Tohoku J. Exp. Med., 2013, **231**, 111-115

A Greater Reduction of Anterior Cruciate Ligament Elasticity in Women Compared to Men as a Result of Delayed Onset Muscle Soreness

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Women have a higher risk for anterior cruciate ligament (ACL) injuries compared to men. ACL elasticity and muscle flexibility are major risk factors for knee injuries. The presence of estrogen receptors in connective tissue allows estrogen to change the mechanical properties of muscles and ligaments. Delayed onset muscle soreness (DOMS) happened when begin unaccustomed levels of exercise. Thus, the purpose of this study was to examine ACL elasticity after exercise meant to produce DOMS. As a measure of DOMS, visual analog pain scale and quadriceps strength were measured. One hundred forty healthy students (age: 25.2 ± 2.4 years, height: 165.9 ± 8.0 cm, weight: 62.5 ± 10.5 kg, BMI: 22.6 ± 3.1) participated in this investigation and were divided into two groups: men (n = 70) and women (n = 70). Visual analog pain scale, ACL elasticity, and quadriceps strength were measured before and after the intervention. Subjects participated in the same exercise to induce DOMS. To provoke DOMS, subjects accomplished squats for 5 minutes for 3 rounds. Greater ACL elasticity, greater pain on the subjective pain scale and less muscle strength were found (p < 0.001) in women compared to men before and after exercise. A greater reduction of ACL elasticity (p < 0.05) was found as a result of DOMS in women compared to men. Women are likely to have the damage to the ACL and recover slower compared to men after exercise. Thus, we suggest that women should have more time for musculoskeletal recovery after heavy exercise.

Keywords: anterior cruciate ligament elasticity; delayed onset muscle soreness; high-induced exercise; quadriceps strength; sex difference
Tohoku J. Exp. Med., 2013 October, **231** (2), 111-115.

Introduction

Women are at greater risk for anterior cruciate ligament (ACL) injury than do men (Arendt et al. 1999; Griffin et al. 2000; Zazulak et al. 2006; Vauhnik et al. 2008). Anatomical, neuromuscular, behavior patterns and hormonal differences between men and women make women more susceptible to ACL injuries (Griffin et al. 2000; Barber-Westin et al. 2009). Recently, many studies have examined the relationship between estrogen and the mechanical properties of the ACL (Liu et al. 1997; Yu et al. 1999; Shultz et al. 2004; Hansen et al. 2009) and the presence of 17-beta estradiol receptors in human ACL and muscle (Liu et al. 1997; Yu et al. 1999; Shultz et al. 2004; Hansen et al. 2009). Human tendons, muscles, and ligaments are composed of collagen fibers closely packed together. Due to the decrease of collagen formation and fibroblast proliferation with an increased estrogen serum concentration, the decreased collagen synthesis causes ligament relaxation, weak muscle strength and tendon elasticity all of which makes the ACL more prone to injuries in women compared to men (Liu et al. 1997; Yu et al. 1999; Park et al. 2009). In addition, restricted knee extension affects normal leg movement and this can lead to more non-contact ACL injuries (Kvist and Gillquist 2001). The quadriceps muscle is one of the knee extensor muscles which is crucial to stabilize and create range of motion at the knee (Wall et al. 2012).

When people who do not exercise often begin an unfamiliar exercise program, they easily feel delayed onset muscle soreness (DOMS) (Higbie et al. 1996; Calbet et al. 2001; Kauranen et al. 2001; George et al. 2007; Hubal et al. 2008). DOMS is defined as post exercise muscle discomfort that includes muscle pain, soreness, and stiffness (Cleak and Eston 1992; Lewis et al. 2012). Microscopic tearing of the muscle fiber leads to DOMS and eccentric muscle con-

Received August 13, 2013; revised and accepted September 20, 2013. Published online October 8, 2013; doi: 10.1620/tjem.231.111.
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traction is thought to cause the most muscle soreness after sever exercise (Lewis et al. 2012; Olsen et al. 2012; Vila-Cha et al. 2012). Gender differences in DOMS have been examined in humans and animals. Previous studies have demonstrated that women have more damage in their muscle after high-intensity exercise compared to men (Clarkson and Sayers 1999).

Women's ACL elasticity and muscle strength are influenced by their reproductive hormones and there are differences in DOMS between men and women (Barber-Westin et al. 2009; Park et al. 2009; Wall et al. 2012). Since ACL elasticity in greater in women than men, then might be more damage to the ACL during heavy exercise in women versus men. Thus, the purpose of this study was to examine ACL elasticity after exercise meant to produce DOMS in the lower body. As a measure of DOMS, visual analog pain scale and quadriceps strength were measured.

