Clinical Biomechanics 28 (2013) 705–711

Contents lists available at SciVerse ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Associations between muscle structure and contractile performance in seniors

Avleen Randhawa *, James M. Wakeling

Department of Biomedical Physiology and Kinesiology, Simon Fraser University, Burnaby, BC, Canada

ARTICLE INFO

Article history:
Received 22 February 2012
Accepted 29 April 2013

Keywords:
Sarcopenia
Elderly
Atrophy
Muscle-gearing
Ultrasound
Gastrocnemii

ABSTRACT

Background: Changes in muscle structure due to aging occur in a process known as sarcopenia. These changes can alter muscle mechanics during contraction that may limit mobility in seniors. The purpose of this study was to investigate the effect of sarcopenia on muscle fascicle length, pennation and belly thickness in a contracting muscle during isokinetic movements. Fascicles within a pennate muscle shorten at a slower velocity than that of the muscle belly, in a process called belly gearing. Belly gearing may be affected by atrophy and so was also tested in these seniors.

Methods: The gastrocnemii were tested using ultrasound from 10 young adults (20–40 years) and 9 seniors (70–85 years). The muscle structure was imaged during standing and maximal plantarflexion at four constant velocities on a dynamometer and torque, position and time were recorded during contractions.

Findings: The muscle belly thickness and pennation in seniors were significantly lower than young adults during standing. Belly thickness, changes in pennation, the belly gearing, ankle torque and power output were all significantly lower in seniors during plantarflexion contractions of the medial gastrocnemius (MG) and lateral gastrocnemius (LG).

Interpretation: The higher pennation observed in young adults is commonly associated with increased fascicle rotations during contraction causing an increased belly gearing. The decreased fascicle rotations in seniors resulted in reduced belly gearing but the size of this effect did not match the loss in strength or power from the muscles.

1. Introduction

Skeletal muscles play a key role in body movements and locomotion (Dickinson et al., 2000). During concentric contractions the muscle belly shortens and its thickness changes as the fascicles rotate and increase in pennation angle (Fukunaga et al., 1997; Kawakami et al., 1998). Muscle performance depends on the geometrical arrangement of these fascicles (Lieber and Friden, 2000; Powell et al., 1984) and the contribution of the connective tissue both external and internal to the muscle belly (Sejersted et al., 1984; Van Leeuwen and Spoor, 1992). The force generated by a muscle is a function of its shortening velocity (Hill, 1938) and so the slower shortening velocities of pennate muscle fascicles can result in greater muscle force (Azizi et al., 2002; Wakeling et al., 2011) and thus joint torques during contraction (Randhawa et al., 2013). Therefore, the obliqueness of fascicles and their ability to rotate within the belly allow them to be geared to slower speeds of contraction than the muscle belly (higher muscle gearing), and this gives them higher force potentials. Fascicle rotations and gearing thus enhance the overall functional performance of a muscle. This advantageous effect may be lost in an aging muscle due to changes in structural properties controlling the shortening velocity of muscle fascicles (Kubo et al., 2003; Lauretani et al., 2003; Maganaris, 2002; Morse et al., 2005; Narici and Maganaris, 2006; Narici et al., 2003).

As we age, physiological changes occur in the muscles that may limit the activities of daily life (Doherty, 2003). Sarcopenia is an age related loss of skeletal muscle mass (Rosenberg, 1989) and strength (Bemben et al., 1991), and this atrophy occurs with reductions in size, strength and power output (Lauretani et al., 2003; Lindle et al., 1997). Sarcopenia is prevalent in 30% of those over 60 years. It mainly involves wasting of type II fibers (Lexell, 1993), and is associated with a reduction in mobility.

