THE INFLUENCE OF AGING ON MUSCLE QUALITY, MUSCLE SIZE, AND ISOKINETIC STRENGTH IN THE PLANTARFLEXOR MUSCLES

Gilbert Edward King

A thesis submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Masters of Arts in the Department of Exercise and Sport Science (Exercise Physiology).

Chapel Hill
2013

Approved by:
Eric D. Ryan, Ph.D.
Abbie E. Smith-Ryan, Ph.D.
Eric J. Sobolewski, M.S.
ABSTRACT

GILBERT EDWARD KING: The Influence of aging on muscle quality, muscle size, and isokinetic strength in the plantarflexor muscles
(Under the direction of Dr. Eric Ryan)

Aging often results in numerous physiological changes that result in reductions in maximal strength. Few previous studies have examined the influence aging on muscle size and quality and its impact on dynamic strength measures in the plantarflexor muscles. The primary purpose of this study was to examine the influence of aging on medial gastrocnemius muscle cross-sectional area (CSA), echo intensity (EI), and isokinetic plantarflexion strength. Twenty young (20±2 years) and 10 older (68±3 years) men volunteered for this study. Our results demonstrated that older adults produced (21 and 23 %) less torque (P<0.05) at 30 and 120°s⁻¹, respectively. In addition, there were no age-related reductions in muscle CSA (P=0.166), but an increase in EI (P=0.015) in the older adults. These findings suggest that the age-related reductions in isokinetic strength are a result of decreases in muscle quality (i.e. increase in connective/adipose tissue) rather than decreases in muscle size in older men.
ACKNOWLEDGEMENTS

I would like to thank everyone who helped make this thesis project possible. I would first like to thank my advisor, Dr. Eric Ryan, your guidance and patience has pushed me to finish this document and you have shown me what it takes to be productive researcher. I would also like to thank my committee members, Dr. Abbie Smith-Ryan and Eric Sobolewski, for taking the time to review my document and for providing feedback to help bring this thesis into fruition. I would also like to thank the research team, Joseph Rosenberg and Michael Scharville, for your dedication and assistance with data collection. I would finally like to thank my classmates for supporting throughout this process.
# TABLE OF CONTENTS

LIST OF TABLES ........................................................................................................ vii

LIST OF FIGURES ................................................................................................. viii

Chapters

I. INTRODUCTION .................................................................................................. 1

  Purpose ................................................................................................................... 5

  Research Questions ............................................................................................... 5

  Hypotheses ............................................................................................................. 5

  Delimitations .......................................................................................................... 5

  Limitations ............................................................................................................. 6

  Theoretical Assumptions ....................................................................................... 6

  Statistical Assumptions ......................................................................................... 6

  Operational Definitions ......................................................................................... 6

  Abbreviations ....................................................................................................... 7

II. REVIEW OF LITERATURE .................................................................................. 8

  Isokinetic characteristics during plantarflexion .................................................. 8

  The effect of aging on isokinetic peak torque ..................................................... 9

  The effect of aging on muscle structure and function ....................................... 13

  The effects of aging on echo intensity and muscle cross sectional area .......... 18

III. METHODOLOGY ................................................................................................ 22
Participants ............................................................... ................................................... ....................... 22
Experimental Design ............................................................... ................................................... ............... 22
Isokinetic Strength Testing: ............................................................... ................................................... ............. 22
Ultrasound Acquisition ............................................................... ................................................... .............. 23
Signal Processing ............................................................... ................................................... .................. 25
Statistical Analysis: ............................................................... ................................................... .............. 25
IV. RESULTS ............................................................................................................................... .............. 27
V. DISCUSSION ............................................................... ................................................... ................... 29
Tables ............................................................... ................................................... ......................... 34
Figures ............................................................... ................................................... ................. 36
APPENDIX ............................................................... ................................................... ................. 39
REFERENCES ............................................................... ................................................... ................. 42
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Means ± SD for age, stature, and body mass for the young (n = 20) and old (n = 10) men</td>
<td>35</td>
</tr>
<tr>
<td>2.</td>
<td>Pearson product moment correlation coefficients between Isokinetic 30, Isokinetic 120, CSA, and EI for the young men</td>
<td>35</td>
</tr>
<tr>
<td>3.</td>
<td>Pearson product moment correlation coefficients between Isokinetic 30, Isokinetic 120, CSA, and EI for the old men</td>
<td>35</td>
</tr>
<tr>
<td>4.</td>
<td>Partial correlation coefficients between CSA, Isokinetic 30, and Isokinetic 120, independent of EI</td>
<td>35</td>
</tr>
<tr>
<td>5.</td>
<td>Partial correlation coefficients between EI, Isokinetic 30, and Isokinetic 120, independent of CSA</td>
<td>36</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure

1. Isokinetic peak torque at 30 and 120°·sec⁻¹ for the young and old men. * indicates a significant difference between groups (P<0.01). † indicates a significant difference between velocities (P<0.01). Values are mean ± SD…………………………………………………………………………37

2. Medial gastrocnemius cross-sectional area (CSA) values for the young and old men. Values are mean ± SD…………………………………………………………………………38

3. Medial gastrocnemius echo intensity (EI) values for the young and old men. * indicates a significant difference between groups (P<0.01). Values are mean ± SD…………………………………………………………………………39
CHAPTER I
INTRODUCTION

The Centers for Disease Control and Prevention (CDC) has identified falls among older adults (≥65 years) as a major public health concern (9). Falling often leads to injury, decreases in mobility, loss of independence, decreased quality of life, or even death (41). In 2009, US emergency departments treated 2.4 million nonfatal falling related injuries among older adults. In 2000, it has been estimated that the United States health care system spent over 19 billion dollars on falls for the elderly, and by 2020 the annual cost (direct and indirect) of fall-related injuries is expected to approach 54.9 billion dollars (9). A previous study by Plujim et al. (32) has demonstrated that in a three year prospective study, 55.3 percent of older adults reported a fall, with 20.9 percent reporting three or more falls over the three year period. Many previous authors (4, 7, 31, 32, 41, 42) have suggested that the increased risk of falling and impaired ability to perform activities of daily living among older adults are due to the numerous changes in the neuromuscular system resulting in reductions in maximal strength.

