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RESEARCH ARTICLE

Estimation of Back Muscle Strength Based on Muscle Thickness of Erector Spinae Measured by Ultrasound Scanner

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ABSTRACT

In the present study, it was confirmed whether the measurement of muscle thickness by ultrasound was as accurate as the measurement by Magnetic Resonance Imaging (MRI) and the relationship between ES thickness by ultrasound and back muscle strength was investigated, in order to establish a method to estimate back muscle strength safely and easily. Fifty-one students (16–26 years old) with considerably different athletic experience participated in the study. First, for 15 subjects randomly selected from 51 subjects, we measured ES thicknesses on the outermost point of the transversus process of the L3 vertebra by ultrasound and MRI in a relaxed prone position, and back muscle strength during maximal isometric contraction were measured by a load cell in a sitting posture.ES thicknesses measured by ultrasound and MRI, and back muscle strength were all distributed normally. An extremely high positive correlation was found between ES thicknesses by ultrasound and MRI ($r = 0.997$, $p < 0.001$, regression equation: $y = 1.00x - 0.21$, root mean square error (RMSE) = 36.936), with no significant difference between them. Back muscle strength was significantly and positively correlated with the ES thickness measured by ultrasound ($r = 0.658$, $p < 0.01$) and by MRI ($r = 0.681$, $p < 0.01$). Next, for all subjects, ES thickness by ultrasound and back muscle strength were measured to calculate the representative equation between them. The linear regression equation of the back muscle strength to ES thickness was $y = 22.73x + 413.52$ ($r2 = 0.904$, RMSE = 87.974).These results suggest that back muscle strength for young adults during sitting can be estimated safely and easily based on ES thickness measured by ultrasound.

Introduction

The Erector Spinae (ES) plays an important role in maintaining both static and dynamic balance [1,2], which is fundamental for motor control. During standing, walking and running, ES delicately controls the movement of the spinal column, which has a large range of motion and s-shape structure to support the trunk and head [3-5]. Therefore, measurement of the back muscle strength, to which ES is strongly related, is important forevaluatingan individual's physical capacity.

In Japan, back muscle strength has been measured by pulling a dynamometer on the floor with the arms at a trunk flexion posture during standing [6,7]. This posture is reported to have risks of inducing pressure on intervertebral disks and slip of the disks [8,9]. Furthermore, a larger load acts on lumbar vertebrae in this posture [10]. These findings suggest that measurement of back muscle strength by such standing posture could induce lower back pain [11], especially for middle-aged and older people. To the best of our knowledge, there have been few studies on this measurement of back muscle strength for middle-aged and older people [12].Moreover, the measurement of back muscle strength for students has been eliminated from the Japan Fitness Test, formulated by the Japanese Ministry of Education, Culture, Sports, Science and Technology [11], because this measurement was not sufficiently safe, and lacked validity. Therefore, a method to measure back muscle strength safely and easily is needed.

The absolute muscle strength of a muscle in human beings is proportional to thecross-sectional area of the muscle [13,14]. The cross-sectional area can be evaluated using Computed Tomography (CT) or Magnetic Resonance Imaging (MRI). However, these measurements are very expensive, and may impose a burden on subjects. For CT measurements, subjects are exposed to radiation, although it is a small dose [15]. In contrast, the measurement of muscle thickness using ultrasound can be applied safely and easily with low cost [16,17]. The cross-sectional area of several muscles of the upper and lower extremities and trunkhas been reported to be positively correlated with the muscle thickness [16,17], which is one of the variables that determines this two-dimensional value (cross-sectional area). However, the relationship between muscle thickness and cross-sectional area has not been demonstrated for ES. Furthermore, positive correlations between muscle thickness and strength have been reported for some muscles mainly of the upper and lower extremities [18-21], especially the knee extensor [17]. For ES, Cuesta-Vargas and González-Sánchez[22] reported no significant correlation between ES thickness and back muscle strength. Their study, however, had the following problems: a trunk posture of 45° backward inclination was used, the action point for back muscle strength measurement was unclear, and measurement of muscle thickness was made during contraction. Muscle thickness differs between contraction and relaxation [23]. Therefore, these problems should be avoided when investigating the relationship between ES thickness and back muscle strength. If a strong positive correlation can be demonstrated between ES thickness and back muscle strength, back muscle strength could be estimated by measuring muscle thickness without the need to directly measure the muscle strength. Furthermore, by obtaining the data from many subjects with considerably different athletic experience, the liner regression formula between ES thickness and back muscle strength could be regarded as a representative equation.

