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Original article

Body mass normalisation for ultrasound measurements of lumbar multifidus and abdominal muscle size

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ABSTRACT

The purpose of this study was to determine if ratio scaling or allometric scaling is the more appropriate method for normalising ultrasound measurements of lumbar multifidus and abdominal muscle size to body mass. In a convenience sample of 62 male career firefighters, cross-sectional area and thickness of the lumbar multifidus, as well as, thicknesses of the external oblique, internal oblique, and transverse abdominal muscles were assessed with ultrasonography. Ratio scaling entailed dividing muscle size by body mass, while allometric scaling entailed dividing muscle size by body mass raised to a power. Significant positive correlations ($r = 0.25$ to 0.49, $p < 0.05$) existed between body mass and all muscle size measurements, except for transverse abdominal thickness ($r = 0.21$, $p = 0.100$). Ratio scaling was deemed inappropriate for normalising the muscle size measurements, because it merely reversed the direction of the correlations between body mass and the muscle size measurements ($r = -0.31$ to -0.50, $p < 0.05$), with external oblique abdominal thickness representing the only exception ($r = -0.17$, $p = 0.192$). Allometric scaling with derived allometric parameters was deemed appropriate for normalising muscle size measurements, because it caused the correlations between body mass and muscle size to become insignificant and near to zero ($r = -0.06$ to 0.00, $p > 0.05$). The current study provides allometric parameters that can be used to normalise muscle size measurements to body mass in male firefighters. Future research is needed to establish reference databases of population-specific allometric parameters in other groups.

1. Introduction

Practitioners and researchers in the rehabilitative sciences frequently utilize ultrasound measurements to assess lumbar multifidus and abdominal muscle size (Koppenhaver et al., 2009). Oftentimes, these measurements are compared across different populations to understand the aetiology and pathophysiology of low back pain and compared across time intervals for assessing the efficacy of injury prevention and rehabilitation programs (Koppenhaver et al., 2009). Given the relationships between low back pain and aberrations in lumbar and abdominal muscle size, morphology, and activation (Koppenhaver et al., 2009), assessing the characteristics of these muscles with ultrasound is reasonable.

Ultrasound measurements of lumbar multifidus and abdominal muscle size have typically been reported in absolute terms (e.g., cross sectional area in cm^2 or thickness in cm) (Stokes et al., 2007) without considering the impact of body mass or other anthropometric variables. However, previous research has demonstrated that absolute muscle size measurements are significantly correlated with body mass (Seo et al., 2003; Mannion et al., 2008). This implies that differences in absolute muscle size across different populations, or changes in muscle size across time intervals, may be due to confounding differences or changes in body mass. Thus, normalising ultrasound muscle size measurements to account for body mass in clinical practice and research settings appears warranted.

Ratio and allometric scaling are two methods used to normalise physiological measurements to body mass. These methods are often applied to measurements of physical fitness, such as strength (Markovic and Jaric, 2004; Jaric et al., 2005; Crewther and Gill, 2009; Crewther et al., 2011). Ratio scaling (also known as isometric scaling) is accomplished by dividing the physiological measurement by the body mass of the individual. Ratio scaling assumes a linear relationship between the physiological measurement and body mass (Jaric et al., 2005). Allometric scaling, which is based on the theory of geometric symmetry (i.e., that all humans have the same shape and differ only in size), is accomplished by dividing the physiological measurement by the body mass of the

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individual raised to an exponential power. This exponential power is referred to as the allometric parameter (b) (Jaric et al., 2005). The allometric parameter is derived from statistical analysis of the relationship between the physiological measurement and body mass. The parameter serves to reduce the influence of body mass on the physiological measurement—that is, to make the physiological measurement independent of body mass. Allometric scaling assumes a curvilinear relationship between the physiological measurement and body mass.

Ratio and allometric scaling methods are rarely applied to measurements of muscle size (Stokes et al., 2005). Stokes et al. (Stokes et al., 2005) reported lumbar multifidus cross-sectional area (CSA) measurements in both absolute terms (cm^2) and in normalised terms using ratio scaling (cm^2/kg). When comparing males and females of significantly different body masses, the researchers discovered a significant difference in lumbar multifidus L5 CSA (males: 8.91 cm^2; females: 6.65 cm^2). However, when ratio scaling was used to normalise CSA to body mass, the values were not significantly different (males: 0.11 cm^2/kg; females: 0.11 cm^2/kg). This finding indicates ratio scaling may be an appropriate method for normalising muscle size measurements to body mass. However, this study did not formally assess the appropriateness of ratio scaling and, to our knowledge, no other previous investigation has formally assessed any scaling procedures for ultrasound measurements of lumbar multifidus and abdominal muscle size. Because no formal investigation has been conducted on this topic, it is unclear if ratio scaling or allometric scaling is the more appropriate method for scaling muscle size measurements. Thus, the purpose of this study was to determine if ratio scaling or allometric scaling is the more appropriate method for normalising ultrasound measurements of lumbar multifidus and abdominal muscle size to body mass. We hypothesized that both ratio scaling and allometric scaling methods would be equally appropriate for normalising muscle size measurements.

