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Relationship Between Muscle Stiffness Derived from Fatigue and Estimated Muscle Mass

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ABSTRACT

Background: This study aimed to investigate the relationship between muscle mass and the effect of contraction tasks leading to biceps fatigue on the joint drive resistance of the elbow joint.

Methods: A total of 23 healthy men were included in this study. A muscle tone electromyograph was used to measure joint drive resistance in passive flexion and elbow joint extension before and after the muscle contraction task. The slope of the regression line of the angular torque during passive motion was calculated and analyzed as the elastic coefficient. We also investigated the relationship between the estimated muscle mass and the joint drive resistance.

Results: Muscle contraction leading to biceps fatigue increases the elastic coefficient of the elbow joint. During muscle fatigue, a relationship was observed between the rate of change in the elastic modulus and the estimated muscle mass.

Conclusion: The muscle contraction task leading to fatigue increases joint drive resistance, and the rate of increase is related to muscle mass.

Keywords: Muscle fatigue; Joint-driven resistance; Muscle mass; Range of motion.

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INTRODUCTION

Muscle fatigue can affect the inherent properties of muscles. Therefore, daily conditioning is important for athletes to prevent muscle fatigue and improve performance. Muscle fatigue can be caused by high-intensity or prolonged exercise and is known to increase muscle hardness transiently. Muscle relaxation is suppressed by muscle fatigue and delayed onset muscle soreness (DOMS) caused by the application of eccentric load due to contraction of the antagonist[1,2]. Muscle hardness also increases after strength training[3] and can affect the cross-linked structure (cross-bridges) of actin and myosin at rest[4]. Changes in muscle stiffness due to muscle fatigue can increase joint stiffness. In clinical practice, the examiner often evaluates muscle and joint stiffness subjectively based on palpation and resistance during exercise. As an objective evaluation method, measuring the passive torque when a joint is moved passively has been devised[5,6]. It measures the joint angle and torque through joint movement to obtain a load-displacement curve. Quantifying the changes in joint stiffness caused by exercise is a significant index for recovery from muscle fatigue. It is also important to determine the effects of stretching and physiotherapy after intervention and to evaluate muscle extensibility. Joint stiffness is affected by the contractile elements of the cross-linked structure of actin and myosin, which comprise muscle fibers. The elastic elements of tendons, fascia, and connective tissue are also involved in joint stiffness[7]. It is essential to know whether the increase in joint stiffness associated with fatigue is strongly affected by contractile and non-contractile components, as this may have implications for myalgia prevention, post-fatigue care, and the content of fatigue recovery programs. This study was conducted to investigate how biceps muscle fatigue alters elbow joint stiffness and to understand the relationship between muscle fatigue and estimated muscle mass.

PARTICIPANTS AND METHODS

1. Participants

The participants were 23 healthy men without neuropathy or osteoarticular disease in their upper limbs. All participants were right-handed.

This study was performed in accordance with the principles of the Declaration of Helsinki. The purpose and content of the study were explained to all participants in advance, either orally or in writing. It was explained that the obtained data would not be used for any purpose other than research, that personal information would be strictly managed to ensure privacy, and that participation in research was voluntary. All participants understood the content of the study and signed a consent form before participating in the study. This study was approved by the Aino University Research Ethics Committee (Aino2019-02).

2. Analysis items

1) Skeletal muscle mass was measured using a body composition analyzer (In Body Japan, In Body S10). This device uses the direct segmental multi-frequency bioelectrical impedance analysis method (DSM-BIA). The measurement of limb position was done standing, and the 8-point contact electrode method was used. Finger electrodes were attached to the thumb and the middle fingers, while the foot electrode was attached to the ankle. The skeletal muscle mass of the right arm was used to evaluate skeletal muscle mass by site.

2) Joint-Driven Resistance: We used a muscle tonus electromyograph (MTM-06 Muscle Master) manufactured by Medicalnics (Osaka, Japan) to measure the elbow joint resistance before and after the muscle contraction task. The joint angle and torque during the passive movement were plotted. The slope kf (Nm/rad) of the regression line ($y = kfx + b$), calculated from the plot, reflects the elastic coefficient. In this study, this was used as a measure of the joint-driven resistance.