Age-related reductions in maximal strength are often linked to a number of alterations in the neuromuscular system that include changes in motor unit number, muscle fiber size, and the proportion of fiber types which results in sarcopenia or the age-related loss of muscle mass (26). It has been reported that sarcopenia begins as early as 25 years of age, with a 40% reduction in muscle cross-sectional area (CSA)
between 20 and 80 years of age (28). Studies examining single fibers have indicated that fast-twitch type II fibers atrophy at a greater extent than slow-twitch type I fibers, accounting for 60% of the total fiber reduction with aging (27). In a recent review by Aagaard and colleagues (1), the authors suggested that the gradual loss of alpha motor neurons may be due to apoptosis, reduced insulin-like growth factor I signaling, increased amounts of circulating cytokines, and/or greater cell oxidative stress. The subsequent denervated muscle fibers from larger motor units are then often reinnervated by adjacent motor units resulting in larger slow-twitch motor units (4, 25, 27, 39). This was demonstrated by Aniansson et al (4) who reported a decrease in muscle fiber area for type II fibers (14 – 25%) over an eight year period in elderly participants, whereas there were no significant changes in the type I fiber area, which may be due to the increase sprouting and reinnervation of the slow-twitch fibers. In addition, denervated muscle has been suggested to be replaced by connective and adipose tissue which may reflect an alteration in muscle tissue quality (8, 14). This has been supported by Lexell et al. (26), who reported that elderly individuals only have 50% of their total muscle area composed of muscle fibers, while their younger counterparts have around 70% of their total muscle area comprised of muscle fibers. Muscle quality, or the infiltration of fat and/or connective tissue, has been assessed previously using computed tomography (CT) and ultrasound imaging. For example, Goodpaster et al. (17) demonstrated that a decrease in skeletal muscle attenuation (Hounsfield units) as measured by CT was associated with an increase in lipid content. The authors (17) reported that higher muscle attenuation values were associated with greater isokinetic leg extension torque production and accounted for 36% of the total variance of strength in men. More recently, the
computer-aided gray-scale analyses of ultrasound images offer a potential alternative to CT muscle quality assessments, whereby enhanced echo intensity (EI) value represents a greater accumulation of connective and/or adipose tissue. For example, Fukumoto et al. (14) reported a negative relationship between EI and maximal isometric leg extension strength (-0.40); and the authors also reported a positive relationship with EI and aging (0.34), as age increases EI increases as well. Cadore et al. (8) also reported a negative relationship between EI and isometric (-0.51) and fast (360° s⁻¹; -0.67) and slow (60° s⁻¹; -0.48) isokinetic muscle actions.

Many previous studies have demonstrated an age-related decrease in isometric strength, however some authors (7, 23, 24, 42) have suggested dynamic muscle actions may be more related to functional abilities. This was suggested by Rothstein et al. (32) who stated "because the patient's limb is moving during an isokinetic test, these measurements may appear to provide more meaningful indexes of function than isometric measurements". For example, a study by Whipple et al. (42) compared elderly fallers to non-fallers and reported that the fallers were only able to produce 21.4% of the plantarflexion peak torque then that of the non-fallers at the fastest velocity tested (120° s⁻¹). This demonstrated that isokinetic testing may be an appropriate indicator of functional ability between groups. It has also been suggested that peak torque at the fastest isokinetic velocities is most influenced by the age-related reduction in type II fibers. Larsson et al. (24) suggested that the decrease in percent of type II fibers from the adult group (63.2%) to the elderly group (45.0) is a contributing factor for the decrease is isometric and isokinetic strength. Furthermore, plantarflexor muscles have been reported to demonstrate a larger decrease (63.7%) in isometric strength with aging.
when compared with other lower extremity muscle groups (i.e. hip flexors, hip abductors, hip extensors, and knee extensors) (38). Previous research suggests that plantarflexion strength is a major risk-factor for falling in the elderly population, and most likely due to the important role of plantarflexor muscles for propulsion and balance during gait (12, 38, 42). These findings highlight the need for future studies to examine the influence of aging on isokinetic strength at fast and slow velocities in the plantarflexor muscles.
Purpose

1. The primary purpose of this study was to determine the influence of aging on muscle quality, muscle size, and isokinetic peak torque of the plantarflexor muscles.

2. A secondary purpose was to determine if muscle quality is associated with isokinetic strength independent of muscle size and if muscle size is associated with isokinetic strength independent of muscle quality for both young and older men.

Research Questions

1. Did aging effect muscle quality, muscle size, and isokinetic plantarflexion peak torque at 30° s⁻¹ and 120° s⁻¹?

2. Did EI effect isokinetic strength independent of muscle CSA, and does muscle CSA effect isokinetic strength independent of EI?

Hypotheses

1. Old men would experience decreases in muscle quality and size and isokinetic plantarflexion peak torque at 30° s⁻¹ and 120° s⁻¹.

2. Aging had a positive relationship with EI, a negative relationship with muscle CSA, and a negative relationship with isokinetic strength.

3. There would be a negative relationship between muscle quality and isokinetic peak torque, and a positive relationship between muscle size and isokinetic peak torque.

Delimitations

1. Twenty young (18-30 years) and ten old (65-74 years) recreationally active men
were recruited to participate in this study.

2. Participants would not exceed more than 1 - 5 hours of exercise per week.

3. Participants did not have a current or recent injury of the low back, hip, knee, or ankle within the past three months, or a neuromuscular disease that may affect their ability to produce maximum torque.

4. The duration of the two sessions was approximately 60 minutes, 2-7 days apart.

Limitations

1. Participants were recruited from lifetime fitness classes and fitness areas on the University of North Carolina at Chapel Hill's campus. In addition, the old men were recruited from communities within and surrounding the campus. Therefore, the participant population was not truly random.

2. The sample included volunteers, therefore not meeting the underlying assumption of random selection.

Theoretical Assumptions

1. Participants provided accurate health, medical, and physical activity history.

2. Participants gave maximal effort during the isokinetic testing.

3. Participants followed to guidelines pertaining to lower body exercise before testing.

4. All equipment was function properly for all testing sessions.

Statistical Assumptions

1. The population from which the samples are drawn was normally distributed.

2. The sample was randomly selected.

Operational Definitions
*Isokinetic peak torque* - the maximum torque produced during a muscle action performed at a constant velocity.

*Muscle cross-sectional area (CSA)* - the area of the cross section of a muscle perpendicular to its longitudinal dimension, generally at its largest point.

*Muscle quality* - the amount of adipose and connective tissue in a given cross-sectional scan of skeletal muscle as measured from the echo intensity of a computer-aided gray scale analysis of an ultrasound image.

**Abbreviations**

CSA - cross-sectional area
EI - echo intensity
MG - medial gastrocnemius
MVC - maximum voluntary contraction
PT - peak torque
CHAPTER II

REVIEW OF LITERATURE

Isokinetic characteristics during plantarflexion

So et al. (1994)

The purpose of this study was to compare the isokinetic characteristics between athletes and non-athletes during plantarflexion and dorsiflexion. Twenty-three athletes (6 = cyclist, 7 = gymnasts, 10 = soccer players) and 25 non-athletes were tested. Peak torque (PT), torque acceleration energy (TAE), average power (AP), total work (TW), endurance ratio (ER), torque ratio (TR), and work ratio (WR) were measured at velocities of 60°·s⁻¹ (5 consecutive repetitions) and 180°·s⁻¹ (25 consecutive repetitions) for the dominant and nondominant limb. Significant bilateral differences were only found between the three sport groups. At 60°·s⁻¹, cyclists generated greater dorsiflexion PT for the dominant limb (28.7Nm) when compared to the nondominant (24.8Nm), soccer players produced greater dorsiflexion PT for the nondominant limb (34.4Nm) when compared to the dominant limb (31.3Nm), and gymnasts showed a significantly higher TR for the nondominant limb (37.7%) when compared to the cyclists (23.3%). At 180°·s⁻¹, gymnasts generated greater plantarflexion PT for their nondominant limb (39.7Nm) when compared to the dominant limb (36.7Nm) and gymnasts had a significantly higher TR and WR for the nondominant limb (44.3% and 57.3%, respectively) when compared to the cyclists (29.3% and 26.2%, respectively). For all participants, PT was greatest at the slowest velocity (60°·s⁻¹ > 180°·s⁻¹). For both
dorsiflexion and plantarflexion, the non-athletes had a significantly lower ER than the gymnasts or soccer players, but only had slightly lower ER than the cyclists for plantarflexion. These findings suggest that the sport-specific requirements of these different athletes may lead to significant bilateral differences in isokinetic muscular performance. For example, the authors (35) suggested that stepping forward on the foot pedal would result in improved plantarflexion isokinetic strength but minimal improvements in dorsiflexion isokinetic strength.