In the present study, it was confirmed whether the measurement of muscle thickness by ultrasound was as accurate as the measurement by MRI and the relationship between ES thickness by ultrasound and back muscle strength was investigated, in order to establish a method to estimate back muscle strength safely and easily. The working hypothesis was that ES muscle thickness measured by ultrasound would not significantly differ with the thickness measured by MRI, and show a high positive correlation with back muscle strength.

Materials and Methods

1. Subjects

To investigate the relationship between ES thickness measured by ultrasound and back muscle strength, 51students belonging to the Department of Sports and Health and other departments at Kanazawa Gakuin University, and the Sports Course at Kanazawa Gakuin high school, with considerably different athletic experience, participated in the study. Mean values (Standard Deviation (SD)) for age, height and weight were 19.9 (3.1) years, 166.9 (8.7) cm, and 69.0 (18.9) kg, respectively. Prior to this investigation, to demonstrate the validity of the measurement of muscle thickness by ultrasound, 15 students, who were randomly selected from the 51 subjects, also participated in the measurements of muscle thickness and cross-sectional area of ES using MRI. No subjects reported any history of neurological or orthopedic impairment. In accordance with the Declaration of Helsinki, all subjects provided informed consent after receiving an explanation of the experimental protocol, which was approved by the ethics committee at Kanazawa Gakuin University.

2. Measurement of muscle thickness of ES

Muscle thickness of the longissimus, which is one of the ES muscles, was measured at the same point by ultra sound and MRI. The cross-sectional area of ES was reported to be the largest at the L3 level [24,25]. It is relatively easy to locate thetransversus process of the L3 vertebra since the process isat the same height as the L2 acantha [26]. Therefore, the longissimus thickness was defined as the anterior-posterior distance between the midpoints of the fascia posterior to the outermost point of the transversus process of the L3 vertebra on the right side of the body. The details for determining this measurement point of the thickness using ultrasound or MRI is described below.

2.1. Measurement of muscle thickness of the longissimus using ultrasound

The measurement was carried out with the subjects in a comfortable and relaxed prone position. The longissimus thickness was measured using a real-time B-mode ultrasound scanner (EUB-405B; Hitachi Medico, Tokyo, Japan) with a 3.8-cm, 10-MHz linear array probe (Figure 1A). Measurements were performed directly on the screen using electronic calipers with 0.1-mm resolution. First, the L5 acantha point on the skin was determined by palpation on the basis of the point of the posterior sacroiliac spine, and was marked with a red permanent marker. Next, around the marked point, the L5 acantha was determined by ultrasound. The probe was moved upward, and the L2 acantha was determined. Subsequently, the probe was moved outward, and the outermost point of the transversus process of the L3 vertebra was determined. The longissimus thickness was measured at this point. The ultrasound measurement was performed by two skilled experimenters. Before this study, it was preliminary confirmed that the thickness value measured by them was almost same. It has been reported that the inter-rater and intra-ratercorrelationsof muscle thickness of the triceps surae measured by ultrasound were extremely high [27]. For ultrasound scanning, the probe head was coated with coupling gel. The probe was oriented vertically, perpendicular to the muscle. The ultrasound image under the probe was displayed on a computer screen (Figure 1B). During scanning, great care was taken to manipulate the probe so that the fasciae were parallel and to avoid compressing the dermal surface.

2.2. Measurement of muscle thickness of the longissimus using MRI

Subjects laid on a bed in the MRI device in a comfortable and relaxed prone position. A capsule was attached at the same point as the ultrasound measurement.