Methods

Participants

The subjects in this study were 140 healthy individuals between the ages of 20 and 40 years old, divided into 2 groups. The groups were males and females. Subjects were recruited from among the students of Loma Linda University. All subjects were physically inactive. Their body mass index (BMI) was less than 40. Subjects had no cardiovascular disease, hepatic disease, diabetes, lower limb neuropathies, or recent lower limb injuries. Subjects were not taking alpha or beta agonist/antagonists, any type of NSAIDS, Cox 2 inhibitors, Calcium channel blockers, Pregabalins (Lyrica), or pain reducers. Female subjects were with either a regular menstrual cycle or oral contraceptives. The demographics of the subjects are shown in Tables 1 and 2. All methods and procedures were approved by the Institutional Review Board of Loma Linda University and all subjects signed a statement of informed consent.

Measurements

Visual Analog Pain Scale: A 10 cm visual analog pain scale was used to measure subjective pain scales. It had a horizontal line across a piece of paper 10 cm long. Left end was marked "pain free" and the right was marked "very, very sore". The subject was asked to place only one vertical slash across the line where appropriate. The location of the slash was converted into a number, where 0 indicated pain free and 10 indicated very, very sore. A vernier caliper was used to interpret subjective pain scale.

Table 1. General characteristic of male group (n = 70).

	age (years)	height (cm)	weight (kg)	BMI
mean	26.14	175.56	76.81	24.91
sd	2.92	7.03	16.45	4.94

Table 2. General characteristic of female group (n = 70).

	age (years)	height (cm)	weight (kg)	BMI
mean	25.11	163.46	58.95	22.09
sd	2.42	6.64	8.16	3.08

Anterior Cruciate Ligament Elasticity: Knee elasticity of the ACL was measured by a kinematic knee device which is commercially produced and has been validated for over twenty years in both clinical and research areas. The device was the Medmetric KT 2000 (Medmetric Corporation, San Diego, CA). The subject lay supine with the angle of the knee at 25 degrees. A strain gauge bridge arranged as a load cell was used to measure the force necessary to generate an anterior/posterior glide of the proximal end of tibia on the femoral condyles thus generating a force curve of elasticity of the ACL. A foot positioning device and thigh strap was used to position the leg of the subject. Force was applied for the ACL at 15, 20 and 30 lbs. (66.6, 88.8, 133.2 Newton's respectively). As force was applied, the force and measured displacement were plotted on an x-y plotter to record the ligament elasticity. The device has been well validated and published (Araki et al. 2011; Shelbourne et al. 2011; Lawhorn et al. 2012).

Quadriceps Strength: Muscle strength was measured with a strain gauge transducer, which used four strain gauges placed on opposite sides of a steel bar. The bar was fixed to a chair base with a leather ankle strap that was placed just above the malleolus and measured force developed during extension by the quadriceps muscle with the knee bent at 90 degrees. When the bar was bent, the strain gauges, arranged as a Wheatstone bridge, were deformed and an electrical output was provided to a Bio Pac (Bio Pac Systems, Goleta, CA) system DAC100 c bioelectric amplifier. The signal was amplified 5,000 times and then digitized through a Bio Pac MP 150 analog to digital converter at a resolution of 24 bits and a frequency of 1,000 samples per second, and stored digitally for later analysis. Data analysis and storage were accomplished using the Acknowledge 4.1 software from Bio Pac Inc. (Bio Pac Systems, Goleta, CA). Muscle strength was determined on two occasions as a maximum isometric contraction, with each contraction lasting for three seconds in duration with at least one minute of rest separating the contractions. The average of the two strength measurements was used in the data analysis as the subject's maximum strength.

Intervention

All subjects participated in the same exercise to produce DOMS in the lower body. To provoke DOMS, the subjects were asked to complete squats as fast as they could for 5 minutes. They repeated the 5 minutes-squat after 3 minutes of rest two more times (total 3 rounds). The depth of each squat was at 90° at the hip or below.

Procedures

On each day, upon arriving to the examination area, subjects relaxed in a thermally neutral to stabilize their body temperature. ACL elasticity and quadriceps strength were collected on a Monday, exercise was accomplished on Tuesday and then measurements were taken again on Wednesday, Thursday and Friday.

Data Analysis

One-way repeated measures analysis of variance (ANOVA) was used to examine mean subjective pain scale, ACL elasticity, and quadriceps strength at four different phases. Bonferroni pairwise comparisons test for multiple comparisons was used to compare means of variables between any two different testing phases. A mixed factorial ANOVA was conducted to compare time phases with respect to the effect of high-induced exercise on subjective pain scale, ACL elasticity, and quadriceps strength between men and women. The level of significance was set at $p < 0.05$.