The effect of aging on isokinetic peak torque

Fugl-Meyer, Gustafsson, and Burstedt (1980)

The purpose of this study was to establish normal physiological data during isometric and isokinetic plantarflexion muscle actions, and to determine if peak torque (PT) could be predicted from demographic and anthropometric measures. Sixty-nine female and sixty-six males (age 20 - 65) volunteered for this study. Age, sex, weight, height, and crural circumference (between the upper and middle thirds of the lower leg) were recorded. The participants were positioned supine in a Cybex II dynamometer (Lumex Inc., New York), with their legs fully extended at 0° below the horizontal plane or flexed at 90° in a randomized order. All participants performed maximal isokinetic muscle actions at 30, 60, 90, 120, and 180°·s⁻¹ with their ankle joint starting in maximum dorsiflexion. Isometric PT was measured at maximum dorsiflexion and the same joint angle where PT occurred during the isokinetic muscle action at 30°·s⁻¹. For both sexes, PT was lower at the flexed leg position when compared to the fully extended position, however females generated less PT compared to males at all velocities. Participants over the age of 50 showed a significantly lower isometric and isokinetic PT than the
younger group (approximately 70%). The authors (13) suggested that the decrease is PT at 90° is supported by a decrease in medial gastrocnemius muscle activation (e.g. EMG amplitude) and tension with the leg flexed. In addition, the age-related decrease in isokinetic strength may be related to changes in skeletal muscle morphology (e.g. fiber type alterations) rather than muscle size.

Gerdle and Fugle-Meyer (1985)

The purpose of this study was to develop a clinically applicable prediction equation for plantarflexion peak torque (PT) and contractile work (CW) in healthy middle-aged and elderly adults. The secondary purpose was to evaluate the relationship between CW and electromyographic (EMG) amplitude of the soleus (Sol), medial gastrocnemius (MG), and lateral gastrocnemius (LG) muscles. Eighty-eight (male, n = 45; female, n = 43) healthy individuals between the ages of 40-64 years were recruited for this study. Demographic (age and gender) and anthropometric measures of height, weight, leg length, and crural circumference (between the upper and middle thirds of the lower leg) were recorded. The participants were positioned supine in a Cybex II dynamometer (Lumex Inc., New York) with their hips and legs fully extended (0° below the horizontal plane). Three maximum plantarflexion isokinetic muscle actions were performed at 30, 45, 60, 120, and 180°·s⁻¹ with surface EMG electrodes placed on the left or right MG, LG, and Sol muscles (limb was randomized). The elderly group (60-64 yrs) demonstrated a steeper decrease in PT (60Nm reduction from 60 to 180°·s⁻¹) and CW (33 J decrease from 60 to 180°·s⁻¹) at the highest velocity when compared to the younger groups. EMG/maneuver time (the ratio of muscle activation over the amount of time it took for the muscle action to be completed) stayed fairly constant for each velocity (males = 4.5 -
4.4 watts, females = 2.91 - 2.74 watts), and was unaffected by age. The age and sex variables correlated the best with the generated PT and CW prediction equations for the elderly participants. The authors (15) suggested that the loss of muscle fibers that is associated with aging is responsible for the significant decrease in PT, CW, and EMG amplitude in the elderly group. However, the consistency of the EMG/maneuver time indicates that motor unit recruitment occurs independent of velocity and age.

Gerdle and Fugle-Meyer (1986)

The purpose of this study was to establish a clinically acceptable prediction equation for isokinetic plantarflexion peak torque (PT) and contraction work (CW) in individuals between 40 and 64 years old. Eighty-eight (men, n = 45, women, n = 43) healthy individuals were recruited for this study. Demographic (age and sex) and anthropometric measures of height, weight, leg length, and crural circumference (between the upper and middle thirds of the lower leg) were recorded. The participants were positioned supine with their hips and legs fully extended in a Cybex II dynamometer (Lumex Inc., New York). Participants performed three maximum isokinetic plantarflexion muscle actions with each leg (in a randomized order) at 30, 60, 120, and 180°·s⁻¹. A prediction equation for PT and CW, using the recorded anthropometric measures, was generated for each age group and isokinetic velocity. The age, gender, and crural circumference measures were able to explain greater than 60 percent of the variance in PT and CW between the participants at 30, 60, and 120°·s⁻¹ (30°·s⁻¹ = 0.82 and 0.63; 60°·s⁻¹ = 0.79 and 0.63; and 120°·s⁻¹ = 0.75 and 0.60). Aging showed a negative relationship with the PT and CW prediction equations. The results also demonstrated that PT occurred at greater plantarflexion joint angles with each increase in
velocity \(30^\circ\cdot s^{-1} = 14^\circ, 60^\circ\cdot s^{-1} = 21^\circ, 120^\circ\cdot s^{-1} = 27^\circ, 180^\circ\cdot s^{-1} = 31^\circ\). The authors (16) suggested that the decrease in \(r^2\) values with the increase in isokinetic velocity is due to the increased contribution of the gastrocnemius muscles to that of the soleus for torque production at greater velocities.

Whipple, Wolfson, and Amerman (1987)

The purpose of this study was to examine differences in leg extension and flexion and plantar- and dorsiflexion isokinetic peak torque (PT) and power output in elderly participants with and without a history of falls. Seventeen "fallers" (age 82.2) and 17 nonfallers (age 84.6) (males = 3 per group; and females = 14 per group) volunteered for this study. The participants performed eight to ten isokinetic muscle actions (extension and flexion) with the dominant limb on a Cybex II dynamometer (Lumex Inc., New York) at 60 and 120°·s\(^{-1}\) (contralateral limb was used if injury prevented testing on the dominant limb). The participants were seated erect with their leg flexed (90°) for the leg extension and flexion assessments, and seated at a semi-supine angle of 30° for plantar- and dorsiflexion assessments. The fallers generated 12% of their leg extension PT (12.1Nm) when performing plantarflexion (2.2Nm), while the nonfallers generated 24.1% of their leg extension PT (33.2Nm) when performing plantarflexion (8.0Nm). At 120°·s\(^{-1}\), the nonfallers produced 19.8% greater power output (9.0Nm·rad·s\(^{-1}\)) when compared to the fallers (1.8Nm·rad·s\(^{-1}\)). In addition, the fallers produced 7.5 times less dorsiflexion power output (0.42Nm·rad·s\(^{-1}\)) when compared to the nonfallers (3.21Nm·rad·s\(^{-1}\)). The authors (42) indicated that this was the first study to demonstrate a decrease in lower extremity PT and power output in elderly participants with a history of falls. In conclusion, these results suggested that the greater loss in isokinetic strength
(especially at higher velocities) in the fallers may be related to the substantial decline in
type II muscle fibers and may lead to greater joint instability in elderly adults

The effect of aging on muscle structure and function

Vandervoort AA and McComas AJ (1986)