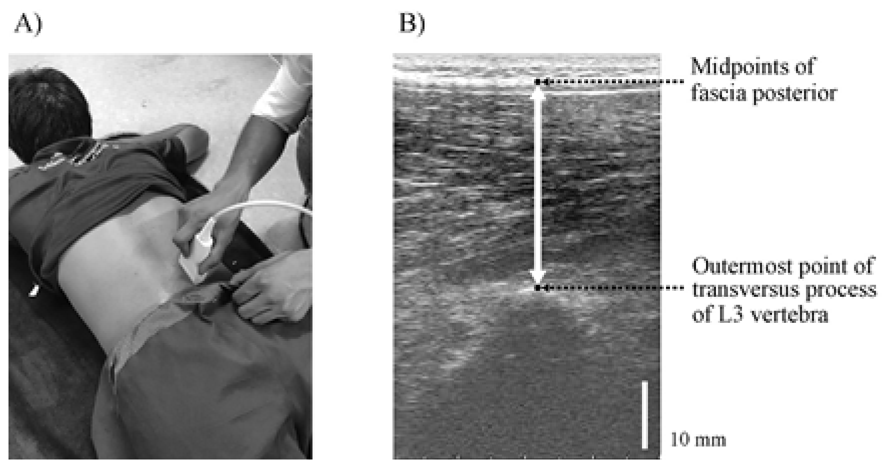

Figure 1: Measurement of the longissimus thickness using anultrasound scanner. (A) Experimental setup, (B) A typical ultrasound image of the longissimus. The white line indicates the thickness.

MRI examinations were performed using a 1.5-T MRI scanner (MAGNETOM ESSENZA; Siemens AG, Erlangen, Germany). MR images were taken to include the capsule level. T2-weighted fast spin-echo imaging was used to obtain sagittal and horizontal images of the lumbar spine (repetition time, 3200 ms; echo time, 90 ms; matrix, 320 × 280; field of view, 320 mm; slice thickness, 3.2 mm). The longissimus thickness, and the cross-sectional area and width of ES were analyzed on the image including the capsule (Figure 2).

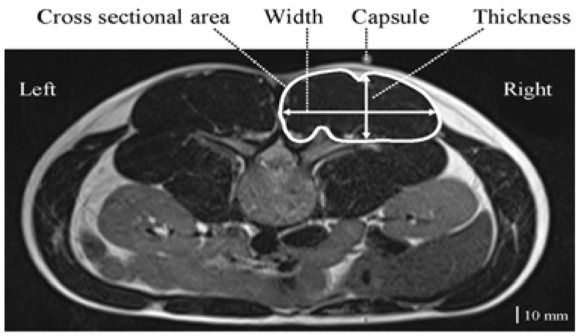

Figure 2: Measurement of the longissimus thickness, width and cross-sectional area of erector spinae by magnetic resonance imaging.

3. Measurement of back muscle strength

The back muscle strength was measured during a maximal voluntary isometric contraction (Figure 3).To avoid the measurement problems associated with the study by Cuesta-Vargas and González-Sánchez[22] mentioned in the Introduction, this measurement was conducted as follows. Subjects sat on a steel-frame chair with their trunk vertical, the knee and hip joints flexed at approximately 90° and the lower legs hanging down. The pelvis and distal side of the thighs were secured by two belts. The trunk at the level of the inferior angle of the scapula was wrapped by a cotton band, and was connected via a rope to a load cell (LUB-200KB; Kyowa, Tokyo, Japan), which was set at the height of the inferior angle of the scapula and 1.5 m in front of the subject. Subjects kept the trunk vertical with anterior curvature of the lumbar vertebrae, and then extended the trunk for 3 s. The measurement was carried out after sufficient practice and rest. During the measurement, subjects were encouraged by an experimenter to perform maximum voluntary contraction. They were asked to generate the force during expiration to prevent rapid elevation of blood pressure. The force of traction was sent to an oscilloscope (DS6612; Iwatsu, Tokyo, Japan) via a strain amplifier (6G01; AND, Tokyo, Japan), and the peak force was measured as back muscle strength. The measurement of back muscle strength was performed twice, and the higher value was used for analysis.

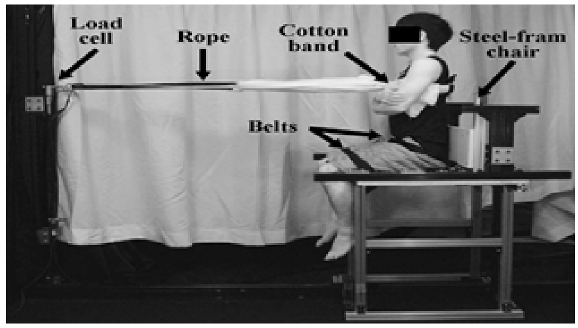

Figure 3: Experimental setup for measurement of back muscle strength.