Muscle power output is a more important determinate of physical performance than impairments in strength for older adults (Bean et al., 2003) as it also incorporates the speed at which a task is executed. Force and power deterioration have been observed in seniors between 75 and 85 years and it was found that reduction in power (60%) was more pronounced than muscle strength (knee-extension torque, 43%) in seniors between 75 and 85 years compared to young adults between 20 and 29 years (Lauretani et al., 2003). One of the reasons for a greater loss in power in seniors may be due to the predominant atrophy of fast muscle fibers (Lang et al., 2010; Lexell, 1993) that would otherwise have produced greater power during shortening.

When muscle shortens, it must bulge or increase in cross sectional area (CSA) to conserve volume (Baskin and Paolini, 1967). Muscle bulging occurs by increases in thickness (parallel to fascicle planes) or increases in width (perpendicular to fascicle planes). The exact

---

* Corresponding author.
E-mail address: ara46@sfu.ca (A. Randhawa).

0268-0033/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.clinbiomech.2013.04.010

direction of this bulging is constrained by surrounding connective tissues such as superficial aponeurosis, deep aponeurosis and the tendon. In mammalian muscle, the pennation angle varies between 0° and 30° at rest (Zuurbier and Huijing, 1993) and may increase to approximately 70° in the medial gastrocnemius in man with maximal contraction (Kawakami et al., 1998). Thicker muscles, with greater pennation, would typically be able to allow greater fascicle rotations and gearing. Muscle hypertrophy changes the structural properties of a muscle with increases in pennation angle (Kawakami et al., 2000), CSA (Aagaard et al., 2001) and thickness (Duclay et al., 2009) and so it may be expected that hypertrophied muscle would operate with a higher gearing. Conversely, the muscle atrophy that occurs with sarcopenia may result in a decreased gearing and thus decreased performance during dynamic contractions, but this idea remains untested.

Changes in muscle structure with sarcopenia have previously been reported for seniors during static muscle tests using ultrasound (Narici et al., 2003) and magnetic resonance imaging (MRI) (Morse et al., 2005). It has also been shown that connective tissue properties change with aging (Maganaris, 2002; Narici and Maganaris, 2006). These studies reported that as muscle size reduces, the fascicles become shorter and less pennate. Specifically, pennation angles reduce by 10–16% in medial gastrocnemius and by 18% in lateral gastrocnemius. Additionally, fascicle lengths in the medial gastrocnemius were also reduced by 13–16% in seniors. Cross sectional area was reduced to 74% in muscles of individuals above 75 years as compared to those between 20 and 40 years (Lauretani et al., 2003) along with significant reductions in muscle volume. Importantly, the relation between structural changes and the reduction in performance in the elderly have never been researched previously.

As a muscle undergoes sarcopenia the changes to its structure should affect its contractile performance. The main goal of this study was to investigate associations between the structural characteristics of a muscle and its functional output reflected as lower joint torques and power generation in seniors as compared to the young adults that are linked to limitation in performance in seniors. We hypothesized that changes in fascicle rotations and muscle thickness in seniors would lead to a reduction in the belly gearing with a subsequent reduction in the power output during dynamic contractions.

2. Methods

2.1. Participants

Ten young-adults (Y) (males, age: 27.8 (4.4) year, height: 180.9 (7.1) cm, body mass: 77.7 (15.3) kg; means (SD)) and nine seniors (S) (males, age: 75.5 (4.0) year, height: 176.0 (6.0) cm, body mass: 83.5 (8.3) kg) were tested. Both groups included physically active participants without any subjective evidence of an ongoing musculoskeletal disease or injury. The institutional research ethics committee approved this study, and participants provided informed consent.

The seniors were recruited from a local confederation center with prior physical and functional assessments. The inclusion criteria for seniors were individuals who were active, mobile and capable of walking on level ground and up and down the stairs. The exclusion criteria were individuals with on-going serious cardiovascular problems (recent heart attack, stroke, or chest pains), musculoskeletal injuries (fracture or injury to lower body in past one year), neurological disorders (Parkinson, Multiple sclerosis, Alzheimer's, Huntington's, Polio) or individuals who had undergone surgical procedures within one year prior to testing. The assessment of seniors included a medical screening questionnaire that included general questions on senior's overall health. Some standardized and validated tests were performed prior to testing to analyze the cognitive health of seniors through mini-mental state exam (MMSE) (Woodford and George, 2007) and to assess the functional ability using timed up and go test (TUG) and Berg's balance scale (BBS) tests (Steffen et al., 2002).