Results

Measure of DOMS

Visual Analog Pain Scale: The results of the pain scale are shown in Fig. 1. Both groups showed an increase in pain after exercise. Women showed a significantly higher pain compared to men after exercise ($p < 0.05$). The pain peaked by the 1st day post exercise in women and the 2nd day post exercise in men. However, there was no significant difference in the subject pain between 2nd day and 3rd day post exercise in both groups ($p > 0.05$).

Quadriceps Strength Measurement: As shown in Fig. 2, women showed significantly less strength compared to men ($p < 0.001$). There was a reduction in strength the day after exercise in both groups. This significant reduction was 12.5% less than the resting (pre exercise) strength in men versus 21% in women ($p < 0.001$). For the male group, there was no significant reduction between resting and the 2nd day post exercise ($p = 1.00$). In contrast, women showed a significant reduction in quadriceps strength between resting and the 2nd day post exercise ($p < 0.001$).

Anterior Cruciate Ligament Elasticity: Anterior knee ligament elasticity was measured by anterior tibial displacement (ATD). A lower ATD value means less elasticity of the ACL. The results of the ATD measured at four different times between men and women are shown in Fig. 3, ATD was significantly lower in men compared to women ($P < 0.05$). There was a significant reduction in ATD between rest (pre exercise) and the 1st day post exercise in men, while a significant reduction in ATD was found between rest and the 1st day post exercise as well as rest and the 2nd day post exercise in women. There was no difference between the 1st day and the 2nd day post exercise in men ($p > 0.05$). In contrast, there was significant ATD reduction in the 2nd post exercise from 1st day post exercise in women ($p = 0.02$). In addition, ATD decreased 7.1% from resting to the lowest day (1st day post exercise) in men versus 8.3% decreased from resting to the lowest day (2nd day post exercise) in women.

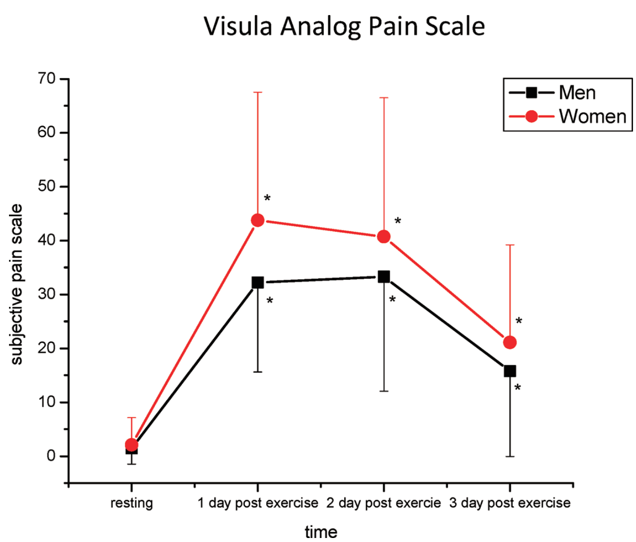

Fig. 1. The measured visual analog pain scale of the subjects before exercise (rest) and 1, 2 and 3 days post exercise. Each point is the mean of 70 subjects +/− the standard deviation.
*Significant changes from resting.

Discussion

Women have a higher risk for ACL injuries compared to men who participate in the same sports activities. ACL elasticity and muscle and tendon flexibility are major risk factors for knee injuries during sports (Arendt et al. 1999;

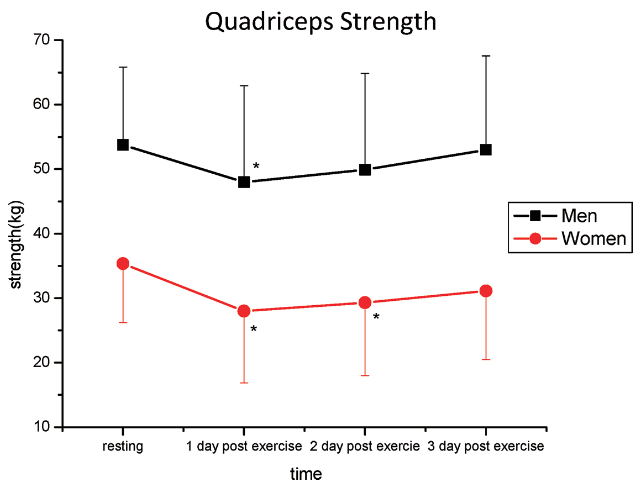

Fig. 2. The quadriceps strength of the subjects before exercise (rest) and 1, 2 and 3 days post exercise. Each point is the mean of 70 subjects +/− the standard deviation.
*Significant changes from resting.