Statistical analyses

For 15 subjects with MRI measurement, Shapiro-Wilk tests were used to confirm whether the data (longissimus thickness measured by ultrasound or MRI, cross-sectional area and width of ES, and back muscle strength) satisfied the assumptions of normality. A paired t-test was used to compare the longissimus thicknesses between measurements by ultrasound and MRI. Pearson correlation was used to evaluate the magnitude of the correlation between the measurement values. For all subjects, after confirmation of normal distribution of the longissimus thickness measured by ultrasound and back muscle strength using Shapiro-Wilk tests, linear regression equation, coefficient of determination and root mean square error (RMSE) of the back muscle strength to the longissimus thickness were calculated. The alpha level was set at $p < 0.05$. When a statistical analysis was repeated for the same population, p value was adjusted by Holm correction. All statistical analyses were performed using IBM SPSS Statistics 19 (IBM Japan, Tokyo, Japan).

Results

For 15 subjects, the longissimus thicknesses measured by ultrasound and MRI, the cross-sectional area and width of ES, and back muscle strength were all distributed normally. The mean and SD of each were 37.9 ± 7.7 mm, 37.9 ± 7.7 mm, 2483.3 ± 509.0 mm2, 76.2 ± 6.5 mm and 1109.8 ± 225.1 N, respectively. Extremely high positive correlations were found between the cross-sectional area and longissimus thickness (r = 0.900, p < 0.001) or width (r = 0.852, p < 0.001) measured by MRI. There was an extremely high positive correlation between longissimus thicknesses measured by ultrasound and MRI (r = 0.997, p < 0.001, regression equation: y = 1.00x – 0.21, RMSE = 36.936) (Figure 4), with no significant difference between them. Back muscle strength was correlated with the longissimus thicknesses measured by MRI (r = 0.681, p < 0.01) and by ultrasound (r = 0.658, p < 0.01) (Figure 5), and cross-sectional area (r = 0.620, p < 0.05), but not with the width of ES.

For all subjects, the longissimus thicknesses measured by ultrasound and back muscle strength were also distributed normally. The mean and SD of each were 33.1 ± 12.0 mm and 1166.8 ± 286.7N, respectively. The linear regression equation of the back muscle strength to the longissimus thickness was y = 22.73x + 413.52 (r2 = 0.904, RMSE = 87.974) (Figure 6).

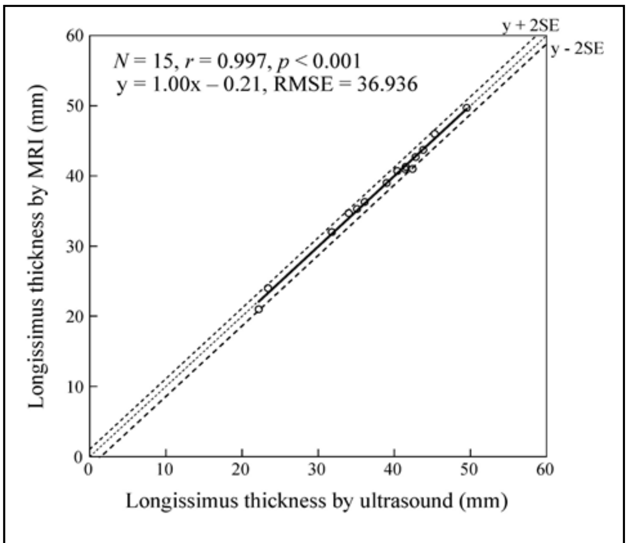

Figure 4: Correlation between the longissimus thicknesses measured by ultrasound and magnetic resonance imaging (MRI). SE: standard error, RMSE: root mean square error.

Discussion

In the measurements obtained from MRI for 15 subjects, the cross-sectional area of ES showed higher correlation with the longissimus thickness than with width. Back muscle strength was correlated with the thickness, or cross-sectional area, but not with width. The absolute muscle strength of a muscle in human beings is proportional to the cross-sectional area of the muscle [13,14].In the present study, the point of action during trunk extension was set at the height of the inferior angle of the scapula. Thus, although the strength of each individual muscle included in back muscles could not be measured, at least whole back muscle would act to bend the lower trunk backward, pivoting at the lumbosacral joint. The longissimus may greatly contribute to this movement according to its origin and insertion. Back muscle contains some muscles involved in rotation of the spinal column and lateroflexion of the trunk [26]. Therefore, the measurement of the longissimus thickness would be more suitable for investigating the relationship with back muscle strength when bending the trunk backward.