The purpose of this study was to examine the effects of aging on the contractile
properties of plantar- and dorsiflexor muscles. One hundred and eleven healthy men
and women (between 20-100 years old) volunteered for this study. The participants
were positioned at 10° of dorsiflexion for isometric plantarflexion testing and 30° of
plantarflexion for isometric dorsiflexion testing (0° or neutral = 90° between the foot and
leg). Voluntary or evoked torque responses were measured using an oscilloscope
(Hewlett-Packard type 141B) and stimulated M-waves were measured using
electromyographic (EMG) recording electrodes. Participants performed multiple
maximum voluntary contractions (MVC) for five seconds prior to the application of the
electrical stimuli. Stimulating electrodes were placed on the skin at the peroneal nerve
at the neck of the fibula and the uppermost part of the tibialis anterior muscle during
dorsiflexion and over the popliteal fossa during plantarflexion. Muscle cross-sectional
area (CSA) was examined with a B-mode ultrasound imaging system at the greatest girth
of the calf. Estimations of the number of motor units were taken from the five eldest
participants by using subthreshold stimulation increments and comparing it with their
maximal M-wave values. The eldest men (80-100 yrs) produced less voluntary torque
(56% for dorsiflexion, 55% for plantarflexion) and stimulated twitch torque (38% for
dorsiflexion, 23% for plantarflexion) when compared to the youngest group (20-30 yrs).
In addition, the elderly men had a significantly smaller muscle CSA (28.0cm) and
estimated number of motor units (70% reduction) when compared to the younger adults (CSA = 36.5cm). The authors (40) suggested that by the age of 75, only 80% of voluntary strength is remaining and this may be caused by the denervation of motor units. The decrease in muscle CSA that occurs with aging is reduced by the increased presence of connective tissue following the atrophy of the type II fibers, and this is the primary cause of the large decrease in muscle strength, with only a slight decrease in muscle CSA, that is seen with aging.

Lexell, Taylor, and Sjöström (1988)

The purpose of this study was to examine the age related changes in muscle area, total number, size, proportion, and distribution of fiber types of the vastus lateralis in men. Forty-three previously healthy male cadavers (15-83 years old) that were less than three days post-mortem were used in this study. A 10 mm slice was taken from the vastus lateralis (taken half way between origin and insertion) and stained for mATPase. A 1x1 square grid was placed on the muscle cross-section to divide the muscle into quadrants and then it was used to calculate muscle area (multiplying the number of sampled quadrats by 48), fiber density (mean number of fibers per mm$^2$), total number of fibers (multiplying muscle area by fiber density) and proportion of fiber types (values of type I and type II in the squares). Fiber size was calculated by measuring fibers of each type in five different regions (for each region, one fiber was selected and 24 of the closest fibers of the same type were measured). Fiber type distribution was measured by taking the amount of type I fibers in every 48$^{th}$ mm$^2$ cross-section and then it was converted it into a contour plot. For the older age groups (70 and 80), the muscle fibers were not as closely packed as the younger participants and they contained structural characteristics
not seen in the younger age groups (e.g. angulated fibers, variations in fiber shape, and isolated fibers). Muscle area reached its peak size at 23.7 years of age and showed a 40% drop from 20 to 80 years old. For fiber size, type II fibers decreased with increasing age and demonstrated a 26% reduction from 20 to 80 years old, while no significant relationship was shown between age and the size of type I fibers. For fiber density, the younger groups demonstrated that 70% of their muscle area was comprised of muscle fibers, while the older groups only demonstrated that 50% of their muscle area was comprised of muscle fibers. In addition, type II fibers were more superficial and type I fibers were deeper in the muscle of younger groups, whereas the older groups did not show a clear distribution between the two fiber types. The authors (27) suggested that denervated and inactive fibers are the cause for the change in fiber size and number (especially in type II fibers) and that the replacement of those fibers by fat and fibrous tissue is responsible for the decrease in fiber density.

Brooks SV and Faulkner JA (1988)

The purpose of this study was to examine the change in contractile properties of the soleus (Sol) and the extensor digitorum longus (EDL) muscles in young, adult, and aged mice. Fifty-five male mice (young (2-3 months) n = 11, 15; adults (9-10 months) n = 14, 18; aged (26-27) n = 14, 18; respectively for the Sol and EDL) were used in this study. The Sol and EDL muscles were removed from the mice and isolated in silk sutures. The muscles were then stimulated by two platinum electrodes (200 µm pulse at a supramaximal intensity) to measure twitch force, contraction force, half-relaxation time, and shortening velocity. Following the stimulus, the muscles were blotted, weighted, and pinned down to be measured for fiber and muscle length. The aged mice showed a
20 (Sol) and 13% (EDL) decrease in muscle mass when compared to the adult mice. No significant changes were found for fiber length or cross-sectional area with aging when compared to the younger groups. The aged group showed a decrease in maximum isometric torque for the EDL muscle (18.6Nm) when compared to the young (23.0Nm) and adult (23.8Nm) groups. The authors (6) suggested that the decrease in maximum force with aging is not due to changes in pennation angle or alterations in myosin ATPase or myosin light or heavy chains due to the lack of changes in fiber length/muscle length ratio or the force-velocity relationship. The reduction in the number of cross-bridges during the driving stroke of a contraction could be the cause of the decrease in force by the skeletal muscle.

Narici, Maganaris, Reeves, and Capodaglio (2003)

The purpose of the study was to examine the sarcopenic changes in muscle mass and structure. Sixteen elderly men (70-81 years old) and fourteen younger men (27-42 years old) volunteered for this study. Muscle cross-sectional area (CSA) and volume were determined with the participants positioned supine in a General Electric scanner (ProSpeed Sx power) and by measuring the size of the medial gastrocnemius (MG) in 40 continuous images. Resting fascicle length (Lf) and pennation angle was examined in the dominant limb at the midbelly of the MG using realtime ultrasound (HDI-300, ATL, Bothell) with the probe placed along the median longitudinal plane of the MG muscle. The younger groups showed a greater muscle CSA (17.4cm$^2$) and volume (279.3cm$^3$) when compared to the elderly group (CSA = 14.0cm$^2$; volume = 208.7cm$^3$). The younger group also had a longer Lf (4.78cm) and a greater pennation angle (27.2°) when compared to the elderly group (Lf = 4.29cm; angle = 23.6°). The authors (27) suggested
that the decrease in pennation angle and shortening of the fascicles was related to the loss of sarcomeres in parallel and in series. In addition, the shortened fascicles and reduction in muscle volume resulted in a significant decrease in physiological CSA.

Clark DJ et al. (2010)

The purpose of this study was to examine the influence of rapid muscle activation on isokinetic leg extension peak torque and power output between healthy middle-aged, old, and mobility limited older adults. Eighty-nine participants (healthy middle-aged (MH) aged 40-55 yrs, n = 29; healthy old-aged (OH) aged 70-85 yrs, n = 28; limited mobility old-aged (LM) aged 70-85, n = 32) volunteered for this study. Participants were seated upright with their dominant leg flexed at 90° in a Cybex-II dynamometer (Cybex, Ronkonkoma, NY). Five consecutive maximum isokinetic muscle actions were performed at 60, 90, 180, and 240°·s⁻¹ (progressing from slowest to fastest velocity). Three isometric maximum voluntary contractions were performed with the leg fixed at 60° leg flexion. Surface electromyographic (EMG) electrodes were placed on the rectus femoris (RF), vastus medialis (VM), vastus lateralis (VL), biceps femoris (BF), and semimembranosus (SM) to measure muscle activation. Computer tomography scans using a Siemens Somatom Scanner (Erlangen, Germany) were used to determine muscle cross-sectional area (CSA) (at the midpoint of the femur). In addition, normalized torque (torque divided by total quadriceps CSA) and specific torque (torque divided by a specific muscle's CSA) values were calculated. The LM group produced significantly lower normalized torque, specific torque (at 240°·s⁻¹) and power output than the other groups. For muscle activation, EMG amplitude values were lower for the LM elderly group in the RF, VM, and VL when compared to the other two groups. The authors (10)
suggested that the decrease in power output and peak torque is not completely attributed to a decrease in muscle size but also a reduction in agonist activation for the mobility impaired older adults. The authors also speculated that the mechanisms for the impaired neuromuscular activation may be related to decreased inhibition between cerebral hemispheres, reduced excitability of the corticospinal pathway, and/or a decrease in cortical projections to motor-neurons.