3. Exercise tasks and experimental procedures

1) Exercise task: Muscle contraction tasks were performed with elbow flexion. The elbow flexion task was performed with the right upper limb while sitting in a chair. Using a 5 kg iron array, the participant repeated the exercise from the maximum extension of the elbow joint to 90° flexion. The movement speed of the flexion/extension was synchronized with that of the metronome. The movement rhythm was 2 s for the return movement (flexion and extension). The exercise was performed until it became difficult to flex the elbow joint up to 90° owing to muscle fatigue or until the participant could no longer synchronize the exercise with the rhythm. While the participant continued the exercise task, the examiner confirmed the exercise range and evaluated it at the end of the exercise.

2) Experimental procedure: The elbow joint drive resistance was measured before and after muscle contraction. First, the participant's weight and forearm length were measured, and the data were entered into the instrument. This device consists of a main and sensor unit, which incorporates two upper and lower load cells and a gyro sensor. The position for the measurement of the joint-driven resistance was the chair-sitting position. A highly resilient cushion was placed on the desk, and the participant positioned the elbow in the center of the cushion. The upper limb was positioned at a shoulder joint flexion of approximately 60°. The sensor unit was set with the measurement start button positioned at the top and fixed to the participant's proximal wrist joint. The examiner marked the contact surface of the sensor unit on the participant's forearm and identified the part that would be pinched after the muscle contraction task. After 2 min of rest, the examiner measured the experimental data. Measurements were taken according to the instructions on the device's assist screen. The examiner passively performed flexion and extension movements of the participant's elbow joint five times at a rate of once per second. At the time of measurement, the passive movement range was from the maximum extension position of the elbow joint to the maximum flexion angle.

4. Analysis method

The elastic coefficient during mobilization was determined in the direction in which the elbow joint was extended. Data were analyzed over the entire range of motion, except for the initial and final 10°. Measurement data were calculated by dividing the movable range of the processing target into three types: proximal (bending 60° to 110°), distal (10° to 60°), and entire range (10° to 110°). The rate of increase in the elastic coefficient before and after the intervention of the exercise task was calculated, and the effect of muscle fatigue on the drive resistance of the joint was analyzed. We also investigated the relationship between the rate of increase in the elastic coefficient before and after the task and the estimated muscle mass of the upper arm. The item with the highest correlation coefficient was divided into three groups with an elastic coefficient increase rate of less than 100% (n = 3), 100 to 129% (n = 13), and 130% or more (n = 7). The differences between them were also examined.

5. Statistics

Statistical analysis was performed using IBM SPSS Statistics for Windows (version 20.0; IBM Corp., Armonk, NY, USA). The normality of the data was tested using the Shapiro–Wilk test. The relationship between the rate of increase in the elastic coefficient and muscle mass before and after the exercise task was examined using the Pearson correlation coefficient, and the items for which the correlation was found were examined by one-way analysis of variance and Bonferroni multiple comparison tests. The significance level was set to 5%.

RESULTS

The attributes and body composition of the subjects are shown in Table 1.

Table 1. Basic Attributes of participants

Age	27.7 ± 8.8
Height (cm)	168.3 ± 5.5
Body Weight (kg)	64.5 ± 7.6
Right Arm Muscle Mass (kg)	2.7 ± 0.4
BMI (kg/m2)	22.8 ± 2.6

The elbow joint passive movement was performed five times in 60 s, and the angle and torque curves between them are displayed. The elastic coefficient increase rate in the entire range and the proximal and distal ranges were 14.3%, 7.1%, and 28.4%, respectively. The elastic coefficient increased after the exercise task.

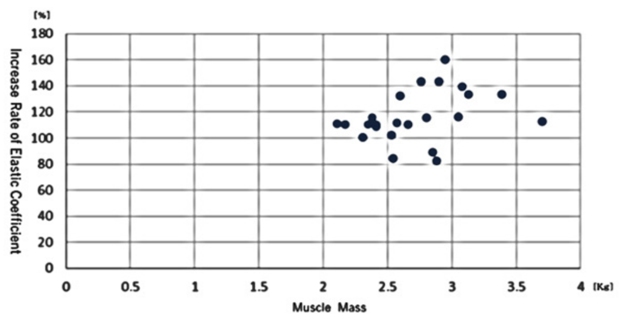

Figure 1. Correlation coefficient between the rate of increase in the elastic coefficient and estimated muscle mass.

