Changes in the hardness of the gastrocnemius muscle during a Kendo training camp as determined using ultrasound real-time tissue elastography

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Abstract Kendo is a high load-type sport, especially for the lower leg muscles. The purpose of this study was to evaluate changes in the hardness of the gastrocnemius medialis (GM) using real-time tissue elastography (RTE) during training at a Kendo training camp. Eleven college male Kendo athletes participated in a 5-day Kendo training camp, and the hardness of the GM, the circumference of the lower legs, and the ankle range of motion (ROM) were examined during the course of training. The strain ratio of the GM to a reference material was used to estimate changes in muscle hardness during the training period. The results showed that the strain ratio of the GM significantly increased at days 3, 4, and 5, in comparison to the baseline values obtained prior to training ($p < 0.05$), indicating that the hardness of the GM increased after high-intensity exercise. Meanwhile, the circumference of the lower leg did not change over the course of training; while the ROM values significantly decreased at days 4 and 5 relative to the baseline, suggesting the increased muscle hardness resulted from increased muscle stiffness. These results suggest the muscle hardness of athletes who engage in repetitious high load-type sports are tense on the next day of hard training, and the hardness continues, as in this case, until the last day of camp. In addition, RTE measurements of muscle hardness may allow a more sensitive detection of changes in muscle properties than what is possible with ROM measurements.

Keywords : musculus gastrocnemius, hardness, real-time tissue elastography, training camp, case series

Introduction

Changes in muscle hardness occur after exercise¹⁾, injury²⁾, and fatigue³⁾. Muscle hardness has been used as an index of condition in athletes and has often been measured by athletes themselves or conditioning coaches using qualitative subjective estimates. However, subjective estimates are deeply affected by the experience of the person making the estimate. Alternatively, muscle hardness has been measured using a tissue hardness meter, which usually involves pushing the meter against a body surface; however, the technique does not take account for the influence of skin and fat.

Ultrasound real-time tissue elastography (RTE) is a technique that allows noninvasive estimation and real-time visualization of the elastic properties of the tissue by using an ultrasonograph⁴⁾. The basis of this technique is that tissue compression produces a lower strain in harder

tissue than in softer tissue⁵⁾. Hence, using an ultrasound transducer, this technique can evaluate the degree of relative distortion of a living tissue under compression, thus allowing tissue hardness to be evaluated through tissue strain⁵⁻⁹⁾. In particular, the hardness of a specific tissue can be quantitatively estimated by comparing its strain rate with that of a reference material (strain ratio)⁹⁻¹¹⁾. RTE has been successfully applied to breast lesions⁵⁾, pancreas⁷⁾, prostate⁸⁾, and lymph nodes¹²⁾, and has recently become a tool for evaluating the hardness of musculoskeletal tissue^{9,11)}.

Recently, Yanagisawa et al.⁹⁾ showed that muscle hardness measured by RTE increased immediately after eccentric exercise, but decreased 30 min later. In contrast, Niitsu et al.¹¹⁾ showed that muscle hardness measured by RTE increased after eccentric exercise, and continued to increase until it peaked at day 2 after exercise, and then decreased thereafter. These previous reports examined the effects of acute exercise; however, athletes continue training over long periods of time. To our knowledge,

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no previous study has used RTE to evaluate changes in the elastic properties of skeletal muscles during repeated training routines.

Kendo is one of the traditional Japanese martial arts. During the course of the game, athletes move quickly and push off with the left leg from the same stance (i.e., with the right foot placed in front and the left foot behind), regardless of the dominant foot and hand. In addition, the athletes use heavy protection and do not wear shoes during practice. Because of the nature of the maneuvers, Kendo results in a high load on the muscles of the lower leg, particularly those of the left leg¹³⁾. Correspondingly, lower leg injuries frequently occur in Kendo athletes¹⁴⁾.

The purpose of this study was to assess, by using RTE, changes in muscle hardness of the gastrocnemius medialis during a Kendo training camp. Such knowledge would be helpful for injury prevention and conditioning regarding fatigue for athletes who participate in sports involving a repeated high load.

Materials and Methods

1. Subjects

Eleven healthy male Kendo athletes [mean $\pm$ standard deviation (SD); age, 19.2 ± 0.4 years; height, 169.5 ± 4.3 cm; weight, 64.1 ± 5.0 kg; years of Kendo experience,

14.4 ± 0.9 years] participated in the study. The subjects had no history of significant orthopedic problems in their lower legs, and the gastrocnemius medialis of the left leg was examined for the presence of any conditions. The subjects had joined the same team and trained in the same training camp program. This team is one of the strongest in Japan, winning the championship at a national college convention many times.

