton Hall weight room. After a warm-up consisting of stretching and light aerobic exercise, subjects will perform six repetitions of both the leg press and bench press lifts. Initially, the resistance will be sub-maximal. Resistance will be progressively added until the subject can no longer perform six repetitions. Rest periods of 3 minutes will be provided between each set for complete recovery. A spotter will be present at all time to assist the subject.

1. **Benefits and risks.**

   **Benefits.** Subjects will learn their body composition and muscle fiber type composition and will be provided with an assessment of their muscular strength. Subjects will also receive a small honorarium for their participation.

   **Risks.** a. Strength testing. The strength testing should cause muscular fatigue and localized discomfort that will dissipate in several hours. Subjects might experience muscle soreness and/or tenderness 2-3 days after the testing procedure. These symptoms should disappear in a day or two. There is a risk of musculoskeletal injury during the muscle strength testing. To reduce this risk, subjects will be given, 1) an adequate warm-up, 2) thorough instruction about the testing procedures, and 3) adequate and supervised practice time. A graduate student knowledgeable about the testing procedures will supervise the testing. A spotter will be used during the free-weight testing in order to minimize risk.

   b. Muscle biopsy. Subjects often report a pressure sensation during the biopsy procedure. They may also experience soreness or tenderness near the biopsy site for up to 72 hrs. following the procedure. The major risk associated with the biopsy procedure is the possibility of infection. To
minimize this risk, the procedure will be performed by a physician using sterile technique. Subjects will also be given explicit care instructions and will be contacted 24-48 hours after the procedure.

2. **Subject population.**

   Male and female subjects will be recruited from the Corvallis, OR area. Advertisements will be posted in local exercise facilities and campus locations (see Appendix). 16 total subjects will be recruited (approximately equal numbers of males and females).

   **Inclusion criteria (experimental):**
   1. 18-35 years of age
   2. A minimum of three years of resistance training experience
   3. Uninterrupted training for two continuous months immediately prior to testing
   4. Training programs designed to elicit skeletal muscle hypertrophy (large muscle groups between 6-12 repetitions)
   5. No self-reported use of anabolic steroids

   **Exclusion criteria (experimental):**
   1. History of frequent aerobic training
   2. Presence of musculo-skeletal disease
   3. History of cardiovascular disease, diabetes, or uremia
   4. Presence of serious injury that will prevent strength testing

   **Inclusion criteria (control):**
   1. 18-35 years of age
   2. No history of resistance training
   3. No self-reported use of anabolic steroids

   **Exclusion criteria (control):** Same as experimental
   1. History of frequent aerobic training
   2. Presence of musculo-skeletal disease
   3. History of cardiovascular disease, diabetes, or uremia
   4. Presence of serious injury that will prevent strength testing

3. A copy of the informed consent is attached to this document.

4. The informed consent will be explained to each subject. The investigator will ask each subject if they have any questions regarding the project, the potential risks, and their rights as a research subject before the subjects give their consent to participate. Subjects will receive a copy of the informed consent for their records.
5. Anonymity will be maintained by assigning each subject an ID number. All data will be referenced to these ID numbers.

6. n/a

7. No other approval is required.

Signed ___________________________ Date ____________
APPENDIX B

COPY OF IRB APPROVAL
TO: Jeffrey Widrick, ExSS

COPY: Todd Shoepe, 644 S.W. 7th St., #16, Corvallis, OR 97333

RE: Contractile function of single muscle fibers from chronically resistance-trained humans.

The referenced project was reviewed under the guidelines of Oregon State University's institutional review board (IRB), the Committee for the Protection of Human Subjects, and the U.S. Department of Health and Human Services. The IRB has approved your application. The approval of this application expires upon the completion of the project or one year from the approval date, whichever is sooner. The informed consent form obtained from each subject should be retained in program/project's files for three years beyond the end date of the project.

Any proposed change to the protocol or informed consent form that is not included in the approved application must be submitted to the IRB for review and must be approved by the committee before it can be implemented. Immediate action may be taken where necessary to eliminate apparent hazards to subjects, but this modification to the approved project must be reported immediately to the IRB.

Date: 08/16/00

Warren N. Suzuki, Chair
Committee for the Protection of Human Subjects
(Education, 7-6393, suzukiw@orst.edu)
APPENDIX C

RECRUITING ADVERTISMENT (CHRONICALLY TRAINED)
Experienced Lifters Wanted

The Muscle Physiology Laboratory at Oregon State University is in need of participants for a resistance training study.

Participation in this study may benefit you by providing:
- Detailed strength assessments
- Knowledge of body composition (% body fat)
- Knowledge of muscle fiber type composition
- Knowledge of muscle fiber type performance

You may qualify to participate in this study if you:
- Are aged 18-35 years
- Have been lifting for > 3 years
- Focus mainly on hypertrophy training
- Take few lengthy breaks from lifting during the year
- Have never used illicit anabolic steroids

For more information contact: Todd Shoepe
541-737-6795 OR 541-737-3471.
APPENDIX D

RECRUITING ADVERTISEMENT (CONTROLS)
Are you interested in learning how to begin a resistance-training program (correctly)?