2. Methods

2.1. Study design

The current study was a cross-sectional study conducted at a university laboratory. Data were collected during baseline assessments for a controlled trial, which investigated the effect of exercise training on back and core muscle endurance in firefighters (Grant EMW-2009-FP-00418 from the Federal Emergency Management Agency, United States Department of Homeland Security). Linear regression was used to assess relationships between independent and dependent variables. The independent variable was body mass and dependent variables were CSA of the lumbar multifidus, and thicknesses of the lumbar multifidus and external oblique, internal oblique, and transverse abdominals.

2.2. Subjects

A convenience sample of 62 male career firefighters (age: 36.2 ± 9.4 y; height: 178.5 ± 8.2 cm; body mass: 88.6 ± 15.3 kg) who were enrolled in a randomized controlled trial participated in this study. Subjects were recruited from the entire population of firefighters ($n = 573$) of Tampa Fire Rescue (Tampa, Florida, United States), a medium-sized municipal fire department. All candidates provided informed consent prior to participation in the on-site screening procedures. The experimental protocol complied with ethical standards and was approved by the university's Institutional Review Board.

Inclusion criteria for participation were: 18 years of age or older and an active, full-duty firefighter. Exclusion criteria were: cardiovascular or orthopaedic contraindications to exercise; history of systemic inflammatory disease or spinal surgery; clinically meaningful self-reported current low back pain or disability; level of readiness for physical activity at screening deemed to preclude participation; presence of a red flag for potential serious condition related to low back pain; abnormal resting blood pressure or heart rate; currently receiving care for spinal pain disorder/injury; currently diagnosed with or receiving care for a psychological or psychiatric disorder; currently performing progressive resistance exercises for the low back or core muscles; active workers' compensation or personal injury case; simultaneously enrolled in another clinical trial; drug or alcohol abuse within the past year; or any other condition, which in the opinion of the investigators would put the candidate at increased safety risk or otherwise make the candidate unsuitable for this study.

2.3. Body mass assessment

A calibrated electronic scale (Life Measurement, Inc., Concord, California, United States) was used to assess body mass. Participants removed all clothing items, except underwear, for this assessment. Measurements were recorded to the nearest 0.01 kg.

2.4. Ultrasonography

Images of muscle CSA and thickness were acquired with a portable ultrasound device (MyLab 25, Biosound Esaote Inc., Florence, Italy) equipped with a 5 MHz curvilinear transducer (CA631, Biosound Esaote Inc., Florence, Italy). Lumbar multifidus CSA and thickness images were acquired from the right side at the L4 and L5 levels. For the lumbar multifidus images, subjects assumed a prone position on a table, with a pillow underneath the abdomen (Hides et al., 2008). The position of the transducer for these images was determined by palpating bony landmarks and identifying landmarks on the device's monitor.

Images of the external oblique, internal oblique, and transverse abdominal muscles were acquired with participants resting in a supine position on a table. These images were acquired from the right side, with the transducer positioned along the midaxillary line, approximately half way between the iliac crest and the inferior border of the rib cage. The position of the transducer was then manipulated until the muscles were visualized on the monitor with the anterior medial edge of the transverse abdominal approximately 2 cm from edge of the image (Ferreira et al., 2004).

The images were stored on the ultrasound device in bitmap format and then imported on to a desktop computer for analysis using ImageJ software (National Institute of Health, Bethesda, Maryland, United States). Anatomical landmarks were used in standardizing muscle size measurements. For lumbar multifidus CSA, the echogenic lamina was used to identify the muscle's deep border, the acoustic shadow of the spinous process was used to identify the muscle's medial border, the thoracolumbar fascia was used to identify the muscle's superficial border, and the fascia separating the lumbar multifidus from the erector spinae was used to identify the muscle's lateral border. The freehand tool from ImageJ was used to trace around the muscle's borders (Hides et al., 2008) (Fig. 1a). Thicknesses of the lumbar multifidus muscle at the L4-L5 facet joint (L4 thickness) and L5-S1 facet joint (L5 thickness) levels were measured as the distances between the most superficial portion of the facet joints and the plane between the muscle and subcutaneous tissue (Teyhen et al., 2011) (Fig. 1b). External oblique, internal oblique, and transverse abdominal