*The effects of aging on echo intensity and muscle cross sectional area*
Goodpaster et al. (2001)

The purpose of this study was to examine the relationship of computer tomography (CT) derived muscle quality and muscle strength in older individuals. One thousand two hundred and eighty-five men (73.7 ±2.9 years) and 1,342 women (73.3 ± 2.9 years) volunteered for this study. CT scans of the mid-thigh were obtained by either a Somatom Plus 4 (Siemens, Erlangen, Germany), 9800 Advantage (General Electric, Milwaukee, WI), or PQ 2000S (Marconi Medical Systems, Cleveland, OH) to measure muscle cross-sectional area (CSA). Skeletal muscle mass, adipose tissue, and muscle quality (average CT pixel intensity) was calculated with the IDL development software (RSI Systems, Boulder, CO). Muscle quality was calculated from muscle attenuation coefficients of the outlined muscle area, with the lower values reflecting greater muscle quality. The participants performed three maximum effort leg extensions on an isokinetic dynamometer (model 125 AP, Kin-Com, Chattanooga, TN) at 60°·s⁻¹. Muscle quality showed a negative relationship with BMI in men (-0.44) and women (-0.43) and total body fat (-0.53). Muscle CSA demonstrated a positive relationship with BMI (men = 0.61, women = 0.60) and a negative relationship with age. Muscle quality
demonstrated a positive relationship with maximum torque (0.20) and specific torque (0.26) for all participants. The authors (17) suggested that the lower muscle quality that occurs with aging is caused by the decrease in muscle fiber density, and that there is an increase in lipid concentration in skeletal muscle. The reduction in type II fibers correlates to the reduction in maximal strength and the increase in type I fibers contributes to the increased lipid content in the muscle. In addition, obese individuals have increased subcutaneous adipose tissue and lower muscle quality, resulting in reduced muscle strength.

Cadore et al. (2012)

The purpose of this study was to examine the effects of aging on the relationship between echo intensity (EI), neuromuscular, and cardiorespiratory performances. Thirty-one elderly males (64.7 ± 4.1 years) volunteered for this study. Each participant performed maximal voluntary isometric contractions of the leg extensors and flexors, and maximal leg extension and flexion isokinetic muscle actions at 60, 180 and 360°·s⁻¹ on an isokinetic dynamometer (Biodex, New York, USA). A B-mode ultrasound (Philips, VMI, MG, Brazil) unit was used to examine muscle thickness (MT) in all of the quadriceps femoris (QF) muscles and echo intensity (EI) of the rectus femoris (RF) muscle. The RF muscle images were analyzed using the gray-scale histogram function and the analyze function in Image-J software (National Institute of Health, USA, version 1.37) to determine EI. Force per unit of muscle mass was calculated by dividing the isometric peak torque by the MT of the sum of the muscles of the QF. Peak oxygen uptake (VO₂peak), and the workload at the first and second ventilatory threshold (VT₁, VT₂) were examined during an incremental cycle ergometer assessment to volitional fatigue.
A significant negative relationship was observed between EI and the isometric and isokinetic peak torque (PT) values (isometric PT = -0.51; PT at 60°·s\(^{-1}\) = -0.48; PT at 180°·s\(^{-1}\) = -0.64; PT at 360°·s\(^{-1}\) = -0.64), and between EI and VT values (VT\(_1\) = -0.46, VT\(_2\) = -0.50). For MT, a significant correlation was observed between VI, VM, and the summed MT of all the muscles of the QF and the corresponding isometric PT and isokinetic PT at all velocities (values ranging from 0.42 to 0.63). For cardiorespiratory performance, significant correlations were observed between the workload at VT\(_1\) and VT\(_2\) and force per unit of muscle mass, isometric PT, and isokinetic PT. The authors (8) suggested that the increase in intramuscular connective tissue resulted in an increase EI and subsequent decrease in muscle strength and workload at VT\(_1\) and VT\(_2\) which may be explained by the age related decrease in capillaries. In addition, the positive correlation between force per unit of muscle mass and cardiorespiratory performance implies that the endurance performance in elderly men is related to the frequency and recruitment of fibers rather than MT.

Fukumoto et al. (2012)

The primary purpose of this study was to examine the relationship between muscle quality measured from echo intensity (EI), muscle strength, and muscle thickness (MT) in middle-aged and elderly women. The secondary purpose was to examine the relationship between EI and body composition. Ninety-two women (70.4 ± 6.6 years) volunteered for this study. A B-mode ultrasound (LOGIQ e; GE Healthcare UK Ltd., Chalfont, Buckinghamshire, England) was used to examine MT and fat thickness (FT) of the rectus femoris (RF) and the vastus intermedius muscles and EI of RF. EI was calculated using the histogram function and gray-scale analysis in Adobe Photoshop
The participants used a battery-operated impedance instrument (Muscle-α; Art Haven 9, Kyoto, Japan) to calculate body fat percentage and body mass index (BMI). Participants were positioned on an isometric dynamometer (Isoforce GT-330; OG GIKEN Co., Okayama, Japan) with their leg flexed at 60° and performed two maximal isometric leg extension muscle actions. MT showed a positive relationship with BMI (0.39) and muscle strength (0.47), but a negative relationship with age (-0.40). EI demonstrated a positive relationship with age (0.34) and negative relationship with strength (-0.40), while muscle strength showed a positive relationship with BMI (0.22) and a negative relationship with age (-0.32). The authors (14) suggested that muscle quantity (MT) and muscle quality (EI) independently effect muscle strength, and the age-related decrease in strength maybe due to the reduction of type II fibers or muscle satellite cells. In addition, EI of the muscle is not related to FT of the muscle, total body fat percentage, or BMI, and only correlates to the adipose and fibrous tissues within the muscle.
CHAPTER III

METHODOLGY

Participants

Twenty young males (age 18-30) and ten older males (age 65-74) were recruited from the University of North Carolina at Chapel Hill (UNC-CH) and the nearby community (Table 1). Participants were excluded if they are accumulating more than 1-5 hours of exercise per week, had a current or recent injury of the low back, hip, knee, or ankle within the past three months, or a neuromuscular disease that may affect their ability to produce maximum torque. Prior to testing, participants filled out a health history and exercise status questionnaire, and a written informed consent form approved by the University's international review board.

Experimental Design

The participants reported to the UNC-CH Neuromuscular Research Laboratory and completed two sessions lasting approximately 60 minutes each. The first session was the familiarization trial where they had their height and body mass measured, underwent a musculoskeletal ultrasound imaging assessment to examine muscle size and quality, and practiced the isokinetic strength testing protocol. Approximately 2-7 days following the familiarization trial, at the same time of day (±2hrs), all participants underwent the same ultrasound imaging assessment followed by the isokinetic strength testing.