The Muscle Physiology Laboratory at Oregon State University is in need of participants for a resistance training study.

Participation in this study may benefit you by providing:

- Detailed strength assessments
- Knowledge of body composition (% body fat)
- Knowledge of muscle fiber type composition
- Knowledge of muscle fiber type performance
- Information on beginning a resistance training program

You may qualify to participate in this study if you:

- Are aged 18-35 years
- Have little or no experience with resistance-training
- Have little or no experience with endurance exercise

For more information contact: Todd Shoepe
541-737-6795 OR 541-737-3471.
APPENDIX E

INTERVIEW CHECKLIST
Contractile Function of Single Muscle Fibers From Chronically Resistance-Trained Humans.

Name: ____________________________
Date of Birth: ________________
Sex: __________________
Height: ______
Weight: ______
Years of weight training experience: ______

Date: ______

Estimate of current squat 1RM: ______

Estimate of current bench 1RM: ______

Which best describes your racial/ethnic identity? (Please check all that apply.)

_____ White, European American, Non-Hispanic
_____ Asian or Asian American
_____ Black, African American, Non-Hispanic
_____ Pacific Islander
_____ Middle Eastern or Middle-Eastern American
_____ Hispanic or Latino American
_____ North African or North African-American
_____ American Indian or Alaskan

If none of the above choices apply to you, please use your own description:

_____ Decline to respond

1. Are you currently or have you ever used any form of anabolic steroids? (If unsure, list all substances that you have used that you are unsure of their classification)

2. List all nutritional supplements that you have used over the past year. (Describe the pattern and frequency of use if applicable).

3. Current injuries/ physical limitations:

4. Major injuries in the past three years:

5. Length of longest interruption in training during the last three years (reason):

6. Duration of current lifting program:

7. Description of current weight training program:

8. Reasons for participation in a resistance-training program:
9. Have you been participating in serious aerobic training in the last 6 months? If so, how much and what type?

10. Has a doctor ever said that you have a heart condition and recommended any medically supervised activity?

11. Do you have chest pain brought on by physical activity?

12. Have you developed chest pain in the past month?

13. Do you tend to lose consciousness or fall over as a result of dizziness?

14. Do you have a bone or joint problem that could be aggravated by the proposed physical activity? (i.e. Do you have any of the following?) If so, describe.
   - Back pain
   - Shoulder problems
   - Knee problems
   - Foot problems
   - Neck problems
   - Arthritis
   - Broken bones
   - Arthritis (Osteo)
   - Joint, tendon, or muscular pain
   - Other __________________________

15. Has a doctor ever recommended medication for blood pressure or a heart condition?

16. Have you ever been told by your doctor that you have one of the following:
   - Coronary Heart Disease
   - Stroke
   - Irregular heart beats
   - Hypertension
   - Angina
   - Chest discomfort
   - Dizziness/fainting
   - Systemic disease
   - Peripheral vascular disease
   - Heart attack
   - Epilepsy
   - Chronic obstructive pulmonary disease
   - Heart murmurs
   - Rheumatic fever
   - Asthma
   - Rheumatic heart disease
   - Congenital heart disease
   - Heart valve problems
   - Cancer
   - Congestive heart failure
   - Shortness of breath
   - Emphysema
   - Diabetes
   - Chronic bleeding disorders

17. Have you ever experienced abnormal bruising or bleeding as a result of injury?

18. Are you aware through your own experience, or a doctor's advice, of any other physical reason against your exercising without medical supervision?
APPENDIX F

INFORMED CONSENT DOCUMENT
INFORMED CONSENT DOCUMENT

I. A. Title

Contractile function of single muscle fibers from chronically resistance-trained humans.

B. Principle investigator

Jeffrey J. Widrick, Ph. D.
Assistant Professor
Dept. of Exercise and Sport Science
Oregon State University
541-737-5923

For a Master's Thesis by
Todd C. Shoepe
Master's Candidate
Dept. Of Exercise and Sport Science
Oregon State University
541-737-6795

C. Purpose

Strength training has been proposed as a method of increasing athletic performance and decreasing impairments in muscle function due to age, injury, inactivity, and spaceflight. Adaptations seen in this study will help to isolate the exact mechanism of increased strength and power associated with long-term resistance training. Therefore, the purpose of this investigation is to examine the effects of long-term resistance training on muscle function.

D. Procedures - I understand that as a participant in this study the following things will happen:

1. Pre-study screening. As a potential participant in this study, I will complete an interview process designed to determine my suitability for this study. I may or may not be asked to participate in the study based on my training history, age, and/or health status.

2. What participants will do in the study.
   a. I will complete a training history and medical questionnaire designed to assess my suitability for this study.
   b. On day one, I will participate in measurements of body-fat percentage, height, and weight. A small muscle sample will then be obtained from my thigh muscle (vastus lateralis). The method used to obtain these samples (percutaneous needle
biopsy technique) is used by the medical community to obtain muscle samples for the assessment of neuromuscular diseases. Muscle samples obtained in this way typically weigh between 2-4 one thousandth of an ounce (approximately the size of a grain of rice - 0.002-0.004 oz.). A physician will perform the procedure.

c. On (approximately) day seven following the biopsy, I will participate in various strength assessments. Isometric and isokinetic testing will be performed with a KinCom dynamometer. Six-repetition maximums for both the bench press and leg press will be assessed with free weights. All assessments will be repeated on day ten following the biopsy.