This study was approved by the Ethics Committee of the Graduate School of Comprehensive Human Sciences, University of Tsukuba (24-19 [Faculty of Health and Sport Sciences]), and written consent was obtained from all subjects. Before examination, the subjects were given brief descriptions of the purpose of the study, the examination procedures, and the potential risks of the examinations.

2. Training camp and measurement protocol

The standardized training program consisted of 6 h of daily training over the course of 4 days, with the exception of day 1 (2.5 h of training), and was categorized into two major groups: general conditioning and Kendo-specific training (Fig. 1). General conditioning primarily consisted of running, whereas the Kendo-specific training comprised 5 different forms of practice: Kirikaeshi, in which the athlete learns the fundamental techniques of

Time	Day 1	Day 2	Day 3	Day 4	Day 5
	Measurement	Measurement	Measurement	Measurement	Measurement
Early morning		General conditioning (0.5 h)	General conditioning (0.5 h)	General conditioning (0.5 h)	
		Meal & Rest	Meal & Rest	Meal & Rest	
Morning		Kendo-specific training (2.5 h)	Kendo-specific training (2.5 h)	Kendo-specific training (2.5 h)	
		Meal & Rest	Meal & Rest	Meal & Rest	
Afternoon	Kendo-specific training (2.5 h)	Kendo-specific training (3 h)	Kendo-specific training (3 h)	Kendo-specific training (3 h)	
Night	Meal & Rest	Meal & Rest	Meal & Rest	Meal & Rest	

Fig. 1 Training camp and measurement protocol.

The daily training included 30 min of general conditioning in the early morning, and 5.5 h of Kendo-specific training (2.5 h in the morning and 3 h in the afternoon). On the first day, however, training was performed for only 2.5 h in the afternoon. Measurements were performed early each morning prior to training.

striking the center of the head, and then the left and right sides of the head with a movement that involves shuffling back and forth; Waza-geiko, in which the player learns and refines the techniques of Kendo with a receiving partner; Ji-geiko, in which the athlete must use the techniques learned during practice against an opponent; Kakari-geiko, an intense training method that teaches continuous alertness and readiness to attack; and Shiai-geiko, a competition practice that may be judged. Each training session was conducted by a training officer. On average, the daily training included 30 min of general conditioning in the early morning, and 5.5 h of Kendo-specific training (2.5 h in the morning and 3 h in the afternoon). On the first day, however, the training consisted only of 2.5 h of Kendo-specific training in the afternoon. None of the subjects were involved in any physical training program at least 1 day prior to the first day of measurements. The measurements were performed early each morning prior to the training sessions.

3. Assessment of measurements

A) Hardness of the gastrocnemius muscle (reference/muscle ratio)

Hardness of the gastrocnemius muscle was measured using an ultrasound scanner (HI VISION Preirus; Hitachi Medical Corporation, Tokyo, Japan) with a 14-6 MHz linear array transducer (L65; Hitachi Medical Corporation). A reference material for elasticity, made from elastomer resin (acoustic coupler for L65; Hitachi Medical Corporation), was placed between the skin and the transducer using a stabilizer (attachment of the acoustic coupler for L65; Hitachi Medical Corporation) (Fig. 2). RTE measurement was always performed at the same physical location, a longitudinal section positioned at a line that had been drawn on day 1 on the skin surface at the largest circumference of the lower leg. The subjects were placed in the prone position while the knee was fully extended on the examination bed; the ankle was placed in a neutral position (angle between the tibia and sole: 90°) and secured by means of a strap to the footplate.

Fig. 2 Use of a reference material with RTE imaging.

A reference material was placed on the transducer using a stabilizer (a). A linear transducer with the reference material was placed on the participant's lower leg (b).