Isokinetic Strength Testing:

Isokinetic testing was conducted on a calibrated, HUMAC Norm dynamometer
The participants were seated at a 135° angle between the thigh and torso with a restraining strap across the thigh and the participants’ arms crossed in front of their chest. The participants’ right leg was fully extended (0° below the horizontal plane) with their foot placed firmly against the foot plate and the lateral malleolus of the fibula aligned with the axis of rotation of the dynamometer. The range of the motion for the ankle joint was set from 20° plantarflexion to 50° dorsiflexion (with 0° representing the ankle at an approximately 90° angle). The foot was secured in a heel cup attached to the footplate with toe and ankle straps over the toes and metatarsals (distal to the malleoli).

Each participant performed three consecutive maximal isokinetic muscle actions at both slow (30°·sec⁻¹) and fast (120°·sec⁻¹) velocities in random order (7). One minute of rest occurred between the three muscle actions at each velocity. Previous studies have suggested these speeds represent a slow and fast velocity during plantarflexion that still exhibit a load range (7, 13, 16). The testing began with the investigator passively pushing the footplate into dorsiflexion at a velocity of 20°·sec⁻¹ until a verbal cue of a slight stretch is given by the participant. The investigator would immediately release the footplate and the participant plantarflexed as hard and as fast as possible until the footplate reaches the end of the range of motion (20° of plantar flexion). The participant performed three consecutive isokinetic muscle actions at each velocity in random order. One minute of rest was given between the three muscle actions at each velocity.

**Ultrasound Acquisition**

The cross-sectional area (muscle size) and echo intensity (muscle quality) of the medial gastrocnemius muscle was measured using a portable ultrasound device (GE
Healthcare, Wauwatosa, WI, USA) at approximately 1/3rd the distance from the articular cleft between the femur and tibia condyles to the lateral malleolus (34). These assessments took place with the participants lying prone and their foot fixed against a wooden platform at a neutral joint angle (90° between the foot and the leg). During the assessments all participants were asked to relax as much as possible. To ensure the 12L-RS ultrasound probe (5-13 Hz) moved along the transverse plane (from lateral to medial), a high-density foam pad was placed perpendicular to the longitudinal axis of the plantarflexor muscles. A generous amount of water-soluble transmission gel was applied to the skin and probe to improve acoustic coupling. The participants were asked to refrain from vigorous physical activity prior to testing for a minimum of 24 hours. Image-J software version 1.37 (National Institute of Health, MD, USA) was used to determine muscle CSA and echo intensity.

Panoramic ultrasound images of the medial gastrocnemius were recorded using LogicView software which complied overlapping images and determined the X, Y, and rotational offsets between the adjacent images. The software used this orientation information and the images to construct one composite image of the entire muscle (5). Echo intensity (EI) and muscle cross-sectional area (CSA) were measured using the polygon function in Image-J. The area of the manually traced muscle was used to calculate muscle CSA. The entire muscle was manually traced inside the surrounding fascia. One instructor performed the manual tracing for all the participants. EI values were determined using the histogram function, where pixels of the image were expressed in values ranging from 0 to 255 (black = 0, white = 255) and the mean gray scale value represented the mean EI value and corresponding index of muscle quality. All images
were examined at a depth of 4 cm using the musculoskeletal setting at a frequency of 10 MHz and a gain of 68 dB.

**Signal Processing**

All signals were collected using a Biopac MP150 data acquisition system (Biopac Systems Inc., Goleta, CA, USA) using AcqKnowledge software (Biopac Systems Inc., Goleta, CA, USA). Torque, position, and velocity signals were sampled from the dynamometer at 2500 Hz. Data was stored on a personal computer and processed offline through custom written LABView (National Instruments Corporation., Austin, TX) software. Isokinetic peak torque was calculated from the highest consecutive 50 data points occurring during the isokinetic load range from the isokinetic muscle action that generated the highest peak torque value (19). The load range is the time frame at which the limb is moving at the designated speed (30°·sec\(^{-1}\) or 120°·sec\(^{-1}\)), and does not include any acceleration and deceleration. The torque, position, and velocity signals were filtered using a zero-phase shift 100-point moving averager. The torque data was gravity corrected for the weight of the foot plate. No gravity correction was performed for the weight of the foot per the recommendation of Salsich et al. (34) who indicated that the foot's mass was considered negligible (approximately 1.5% of the body's mass).

**Statistical Analysis:**

Four independent t-tests were used to analyze the differences between muscle CSA, EI, isokinetic peak torque at 30°·sec\(^{-1}\), and isokinetic torque at 120°·sec\(^{-1}\) between the age groups. Pearson product moment correlations were used to examine the relationships between all four variables for both young and old men. Partial correlations were used to examine the relationship between muscle quality and muscle strength.
independent of muscle size; and the relationship between muscle size and muscle strength independent of muscle quality for both young and old men. The alpha level was set at $P \leq 0.05$, and all analyses were performed with SPSS version 20 (SPSS Inc., Chicago, IL, USA).
CHAPTER IV
RESULTS

Isokinetic Peak Torque

For isokinetic peak torque, the older men produced 21% and 23% (106.4 ± 14.5 and 60.2 ± 8.6 Nm) less torque during the slow (30°·sec^{-1}, P<0.005) and fast (120°·sec^{-1}, P<0.005) velocities when compared to the younger men (134.4 ± 25.2 and 78.2 ± 14.4 Nm, Figure 1).

Echo Intensity

Echo intensity values were lower for the young men (P<0.005, Figure 3) when compared to the older men. For the young men, there was a negative relationship between EI and muscle CSA (r=-0.533, P=0.015). In addition, there was a negative relationship between isokinetic peak torque at the slow velocity (r=-0.512, P=0.021), but no relationship between EI and isokinetic peak torque at the fast velocity (r=-0.424, P=0.062) (Tables 2 and 3). Partial correlations found no relationship between EI and isokinetic peak torque at the slow (r=-0.160, P=0.733) or fast (r=-0.101, P=0.797) velocities, independent of muscle CSA, in the young group (Table 5). For the old group, there was a negative relationship between EI and muscle CSA (r=-0.701, P=0.024), but no relationship between EI and isokinetic peak torque at the slow (r=0.011, P=0.976) or fast (r=-0.195, P=0.589) velocities. There was no relationship between EI and isokinetic peak torque at the slow (r=0.133, P=0.733) or fast (r=-0.101, P=0.797) velocities, independent of muscle CSA, for the old group (Table 5).
Muscle Cross-sectional Area

Medial gastrocnemius CSA was not different between young and old men ($P=0.166$, Figure 2). For the young men, there was a positive relationship between muscle CSA and peak torque at the slow ($r=0.812$, $P<0.001$) and fast ($r=0.839$, $P<0.001$) velocities (Table 2). There was a positive relationship between CSA and isokinetic peak torque at the slow ($r=0.742$, $P<0.001$) and fast ($0.800$, $P<0.001$) velocities, independent of EI, for the young group (Table 4). For the old group, there was no relationship between muscle CSA and peak torque at the slow ($r=0.119$, $P=0.744$) or fast ($r=0.178$, $P=0.623$) velocities. There was no relationship between muscle CSA and peak torque at the slow ($r=0.177$, $P=0.648$) or fast ($r=0.058$, $P=0.882$) velocities, independent of EI for the old group (Table 4).
CHAPTER V
DISCUSSION