3. **Foreseeable risks or discomfort**

   a. **Strength testing**

      i) I will most likely experience muscle fatigue and some localized muscular discomfort following the maximal strength testing procedures.

      ii) I may experience delayed muscle soreness 2 to 3 days following the should subside in 2 or 3 days.

   b. **Body composition**

      i) During the body composition assessment, I will be asked to wear a bathing suit while I sit motionless in an isolated chamber for a few minutes. This chamber is small and may cause claustrophobia. During a test, I will hear a series of clicks that occur as the machine is measuring air displacement for estimation of body density. At any time, I will be able to abort the test by opening the door.

   c. **Muscle biopsy**

      i) I may experience a stinging sensation as a local anesthetic is injected at the sample site.

      ii) A small incision, approximately 3/8 inch long, is made through the skin and the sheath that surrounds the muscle. I understand that I will have a small scar as a result of this incision.

      iii) To obtain the muscle sample, a biopsy "needle", ~2/10 of an inch in diameter, is inserted through the incision and into the muscle. Most people report feeling an odd, "pressure" sensation as this is done.

      iv) Following the procedure, I may experience muscle soreness or tenderness near the biopsy site. This soreness usually disappears within 72 hours.

      v) Like any surgical procedure, there are certain risks. These include the risk of infection and the development of an intra-muscular hematoma. The following precautions will be taken to minimize these risks: a) the biopsy will be performed by a physician, b) the procedure will be performed using sterile technique, c) I will be given verbal and written instructions on how to care for the incision. I will be referred to a physician if there is any evidence of an unusual response.

4. **Benefits to be expected from the research.**
a) I will receive feedback regarding my body composition, the fiber type percentage of my muscle, and my muscular strength. These are important factors in understanding my trainability and developing my resistance training programs.
b) I will receive a $50 honorarium for my participation upon completion of all testing procedures. If I wish to discontinue participation prior to completing all of the testing procedures, my honorarium will be prorated. $30 will be given for day one with $10 given for each of the two strength testing days.
c) This research is being conducted in order to provide better understanding of the adaptations of muscle to strength training. The knowledge gained in this project will help in the development of resistance training protocols for rehabilitation, health, and athletic performance.
d) I will receive free professional advice for beginning, maintaining, or improving my fitness routine from a certified strength and conditioning specialist.

E. Confidentiality

1. Any information obtained from me will be kept confidential. A code number will be used to identify any test results or other information that I provide. The only persons that will have access to this information will be the investigators, and no names will be used in any data summaries or publications.

F. Compensation for injury

I understand that the University does not provide a research subject with compensation or medical treatment in the event that the subject is injured as a result of participation in the research project.

G. Voluntary participation statement

I understand that my participation in this study is completely voluntary and that I may either refuse to participate or withdraw from the study at any time without penalty or loss of benefits to which I am otherwise entitled.

H. Questions

1. If I have question, I understand that any questions I have about the research study and/or specific procedures should be directed to:
   Todd C. Shoepe, Langton Hall rm. 121E, Oregon State University, (541) 737-6795.
   Jeffrey Widrick, Women's Bldg. rm. 105 Oregon State University, (541) 737-5923.
2. If I have questions about my rights as a research subject, I should contact the IRB coordinator, OSU Research Office, (541) 737-8008.

My signature below indicates that I have read and I understand the procedures described above and give my informed and voluntary consent to participate in this study. I understand that I will receive a signed copy of this consent form.

Signature of subject __________________________ Date signed _____________

Name of subject __________________________

Subject’s present address __________________________ Subject’s phone # _____________

Signature of principle investigator __________________________ Date signed _____________
APPENDIX G

CARE OF BIOPSY HANDOUT
Care of Muscle Biopsy Incision

This sheet contains important information on the care of the muscle biopsy site and incision.

1. You may experience some generalized soreness around the biopsy site for 24-48 hours. This is a normal response. You may take Tylenol or Ibuprofen to relieve any discomfort.

2. It is important to keep the bandages as dry as possible. It is OK to take a shower but avoid baths, whirlpools, etc. for 7 days.

3. The large elastic bandage should be removed after 24 hours. The other bandages can be removed in 4-5 days.

4. Please inspect the incision at least once a day. Immediately contact the principal investigator at the number below if you observe or experience any of the following:
   a) redness around the incision
   b) drainage from the incision (more than a teaspoon)
   c) swelling at the incision
   d) soreness in the groin area
   e) fever or chills
   f) severe pain

5. Please contact the principle investigator if you have any questions or concerns:

    Investigators:

    Jeffrey Widrick, Ph.D. (Principal Investigator)    Todd C. Shoepe
    737-5923 office                                 737-6795 office
    737-3471 laboratory                             737-3471 laboratory