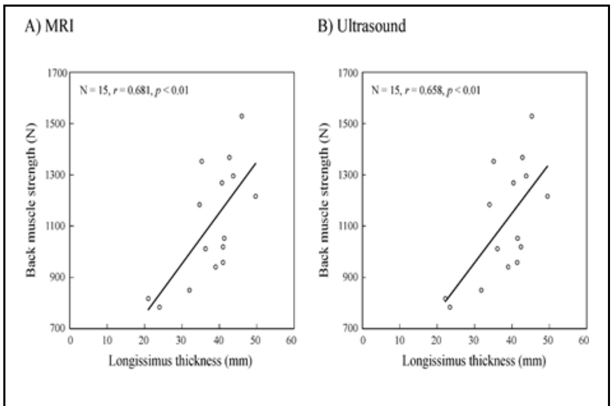

Figure 5: Correlation between back muscle strength and the longissimus thickness measured by Magnetic Resonance Imaging (MRI) (A) or ultrasound (B).

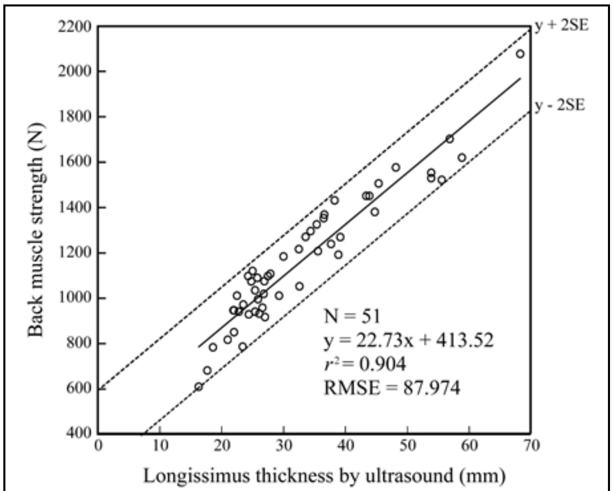

Figure 6: The linear regression equation of the back muscle strength to the longissimus thickness measured by ultrasound. SE: standard error, RMSE: root mean square error.

The high correlation and regression equation (nearly y = x) for the relationship between muscle thickness measured by MRI and ultrasound indicate the validity of the ultrasound method, as in previous studies measuring other trunk muscles [28,29]. Both longissimus thickness measured by ultrasound and MRI showed positive correlations with the back muscle strength. These results suggest that back muscle strength could be estimated from ultrasound measurements of longissimus thickness with the same accuracy as MRI measurement. Before the present study, only Cuesta-Vargas and González-Sánchez[22] investigated the relationship between ES thickness and back muscle strength. Their measurement was also carried out in a sitting posture like our study, however no significant correlation was reported between ES thickness and back muscle strength. As mentioned in the Introduction, their study had the following problems: a trunk posture of 45° backward inclination was used, the action point for back muscle strength measurement was unclear, and measurement of muscle thickness was made during contraction. Muscle thickness differs between contraction and relaxation [23]. In the present study, back muscle strength was measured as mentioned above, and the longissimus thickness was measured during relaxation. In relation to these differences, the positive correlation could be revealed between the thickness and back muscle strength.

This study finally investigated the relationship between longissimus thickness measured by ultrasound and back muscle strength for51 young adults. These final subjects are 16 to 26 years of age and have considerably different athletic experience. The SD of ES thickness was 12.0 mm in the present study, which was approximately double that in a previous study (6.1 mm) [22]. Measurement values of longissimus thicknesses measured by ultrasound and back muscle strength were all distributed normally. These facts suggest that the data obtained from the 51 subjects are well worth considering the representative value for young adults. The liner regression equation for the relationship between the back muscle strength (y) and longissimus thickness (x) was $y = 22.73x + 413.52$. Using this equation, back muscle strength could be estimated from ultrasound measurements of longissimus thickness. However, the posture where maximum voluntary contraction can be performed has been reported to be different by individual person or muscle [30]. Since the back muscle strength was measured only in the sitting posture with trunk vertical in the present study, this equation would be limited to estimating back muscle strength with maximum voluntary contraction during sitting.

The ultrasound scanner is a portable device and can be used to measure muscle thickness easily and safely. In a future study, we will measure the longissimus thickness and the back muscle strength for different age groups, and determine the regression quations to show the relationships between them, separated by age.

Conclusion

The longissimus thickness could be measured using ultrasound, with the same accuracy as MRI. Based on this data, back muscle strength for young adults during sitting can be estimated safely and easily using ultrasound measurements of the longissimus thickness.

Acknowledgement

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