A primary finding of the current study was the decrease in isokinetic peak torque at both slow (21%) and fast (23%) velocities in the older men. These results are similar to a previous study by Thelen et al. (36). The authors reported a 25% reduction in peak torque at both 30°·sec$^{-1}$ and 120°·sec$^{-1}$ in the older group when compared to the younger group. Similarly, Fugl-Meyer et al. (13) reported a 29% decrease in peak torque at the slowest velocity (30°·sec$^{-1}$) for the older men, however, the authors reported a greater decrease in peak torque at faster velocities (90°·sec$^{-1} = 40\%$, 180°·sec$^{-1} = 59\%$). The findings reported by Fugl-Meyer and colleagues (13) coincide with previous research that suggest as the angular velocity increases, there is a greater reduction in peak torque between young and old men. For example, Always et al. (3) reported a 30% decrease in peak torque at 30°·sec$^{-1}$ and a 35% decrease at 120°·sec$^{-1}$. Cunningham et al. (11) also reported a 30% decrease at (30°·sec$^{-1}$), but a larger reduction in strength (52%) at 120°·sec$^{-1}$. The greater reduction in peak torque at faster velocities reported in previous studies has been attributed to decreases in the number of type II fibers (25, 26, 40), decreases in pennation angle, shortening of the fascicles (31), and/or decrease in neuromuscular activation (10). A possible explanation for the higher peak torque values generated at the faster velocity for the old men in the current study when compared to previous studies, may be related to their physical activity status. For example, Fugl-Meyer et al. (13) examined older adults where all but two of the 135 participants
rated themselves as recreationally inactive and Cunningham et al. (11) studied older adults who reported exercising on average 1.5 hours per week. The older men in the current study reported exercising 4.3 ± 1.1 hours per week (young = 8.9 ± 4.1 hours per week). Thus, it is possible that greater habitual levels of physical activity may reduce the magnitude of age-related decreases in peak torque often seen at fast isokinetic velocities. This was previously supported by Kent-Braun and colleagues (20) who suggested that greater levels of physical activity may attenuate the accumulation of intramuscular fat and subsequent muscle function.

One of the most common mechanisms that are attributed to the age-related reductions in peak isokinetic strength is a loss of skeletal muscle mass (2, 40). The older men in the current study did not demonstrate an age-related reduction in medial gastrocnemius muscle CSA. These findings are in contrast to previous studies who have specifically examined the plantar flexor muscles (3, 31, 37, 40). For example, it has been reported that older men demonstrated a 17.3 - 23.3% smaller plantarflexor muscle CSA than their younger counterparts (3, 31, 40). However, fewer authors have reported non-significant age-related changes in muscle CSA for the dorsiflexor muscles (20) and quadriceps muscles (24). Larsson et al. (24) reported no change in thigh circumference between the 20-29 year old age group and the 60-69 year old age group, whereas Kent-Braun and colleagues (20) reported no change in dorsiflexor muscle area between the young and old men. As mentioned in the previous paragraph, physical activity status may attenuate overall reductions in muscle CSA (20). In addition, Williams et al. (21) have suggested that training can also slow the denervation of type II fibers that is commonly seen with aging. Furthermore, a unique finding in the current
study was a positive relationship between muscle CSA and isokinetic strength in the young men ($30^\circ \cdot \text{sec}^{-1} r= 0.812$, $120^\circ \cdot \text{sec}^{-1} r= 0.839$), but not for the old men ($30^\circ \cdot \text{sec}^{-1} r= 0.199$, $120^\circ \cdot \text{sec}^{-1} r= 0.178$). Many previous studies have documented a significant relationship between muscle size and strength in young men (13, 36, 39). The lack of relationship between muscle CSA and isokinetic strength in the older men in the current study may be a result of the lack of change in muscle CSA when compared to the younger men (Figure 2) but significant decrease in peak torque at both velocities. Thus, it is possible anatomical muscle CSA may have not changed but the quality of the tissue may have been altered leading to a reduction in peak strength. These findings may be supported by the increases in EI observed in the older men (Figure 3) and potential increase in non-contractile tissue (i.e. fat and connective tissue). Thus, it is possible that older men in the current study have no detectable changes in muscle CSA, but a greater proportion of non-contractile tissue.

The age-related reduction in muscular strength has been attributed to a decrease in the muscle quality (8, 14, 17). This current study demonstrated that old men had a higher EI value (lower muscle quality) when compared to the younger men. These findings along with previous research addressing muscle quality and EI (8, 14) provide further support that muscle quality may be reduced as we age. An increase in EI is speculated to be the result of an increased amount of intramuscular fat and connective tissue that is commonly seen with aging resulting in a more hyperechoic US image (14). Both the young and old men in the current study demonstrated a negative relationship between EI and muscle CSA. Although speculative, these findings may suggest that larger muscles may have a lower amount of connective tissue or more muscle fibers in a
A negative relationship was also found between EI and peak torque at the slow (-0.512, \( P = 0.021 \)), but not the fast (-0.424, \( P = 0.062 \)) velocity in the young men. A negative relationship between EI and peak torque suggests that muscles with greater amounts of connective or adipose tissue will less peak torque. However, this relationship is lost once the data was normalized for muscle CSA. Previous studies have reported a negative relationship between EI and strength in older adults (\( R = -0.40 \) to -0.67; 8, 14). Our findings are in contrast to these results and may be related to the lack of changes in muscle CSA. For example, Fukumoto et al. (14) have reported that older adults experience a simultaneous reduction in muscle quality (8, 14, 17) and size, thus the proportion of non-contractile tissue is greater in a smaller muscle. However, in the current study, it is possible that proportion of non-contractile tissue increased in the older men, without changes in muscle CSA. It is also possible that these findings are limited by the small sample of elderly men (n=10). Future studies, with larger sample sizes are needed to further explore these issues.

In conclusion, this is first study to investigate the relationship between age, isokinetic strength at both slow and fast velocities, muscle size, and muscle quality in the plantarflexor muscles. The age-related reductions in maximal dynamic isokinetic strength in the current study were likely not due to decreases in muscle CSA, but a reduction in muscle quality. Although no consistent relationship was found between isokinetic strength and EI, past research still suggests that muscle quality is an important factor in torque production (8). In the current study muscle CSA has been shown to have less of an impact on peak torque in old men, which is suggested to be caused by changes in composition rather than overall muscle size. The smaller reduction in peak
torque, specifically at faster velocities, may suggest an influence of physical activity status, which previous authors have noted to influence the number of non-contractile tissue within skeletal muscle (20, 21). The decrease in isokinetic strength with aging has been linked with an increased risk of falling in older men (4, 31). Future studies should look to examine differences in muscle strength, quality and size in different older populations such as those with a history of falling or lower leg injuries. Research could also be applied to investigating intervention techniques or protocols that inhibit the age-related decreases in strength, size, and muscle quality to help further fall prevention initiatives in the older population.
Table 1. Means ± SD for age, stature, and body mass for the young (n = 20) and old (n = 10) men.

<table>
<thead>
<tr>
<th></th>
<th>Young</th>
<th>Old</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20.4 ± 1.9</td>
<td>68.3 ± 2.9*</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>175.6 ± 6.1</td>
<td>175.3 ± 5.6</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>75.2 ± 11.9</td>
<td>80.1 ± 8.9</td>
</tr>
</tbody>
</table>

* indicates a significant difference between groups (P<0.01)

Table 2. Pearson product moment correlation coefficients between Isokinetic 30, Isokinetic 120, CSA, and EI for the young men.