The RTE image was obtained by manually applying a light, repetitive, rhythmic compression-relaxation cycle with the transducer in the scan position. To obtain appropriate images for investigation, we applied the transducer with constant repeated pressure, monitoring the pressure indicator incorporated into the ultrasound scanner. The RTE image appeared as a translucent, color-coded, real-time image superimposed on the B-mode image. The scale ranged from blue for components with less strain (i.e., the hardest components) to red for components with greater strain (i.e., the softest components). Green indicated average strain. After scanning, the sharpest (clear-est) RTE image from the ultrasound scanner was selected automatically for analysis by a computer. Rectangular regions of interest (ROIs) were individually positioned on the gastrocnemius medialis and the reference material. The strain rate within each ROI was automatically measured using built-in software, and the strain ratio (reference/muscle ratio, i.e., the strain measured in the ROI of the reference divided by the strain in the ROI of the muscle) was calculated for each image (Fig. 3). RTE measurements were performed three times, and the mean values were calculated. The same examiner positioned all ROIs and performed all measurements. The intra-investigator reliability of this RTE measurement method was considered good¹⁵⁾.

B) Circumference of the lower legs

With the subject positioned in the same manner as for RTE measurement, the circumference of the lower leg was measured using a tape measure. During the first

measurement, a line was drawn on the skin surface at the maximal circumference point of the lower leg.

C) Ankle range of motion (ROM)

The subjects were placed in the supine position, with the knee fully extended on the examination bed. Using a goniometer placed at the intersection of lines parallel to the longitudinal axes of the fibula and the fifth metatarsal, two examiners (the same two examiners were used throughout the study) measured the subjects' ankle ROM as the degree of motion from full, passive plantar dorsiflexion. One of the examiners pressed the subjects' ankle for dorsiflexion as much as possible with a constant force, whereas the other measured the ROM using the goniometer. This ROM was used as an index of muscle tightness.

4. Statistical analysis

Means and SDs were calculated for the reference/muscle ratio, circumference, and ROM. Significant changes in the measured parameters were analyzed with repeated-measures analysis of variance, followed by Dunnett's post-hoc test. The statistical significance was set at $p < 0.05$ for all analyses.

We conducted an uncontrolled study, because the muscle hardness of the RTE measurements in the previous study showed no significant difference from day to day¹¹⁾. Moreover, it is believed that the left leg experiences a higher load compared with the right leg due to the nature of Kendo maneuvers, but the influence of a movement load on the right leg in Kendo cannot be excluded. Thus, the right leg of a Kendo athlete was unsuitable for the control group, and the measurements on day 1 were assessed as standard or baseline values.

In addition, the coefficient of variation (CV) and intra-class correlation coefficients (ICCs) for the three repeated measurements at each measurement time were calculated to evaluate the intraobserver reproducibility of the reference/muscle ratio (95% lower and upper confidence intervals [CI]).

Results

1. Hardness of the gastrocnemius muscle (reference/muscle ratio)

The CV values of the reference/muscle ratio for days 1 (pre-camp), 2, 3, 4, and 5 (post-camp) of the training camp were 10.9%, 14.5%, 11.3%, 8.9%, and 9.8%, respectively. The ICC values of the reference/muscle ratio for these 5 days were 0.883 (95% CI: 0.590 - 0.978), 0.890 (95% CI: 0.574 - 0.890), 0.949 (95% CI: 0.802 - 0.992), 0.957 (95% CI: 0.860 - 0.990), and 0.874 (95% CI: 0.659 - 0.963), respectively.

The mean reference/muscle ratios at days 1 (pre-camp), 2, 3, 4, and 5 (post-camp) of the training camp were 0.45 ± 0.14 , 0.58 ± 0.17 , 0.74 ± 0.23 , 1.14 ± 0.47 , and 0.76 ± 0.22 , respectively. The reference/muscle ratio increased

Fig. 3 A transverse axial RTE image of the measurement site of the gastrocnemius medialis.

Rectangular ROIs were positioned within the gastrocnemius medialis (A) and the reference material (B) on an RTE image obtained at each measurement time. The color code indicates the relative strain of the tissues and the reference material to the compression force within the field of view and ranged from red (soft) to blue (hard), with green indicating the average strain.

significantly relative to that of the baseline at days 3, 4, and 5 (Fig. 4a).

2. Circumference of the lower legs

The mean circumference of the lower legs at days 1 (pre-camp), 2, 3, 4, and 5 (post-camp) of the training camp was 36.3 ± 1.4 cm, 36.1 ± 1.5 cm, 36.3 ± 1.5 cm, 36.6 ± 1.5 cm, and 36.6 ± 1.5 cm, respectively. No significant differences were observed between the values obtained during the course of training and the baseline (Fig. 4b).

