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Comparison between muscle activation measured by electromyography and muscle thickness measured using ultrasonography for effective muscle assessment

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A B S T R A C T

In this study, we aimed to compare the intrarater reliability and validity of muscle thickness measured using ultrasonography (US) and muscle activity via electromyography (EMG) during manual muscle testing (MMT) of the external oblique (EO) and lumbar multifidus (MF) muscles. The study subjects were 30 healthy individuals who underwent MMT at different grades. EMG was used to measure the muscle activity in terms of ratio to maximum voluntary contraction (MVC) and root mean square (RMS) metrics. US was used to measure the raw muscle thickness, the ratio of muscle thickness at MVC, and the ratio of muscle thickness at rest. One examiner performed measurements on each subject in 3 trials. The intrarater reliabilities of the % MVC RMS and raw RMS metrics for EMG and the % MVC thickness metrics for US were excellent (ICC = 0.81–0.98). There was a significant difference between all the grades measured using the % MVC thickness metric ($p < 0.01$). Further, this % MVC thickness metric of US showed a significantly higher correlation with the EMG measurement methods than with the others ($r = 0.51–0.61$). Our findings suggest that the % MVC thickness determined by US was the most sensitive of all methods for assessing the MMT grade.

1. Introduction

Trunk stability is essential to avoid excessive strain and injury to its structure (Cholewicki and McGill, 1996). Trunk muscles contribute to trunk stability, which is an important function, and the coordinated pattern of several trunk muscles is considered necessary to achieve a degree of spinal stability. Thus precise clinical assessment of trunk muscles should be warranted for achieving trunk stability (Butcher et al., 2007; Leetun et al., 2004; O'Sullivan et al., 1997).

Intramuscular electromyography (IEMG) is the preferred method for recording and analyzing deep muscles for trunk stability. However, due to the complexity and discomfort of its invasive methods, IEMG is not suited for large clinical trials (Vasseljen et al., 2006). On the other hand, surface EMG (sEMG) is a more practical, cost-effective, and widely used alternative for evaluating muscle activity (Roy et al., 1997).

Currently, ultrasonography (US) is also advocated as a noninvasive method and is becoming increasingly popular for assessing the contractions of the abdominal wall and lumbar muscles and for quantifying muscle morphology and behavior in both research and clinical environments (Hodges et al., 2003; Whittaker, 2008). Previous US studies have indicated that changes in the muscle thickness and cross-sectional area can serve as valid indices of muscle contraction and the results are comparable with those obtained by computed tomography, magnetic resonance imaging (Hides et al., 2006), or EMG (Hodges et al., 2003; McMeeken et al., 2004).

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Previous investigations using EMG have generally used the maximum voluntary contraction (MVC) percentage for normalizing a method which measures muscle activity via EMG (Brown and McGill, 2010; Lee et al., 2011; Silfies et al., 2005), however, no generalized method for measuring muscle thickness via US has been developed. Mannion et al. (2008) used US to measure changes in the thickness of the transversus abdominis, internal oblique, and external oblique (EO) during abdominal hollowing and analyzed their data according to changes in the thickness rate of muscles that were in a relaxed condition. In another study, Brown and McGill (2010) analyzed changes in the thickness of the EO and multifidus (MF) muscles according to changes in the thickness rate of muscles in a condition of maximum contraction. These discrepancies motivated us to undertake a comparative study of US and EMG measurements.

This study had the following aims: (1) to evaluate the intrarater reliability of metrics of measuring the thickness and activity of the EO and MF muscles, (2) to identify the differences in these metrics of measuring the muscle thickness and activity by using US and EMG, respectively, according to manual muscle testing (MMT) which has been widely used to divide the grades of muscle contraction in clinical settings. The final objective of this study was to determine the validity of three previously published metrics for measuring the muscle thickness of the EO and MF using US comparing their estimates with the gold standard for muscle activity determination using EMG. So we (3) examined the correlation between the muscle activity and muscle thickness metrics. Through the above three steps, we therefore investigated the most reliable and valid US metric for muscle assessment.

2. Methods

2.1. Subjects

We recruited 30 healthy subjects (20 men and 10 women) for this study (Table 1). The participants were required to meet the following inclusion criteria prior to enrollment for this study: body mass index (BMI) score between 18.5 and 24.9 to improve signal integrity (John and Beith, 2007), no history of back pain during the 3 months preceding the study, and absence of severe postural or muscular and neurological skeletal abnormalities. Prior to the study, all the study subjects received verbal and written information about the study, following which signed informed consents were obtained from all the participants. This study was approved by the Institutional Review Board of our university.