A weak correlation was found between the rate of increase in the elastic coefficient and estimated muscle mass in the entire range of motion (r=0.34, p-value = 0.08: Fig1). The muscle mass by elastic coefficient increase rate in the entire range of motion was 2.48 ± 0.27 for less than 100%, 2.59 ± 0.29 for 100% to 129%, and 2.97 ± 0.25 for 130% or more, with a statistically significant difference (Fig2).

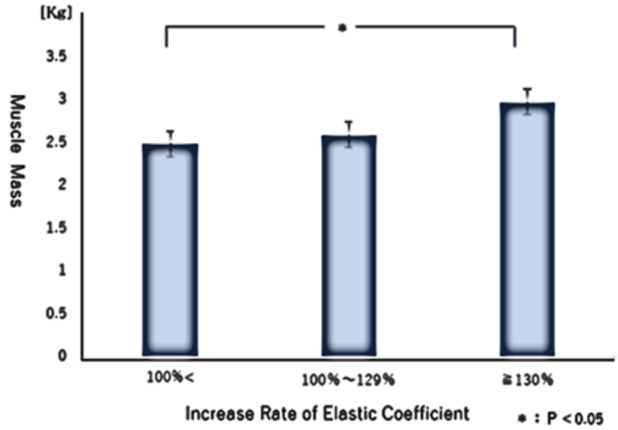

Figure 2. Muscle mass by elastic modulus increase rate in the entire range of motion

DISCUSSION

Contraction leading to fatigue of the biceps and triceps increased the elastic coefficient in the elbow joint's flexion and extension movements. This hardening is caused by an increase in local blood flow in the muscles and water transfer between tissues[8,9]. Increased blood flow during muscle contraction increases the capillary bed due to the dilation of the arterioles and the anterior capillary sphincter. In addition, an increase in the hydrostatic pressure in the capillaries increases the amount of water in the tissue gap. This accumulation of excess tissue water in the interstitial space of myocytes increases intramuscular pressure, resulting in post-exercise muscle hardening and high volume[10,11]. Therefore, water retention in the cell gap causes an increase in intramuscular pressure, which causes muscle swelling and, consequently, an increase in joint resistance. The hydrogen ion concentration is elevated during muscle fatigue and reduces the uptake of calcium ions into the sarcoplasmic reticulum, prolonging the muscle relaxation time[12]. It is also possible that the passive resistance of the joints increases owing to the extension resistance of the muscles applied during exercise, caused by the suppression of muscle relaxation.

A weak correlation was found between the rate of increase in the elastic coefficient and muscle mass. In contrast, a significant difference was found in muscle mass according to the rate of increase of the elastic coefficient. The factors that determine the motion resistance of joints are the contractile elements of muscles caused by actin and myosin and the elastic elements of the fascia and tendons[3]. Muscle contraction leading to fatigue was suggested to increase passive resistance during passive motion, which may involve contractile muscles. An approach to muscles, which are contractile elements, is more important than non-contractile elements in the recovery program from increased joint drive resistance due to muscle fatigue. Known approaches to muscle fatigue include massage, stretching, and physiotherapy[13]; post-exercise massage promotes the drainage of excess tissue water into the lymphatic vessels due to muscle contraction exercises[14]. In addition, laser irradiation improves ATP synthesis[15] in near-infrared light. The results of this study show that when conducting a muscle fatigue recovery program, it is necessary to consider the extension of treatment time, such as physical therapy, and the massage time for those with large muscle mass compared to those with low muscle mass.

CONCLUSIONS

This study investigated the effect of contractile movement leading to biceps fatigue on elbow joint resistance. The results showed that joint resistance increased in the extension direction of the elbow joint after muscle contraction. It was suggested that the muscle mass of the upper arm might influence the increase in the elastic coefficient.

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