3. Ankle range of motion (ROM)

The mean ankle ROM at days 1 (pre-camp), 2, 3, 4, and 5 (post-camp) of the training camp was $20.0 \pm 4.5^\circ$, $20.0 \pm 3.9^\circ$, $16.8 \pm 3.4^\circ$, $14.6 \pm 5.2^\circ$, and $13.2 \pm 4.1^\circ$, respectively. The ROM decreased significantly at days 4 and 5 relative to the baseline (Fig. 4c).

Discussion

In general, CVs of less than 12% are regarded as acceptably low for biological measurements¹⁶⁾, whereas an ICC of more than 0.81 is considered to be excellent¹⁷⁾. Hence, with the exception of day 2 (for which the CV

for the reference/muscle ratio was 12.5%), the reference/muscle ratios of the RTE measurements in the present study appeared to be acceptable. This finding supports the results of a previous study in which the intra-investigator reliability for the reference/muscle ratios of the RTE measurements could be considered good^{15,18)}.

In the present study, a significantly increased reference/muscle ratio was observed on training camp days 3, 4, and 5 (post-camp) compared with baseline measurements, indicating that the hardness of the gastrocnemius medialis increased significantly after a few days at the training camp. This finding supports the results of a previous study in which the hardness of the exercised muscle increased significantly after eccentric exercise, whereas that of the non-exercised muscles did not change significantly¹¹⁾.

In previous studies, the factors associated with an increase in muscle hardness after exercise were an increase in muscle tissue volume¹⁹⁾ and an increase in muscle stiffness¹⁾. In the present study, the circumference of the lower leg was employed as an index of muscle tissue volume¹⁹⁾. Repetitive exercise causes accumulation of tissue fluid in muscle compartments and post-exercise hyperemia, and increases muscle tissue volume^{19,20)}. In the present study, a significantly increased reference/muscle ratio

Fig. 4 Changes in the reference/muscle ratio, lower leg circumference, and ROM during the training camp.

The reference/muscle ratio during the training camp increased at days 3, 4, and 5 (a). No significant differences in the lower leg circumference occurred during the training camp (b). The ROM during the training camp decreased at days 4 and 5 (c).

was observed, although no significant difference in the circumference of the lower leg was observed compared with baseline measurements. Therefore, we thought that the increased hardness of the gastrocnemius medialis did not depend on an increase in muscle tissue volume. It is thought that exercise intensity and pattern contribute to the change in muscle hardness and circumference of a limb after exercise^{1,19)}.

In the present study, the ROM was employed as an index of muscle stiffness. Muscle stiffness is defined as the force required to forcibly extend the muscle's long axis^{21,22)}. Repeated eccentric muscle contractions create microscopic muscle damage, leading to an increased influx of calcium ions into cells. The combined action of actin and myosin also continues during periods of relative inactivity, thereby resulting in muscle stiffness^{1,23)}. In the present study, if muscle stiffness had increased in the leg muscles of the subjects, the ROM would be expected to decrease. In fact, the ROM decreased significantly at days 4 and 5. Therefore, we conclude that the increased muscle hardness resulted from increased muscle stiffness. However, at day 3, the hardness of the muscle increased significantly, whereas the ROM did not show a significant decrease. The measured values of ROM are subject to the influence of many body structures, including adjacent joints and tendons as well as deeper or more superficial muscles. However, when RTE is used in the assessment, the measured values for muscle hardness represent the properties of the muscle itself. Hence, the use of RTE may allow more sensitive evaluation of changes in muscle properties than is possible with ROM.

These data suggested that a subject's muscles changed in day 3 measurements due to microscopic muscle damage^{1,17)}. On the first day of the training camp, the subjects underwent only 2.5 h of Kendo-specific training. Because all subjects had trained quite hard for 2 h each day for 6 days of the week, this load was considered insufficient to damage muscles and could explain the lack of change in muscle hardness on day 2. However, when the subjects began intense training for 6 h beginning on day 2, a longer duration at high load could have led to microscopic muscle damage and resulting muscle stiffness. Thus, muscles changed with day 3 measurements.

In conclusion, muscle hardness increased during Kendo training camp on days 3, 4, and 5, whereas the ROM decreased on days 4 and 5. These results suggest that the muscle hardness of athletes who participate in sports involving a repeated high load increases on the day following intense training and continues until the last day of training. In addition, RTE measurements of muscle hardness may allow more sensitive detection of changes in muscle properties than is possible with ROM measurements.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this article.

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