<table>
<thead>
<tr>
<th></th>
<th>Isokinetic 30</th>
<th>Isokinetic 120</th>
<th>CSA</th>
<th>EI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isokinetic 30 (Nm)</td>
<td>-</td>
<td>0.786**</td>
<td>0.812**</td>
<td>-0.512**</td>
</tr>
<tr>
<td>Isokinetic 120 (Nm)</td>
<td>-</td>
<td>-</td>
<td>0.839**</td>
<td>-0.424</td>
</tr>
<tr>
<td>CSA (cm²)</td>
<td>-</td>
<td>-</td>
<td>-0.533*</td>
<td></td>
</tr>
<tr>
<td>EI (a.u.)</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Isokinetic peak torque at 30°·sec⁻¹ (Isokinetic 30), isokinetic peak torque at 30°·sec⁻¹ (Isokinetic 120), muscle cross-sectional area (CSA), and echo intensity (EI).

Statistical significance: * P < 0.05, ** P < 0.01

Table 3. Pearson product moment correlation coefficients between Isokinetic 30, Isokinetic 120, CSA, and EI for the old men.

<table>
<thead>
<tr>
<th></th>
<th>Isokinetic 30</th>
<th>Isokinetic 120</th>
<th>CSA</th>
<th>EI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isokinetic 30 (Nm)</td>
<td>-</td>
<td>0.846**</td>
<td>0.199</td>
<td>0.011</td>
</tr>
<tr>
<td>Isokinetic 120 (Nm)</td>
<td>-</td>
<td>-</td>
<td>0.178</td>
<td>-0.195</td>
</tr>
<tr>
<td>CSA (cm²)</td>
<td>-</td>
<td>-</td>
<td>-0.701*</td>
<td></td>
</tr>
<tr>
<td>EI (a.u.)</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Isokinetic peak torque at 30°·sec⁻¹ (Isokinetic 30), isokinetic peak torque at 30°·sec⁻¹ (Isokinetic 120), muscle cross-sectional area (CSA), and echo intensity (EI).

Statistical significance: * P < 0.05, ** P < 0.01

Table 4. Partial correlation coefficients between CSA, Isokinetic 30, and Isokinetic 120, independent of EI.

<table>
<thead>
<tr>
<th></th>
<th>Isokinetic 30</th>
<th>Isokinetic 120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young</td>
<td>0.742**</td>
<td>0.800**</td>
</tr>
<tr>
<td>Old</td>
<td>0.177</td>
<td>0.058</td>
</tr>
</tbody>
</table>

Isokinetic peak torque at 30°·sec⁻¹ (Isokinetic 30), isokinetic peak torque at 30°·sec⁻¹ (Isokinetic 120), muscle cross-sectional area (CSA), and echo intensity (EI).

Statistical significance: * P < 0.05, ** P < 0.01
Table 5. Partial correlation coefficients between EI, Isokinetic 30, and Isokinetic 120, independent of CSA.

<table>
<thead>
<tr>
<th></th>
<th>Isokinetic 30</th>
<th>Isokinetic 120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young</td>
<td>-0.160</td>
<td>0.050</td>
</tr>
<tr>
<td>Old</td>
<td>0.133</td>
<td>-0.101</td>
</tr>
</tbody>
</table>

Isokinetic peak torque at 30°·sec⁻¹ (Isokinetic 30), isokinetic peak torque at 30°·sec⁻¹ (Isokinetic 120), muscle cross-sectional area (CSA), and echo intensity (EI)
Figure 1. Isokinetic peak torque at 30 and 120°.sec−1 for the young and old men. * indicates a significant difference between groups (P<0.01). † indicates a significant difference between velocities (P<0.01). Values are mean ± SD.
Figure 2. Medial gastrocnemius cross-sectional area (CSA) values for the young and old men. Values are mean ± SD.
Figure 3. Medial gastrocnemius echo intensity (EI) values for the young and old men. * indicates a significant difference between groups ($P<0.01$). Values are mean ± SD.
Appendix

The following appendix is not to be copyrighted

Health History and Exercise Status Questionnaire

<table>
<thead>
<tr>
<th>Joint Areas</th>
<th>Muscle Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrist</td>
<td>Arm</td>
</tr>
<tr>
<td>Elbow</td>
<td>Shoulder</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Chest</td>
</tr>
<tr>
<td>Upper Spine &amp; Neck</td>
<td>Upper Back &amp; Neck</td>
</tr>
<tr>
<td>Lower Spine</td>
<td>Abdominal Regions</td>
</tr>
<tr>
<td>Hips</td>
<td>Lower Back</td>
</tr>
</tbody>
</table>
B. HEALTH STATUS (✓ Check if you currently have any of the following conditions)

( ) High Blood Pressure  ( ) Acute Infection
( ) Heart Disease or Dysfunction  ( ) Diabetes or Blood Sugar Level Abnormality
( ) Peripheral Circulatory Disorder  ( ) Anemia
( ) Lung Disease or Dysfunction  ( ) Hernias
( ) Arthritis or Gout  ( ) Thyroid Dysfunction
( ) Edema  ( ) Pancreas Dysfunction
( ) Epilepsy  ( ) Liver Dysfunction
( ) Multiple Sclerosis  ( ) Kidney Dysfunction
( ) High Blood Cholesterol or Triglyceride Levels  ( ) Phenylketonuria (PKU)
( ) Allergic reactions to rubbing alcohol

C. PHYSICAL EXAMINATION HISTORY

Approximate date of your last physical examination______________________________

Physical problems noted at that time__________________________________________

Has a physician ever made any recommendations relative to limiting your level of physical exertion? ________YES ________NO
If YES, what limitations were recommended?_______________________________________

D. CURRENT MEDICATION USAGE (List the drug name and the condition being managed)

<table>
<thead>
<tr>
<th>MEDICATION</th>
<th>CONDITION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

E. PHYSICAL PERCEPTIONS (Indicate any unusual sensations or perceptions. ✓ Check if you have recently experienced any of the following during or soon after physical activity (PA); or during sedentary periods (SED))

PA  SED  PA  SED

40
( ) Chest Pain ( ) Nausea
( ) Heart Palpitations ( ) Light Headedness
( ) Unusually Rapid Breathing ( ) Loss of Consciousness
( ) Overheating ( ) Loss of Balance
( ) Muscle Cramping ( ) Loss of Coordination
( ) Muscle Pain ( ) Extreme Weakness
( ) Joint Pain ( ) Numbness
( ) Other________________ ( ) Mental Confusion

F. FAMILY HISTORY (✓ Check if any of your blood relatives . . . parents, brothers, sisters, aunts, uncles, and/or grandparents . . . have or had any of the following)
( ) Heart Disease
( ) Heart Attacks or Strokes (prior to age 50)
( ) Elevated Blood Cholesterol or Triglyceride Levels
( ) High Blood Pressure
( ) Diabetes
( ) Sudden Death (other than accidental)

G. EXERCISE STATUS (Please provide a precise estimation of your previous exercise habits)
Do you regularly engage in aerobic forms of exercise (i.e., jogging, cycling, walking, etc.)?
YES NO
In the past _6 months_, how many hours per week do you spend performing this type of exercise? _____ hours

Do you regularly lift weights? YES NO
In the past _6 months_, how many hours per week do you spend performing this type of exercise? _____ hours

Do you regularly play recreational sports (i.e., basketball, racquetball, volleyball, etc.)?
YES NO
In the past _6 months_, how many hours per week do you spend performing this type of exercise? _____ hours
REFERENCES


41. Weir E and Culmer L. Fall prevention in the elderly population. CMAJ. 171(7):724. 2004