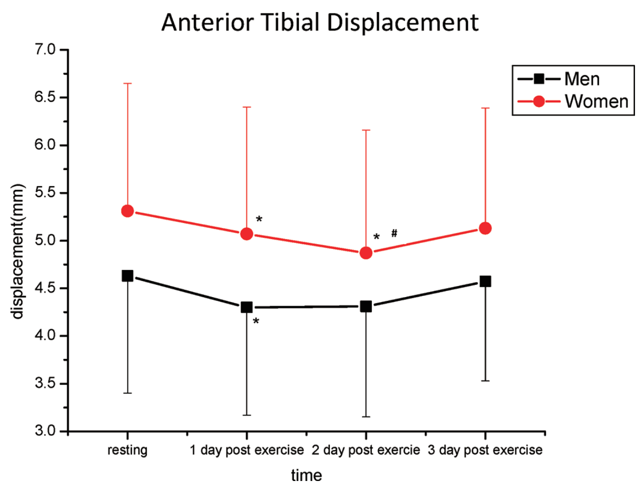

Fig. 3. The anterior tibial displacement (ATD) of the subjects before exercise (rest) and 1, 2 and 3 days post exercise. Each point is the mean of 70 subjects +/− the standard deviation.
*Significant changes from resting.
#Significant changes from 1 day post exercise.

Griffin et al. 2000; Zazulak et al. 2006; Vauhnik et al. 2008). Higher level of estrogen makes women more susceptible to injuries (Chaudhari et al. 2007). The presence of estrogen receptors in connective tissue allows estrogen to change the mechanical properties of muscles and ligaments (Liu et al. 1997; Heitz et al. 1999). DOMS is a common problem in people when begin unaccustomed levels of exercise (Calbet et al. 2001; Mayer et al. 2006). Gender differences in DOMS have been examined in humans and animals. Previous studies have examined the differences in muscle damage after high-intensity exercise between men and women and found that women had more damage in muscle then men after exercise (Clarkson and Sayers 1999). However, no one looked at ACL elasticity after high levels of exercise. When comparing ACL elasticity between the two groups, women have a greater ACL elasticity compared to men before and after exercise and a greater change of ACL elasticity was found in women. We further found that women had more damage in ACL elasticity as a result of DOMS. This corresponded to the pain scale and quadriceps strength data measured at rest and 1st, 2nd and 3rd day post exercise. There was both muscle damage and ACL damage in this study. The ACL significantly lost elasticity, probably due to swelling post exercise in both groups (Roach et al. 2004). However, the pattern of laxness with displacement was different between men and women. At the 2nd day post exercise, there was no change in ATD from 1 day post exercise in men but a significant change in ATD was found in women. In addition, quadriceps strength was much less in women compared to men in all phases. Women had almost 1.7 times higher reduction in muscle strength after squats compared men. At the 3rd day post exercise, men's quadriceps strength was almost recovered to the resting level but not in women. These results imply that women seemed to have more damage in the ACL and quadriceps strength and recovered slower then men after high-induced exercise. It is reasonable to assume this is related to muscle or soft tissue damage in the quadriceps or its tendons. ACL laxity and muscle strength are influenced by their reproductive hormones have been indicated (Barber-Westin et al. 2009; Park et al. 2009; Wall et al. 2012). The reason might be the hormones, and they play an important role in regulating muscle mass, may contribute to slower recovery times in women. The subjective pain scale data agreed with these results in that women had more damage in muscle and ligaments, and recovered slower than men. Thus, we suggest that women may need more time for musculoskeletal recovery than men.

We did not recognize women who are taking oral contraceptive pills (OCP). Since female reproductive hormones could be a key factor that have an impact on musculoskeletal structure, future study should divide women into two groups: women with a normal menstrual cycle and women with ingesting OCP. Also, in previous studies, researchers found the greatest ACL elasticity and less knee stiffness during ovulation where estrogen concentration in the blood was highest compared to menstruation where estrogen concentration was lowest in young healthy women with a regular menstrual cycle (Zazulak et al. 2006; Vauhnik et al. 2008; Park et al. 2009). This was believed to be caused by both estrogen and temperature fluctuation during the menstrual cycle. It will be interesting to see if there are any differences in amount of damage in muscle and ligament after high-induced exercise between ovulation and menstruation in young health women with regular menstrual cycle in future studies.

Conclusion

This study examined ACL elasticity after exercise meant to produce DOMS. As a measure of DOMS, visual analog pain scale and quadriceps strength was measured. In response to the DOMS, women showed greater reduction of ACL elasticity and muscle strength compared to men. These results imply that women have more damage in musculoskeletal structure and recover slower compared to men after high-induced exercise. Thus, the investigation suggests that women should have more time for musculoskeletal recovery.

Acknowledgements

This study was supported by a contract from the pain division at Pfizer pharmaceutical.

Conflict of Interest

The authors declare no conflict of interest.

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