2.2. Isokinetic testing protocol

Ankle plantarflexor movements were tested on a dynamometer (System 3, Biodex, New York, USA) using the isokinetic setting that limits the maximum ankle speed of plantarflexion. The chair and footplate of the dynamometer were adjusted so that the participant was seated, the thigh was elevated using the knee stabilization support and the longitudinal axis of the tibia was horizontal. The medial gastrocnemius, MG, and lateral gastrocnemius, LG, were tested on the left and right legs, respectively, in order to minimize fatigue due to repetitive ankle plantar flexion movements. All the participants were right leg dominant. Both groups had a mean knee angle of 139.4 (s.e.m. 4.1)°. Ankle torque, angle and angular velocity from the dynamometer were recorded at 1 kHz using a 16-bit data-acquisition system (USB-6229; National Instruments, Austin, TX, USA). Participants performed maximal-effort plantar-flexion movements from maximum dorsiflexion to maximum plantarflexion at constant ankle velocities of 150, 120, 90, and 45° s^{-1}. Six trials were performed at each ankle velocity, with a 5–10 s period of rest between contractions. The mean plantarflexion range of motion (ROM) with participants on the dynamometer was −0.02 (2.06)° to 38.86 (0.98)° in seniors and −20.58 (1.56)° to 47.92 (2.14)° in young adults, mean (s.e.m.).

2.3. Structural properties of muscle

Geometrical properties of the muscle were imaged using B-mode ultrasound during standing and during contractions (60 mm linear ultrasound probe; Echoblaster 128, Telemed, Lithuania). The ultrasound probe was aligned to image a fascicle plane within the belly region of the muscle (Fig. 1A), and secured in place using a flexible support and medical stretch-adhesive tape to ensure the same region of the belly was imaged for each trial. Ultrasound scans during standing were also recorded to acquire passive muscle images for the determination of static structural parameters (fascicle length, pennation angle and muscle belly thickness). The maximum calf girth was also measured during standing. The ultrasound images were acquired at 50 Hz, and synchronized to the torque and position data during the dynamometer tests. One ultrasound image from standing and twenty-five images that were evenly spaced in time from each ankle extension were selected and manually digitized (Fig. 1B) (ImageJ software, NIH, Maryland, USA).

Pennation angle β was calculated as the mean of the angles β_1 and β_2, made by the fascicle and the superficial and deep aponeuroses, respectively (Fig. 1C). Fascicle length L_f was the length of linear line passing through the digitized fascicle points and the superficial and deep aponeuroses (Fig. 1C). The muscle belly thickness L_t was the shortest distance from superficial to deep aponeuroses through the center of the measured fascicle (L_f Sin β) (Fig. 1C). The length of the fascicle in the direction of the muscle belly L_b was calculated as L_f Cos β. The rate at which L_b shortens was assumed to equal the rate at which the muscle belly shortens. For the ankle extension tests, these measured muscle parameters were interpolated to 25 values evenly spaced in time per plantarflexion movement, and then calculated as the mean across all repeats for each condition. From these mean traces, the instantaneous fascicle velocity V_f and belly velocity V_b were calculated as the first time-derivative of the changes in L_f and L_b, respectively. The time at which the belly shortening velocity was at a maximum was determined. The belly gearing G_b was calculated for this time as the ratio V_b/V_f.

2.4. Data analysis

Statistical differences in the body mass index (BMI) and the structural parameters during standing (including the calf girth) were tested using two-sample t-tests. During ankle extensions, the age effects on the measured kinematic parameters from the dynamometer (maximum torque and joint power) and the muscle structural parameters (changes in