2.2. Test procedure

MMT was carried out by inducing voluntary contractions of the EO and MF muscles at 4 different grades, and the muscle activity and thickness were simultaneously obtained using sEMG and US, respectively. The MVC and MMT procedures were completed according to the recommendations of Daniels and Worthingham (2003) and presented in Table 2. The test procedure is illustrated in Fig. 1 (A and B for EO and MF respectively), and it has been adopted from others (Mannion et al., 2008; Vasseljen et al., 2006). The reliability and validity measurements for the EO and MF at relaxed condition were taken with subjects in the supine and prone positions, respectively, with the subjects slowly contracting and holding the contraction for 5 s without breathing. Three repeated trials were then performed for each grade with a 5-s rest period. After the subjects performed 1 grade of contraction of MMT for 30 s, they were asked to perform another grade with at least a 1-min rest interval between grades. The MMT sequence for the different positions was randomized using a balanced 4×4 Latin square design to eliminate any potential biasing effects in the repeated measures analysis (Portney and Watkins, 1993).

Table 1
Subject characteristics.

Variables	Men (n = 20)	Women (n = 10)	Total (n = 30)
Age (years)	22.75 ± 2.22	21.70 ± 1.89	22.49 ± 2.14
Height (m)	1.770 ± 0.04	1.630 ± 0.05	1.720 ± 0.08
Weight (kg)	68.90 ± 8.42	52.20 ± 5.59	63.33 ± 10.96
BMI (kg/m^2)	22.06 ± 2.07	19.57 ± 1.20	21.23 ± 2.16

BMI: body mass index.

2.3. US imaging recording and analysis

The US protocol for measuring the thickness of the EO and MF muscles was performed by one examiner using brightness (B)-mode US apparatus (LOGIQ Book XP; GE Healthcare, Princeton, NJ, USA) with a 7.5-MHz linear array transducer. B-mode scans produce a static cross-section image seen through the entire length of the transducer. Rapid deformations of the EO and MF tissues along one scan were recorded using a B-mode apparatus at depths of 5 and 6 cm from the skin surface, respectively (Vasseljen et al., 2006). The US measurement protocol was designed after several pilot trials and based on fundamental knowledge of abdominal and lumbar anatomy. Transmission gel was interposed between the transducer head and the skin. For the EO, the transducer was placed transversely on the dominant side of the body with its center positioned at a point 25 mm anterior to the mid-axillary line, midway between the inferior rib and iliac crest (Mannion et al., 2008). The transducer for the MF was transversally oriented to the fiber direction, placed on a line running from the posterior superior iliac spine to the L1/L2 interspinous space, and positioned on the side of the attached sEMG electrodes (Vasseljen et al., 2006). As the subject performed the contraction, the B-mode image was frozen using the "freeze" mode of the scanner within 5 s of the command to contract. The muscle thickness for each grade of EO and MF MMT was averaged over 3 trials. Care was taken not to apply excessive external pressure through the transducer during imaging. To avoid order effect associated with potential learning or fatigue, the order of presentation of images and muscles were randomized. Image gain and contrast were adjusted for optimal visualization of the muscle fascia boundaries of the EO far from 10 mm displayed in the B-mode scan (Mannion et al., 2008). The thickness of the MF was measured in the bony insertion of the L1/L2 interspinous space (Vasseljen et al., 2006). A total of 360 images were obtained (12 images per subject), and were averaged over 3 trials. These data were exported as text into a custom-written Microsoft Excel program to determine the ratio of muscle thickness at each grade to that at the normal grade (% MVC thickness), contracted muscle thickness at each grade (raw thickness), and the ratio of muscle thickness at contraction to that at rest within each grade (% rest thickness). A numerical formula of three US metrics are presented at the bottom of Table 3.

2.4. sEMG activity recording and analysis

A Myosystem 1400A unit (Noraxon, USA, Inc., Scottsdale, AZ, USA) was used to measure the activation of the EO and MF muscles, and samples were obtained at 1024 Hz into a personal computer system (2.27 GHz processor, 2.00 GB RAM). Raw sEMG signals were band-pass filtered between 10 and 1000 Hz, and the notch filter frequency was 60 Hz. MyoResearch software (MyoResearch XP; Noraxon, USA Inc.) was used for data processing and analysis. Surface bipolar electrodes were used on the EO and MF muscles to obtain EMG recordings. For each MMT grade, these muscles were evaluated unilaterally on the dominant side of the