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Measurement of Tissue Hardness for Evaluating Flexibility of the Knee Extensor Mechanism

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The knee extensor mechanism (hereafter referred to as the KEM) is one of the most common sites for overuse disorder that occurs in football players. The KEM overuse disorders, such as patellar tendinitis and Osgood-Schlatter's disease, are assumed to be related to decreased flexibility in the KEM. Although it is important to check the KEM flexibility for the prevention of overuse disorders, a simple and quantitative measurement has yet to be established. The present study is an attempt to use a tissue hardness meter to evaluate the KEM flexibility. Under the assumption that elongation of the KEM due to knee flexion would increase the KEM tissue hardness, the relation between length and tissue hardness of the KEM in 40 knees of 20 healthy adults was investigated. Subjects were measured for their KEM length and their tissue hardness at the midpoint of the KEM using a tissue hardness meter in five knee positions: knee extended, knee flexed at 30, 60, 90 degrees, and knee fully flexed. There was significant positive correlation between length and tissue hardness of the KEM. In conclusion, the KEM flexibility can be evaluated by the measurement of tissue hardness.

Keywords: sports injury, knee extensor mechanism, tissue hardness, overuse disorder, prevention

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1. Introduction

KEM is one of the most common sites for overuse disorder that occurs in athletes involved in excessive jumping or kicking, such as football players. Overuse disorders of the KEM include patellar tendinitis (jumper's knee), patellofemoral stress syndrome and traction apophysitis in adolescents, such as Osgood-Schlatter's disease (Ekstrand, 1994; Krivickas, 1997). These disorders are said to be related to decreased flexibility in the KEM (Micheli, 1987; Krivickas, 1997; Hawkins, 2001; Witvrouw, 2001). Although it is important to check the KEM flexibility for the prevention of overuse knee disorders, a simple and quantitative measurement has yet to be established (Gilbert & McHugh, 1997). We hypothesized that the KEM flexibility could be evaluated using a tissue hardness meter. In this study, under the assumption that elongation of the KEM due to knee flexion would increase the KEM tissue hardness, the relation between elongation and tissue hardness of the KEM in healthy adults was investigated. Also, other factors thought to influence the measurement of tissue hardness were evaluated.

2. Methods

All procedures were approved by the Research Ethical Committee in Graduate School of Comprehensive Human Sciences, University of Tsukuba and conformed to the Helsinki Declaration.

2.1. Subject characteristics

We studied 40 legs belonging to 10 healthy male [mean (SD) age 23.0 (0.9) years, height 170.4(6.1) cm, body mass 68.0(7.5) kg] and 10 healthy female [age 22.9 (1.3) years, height 162.5(6.8) cm, body mass 55.5 (7.2) kg] graduate school student volunteers with no history of the KEM injury.

2.2. Instrument

The tissue hardness meter, Muscle Meter PEK-1 (Imoto Machinery Co. Ltd., Japan; **Figure 1**), used in this investigation is an electronic device

Figure 1 Tissue hardness meter (Muscle Meter PEK-1).

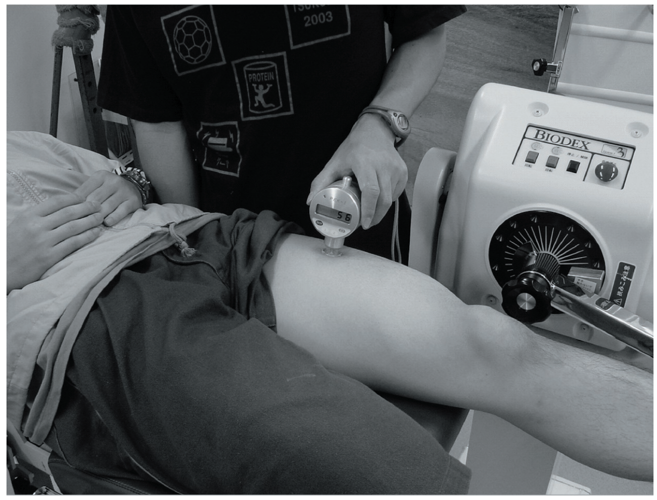

Figure 2 Measurement of the KEM tissue hardness at knee extended position using a tissue hardness meter.

that quantifies the amount of tissue displacement applied by a probe as it is pressed onto the skin overlying the muscle tissue. The probe, which consists of a main pointer and a subcylinder with different spring constants in the body of the machine, is pressed against the underlying tissue, and the distance between the main pointer and subcylinder is used as the stiffness index, measured in arbitrary units ranging from 0 to 99. The performance, reproducibility and accuracy, of this instrument have been highly estimated and it is available commercially in Japan.

2.3. Measurement

Subjects were secured in the supine position on the Biodex Dynamometer Accessory Chair to measure their KEM length (length from the anterior inferior iliac spine to tibial tuberosity: cm) and their tissue hardness at the midpoint of KEM (anterior thigh) using the tissue hardness meter in five knee positions: knee extended, knee flexed at 30, 60, 90 degrees, and knee fully flexed (**Figure 2**). The mean (SD) angle of a fully flexed knee measured on the Biodex Dynamometer Accessory Chair was 107.9 (5.9) degrees. During the measurement of tissue hardness, subjects were told to relax their thighs. Tissue hardness was measured as the mean value of three trials. Body mass index (BMI), thigh circumference, skinfold thickness and knee extensor peak torque were measured at supine, knee extended position. Thigh circumferences (cm) were measured at height of the midpoint of KEM length. Skinfold caliper was used to measure anterior thigh skinfold thickness (mm) at the midpoint of KEM length. Knee extensor peak torque/body weight (%) at 60 degrees was assessed by the Biodex System Isokinetic Dynamometer (Biodex Medical, Shirley, N. Y., USA).

2.4. Statistical Procedures

All values were expressed as mean (SD). Multivariate regression models were used to test the relationship between the KEM tissue hardness, BMI, thigh circumference, skinfold thickness and knee extensor peak torque. For the analysis of changes in the KEM length and the KEM tissue hardness, a one-way analysis of variance was used to determine the difference among the five groups with different knee positions. To identify specific group differences, post hoc tests were performed by using the Tukey HSD multiple-comparison procedure because the variances were homogeneous. To test the relationship between length and tissue hardness of the KEM, we used Pearson correlation coefficients. Significance was accepted at the 0.05 level.

3. Results

3.1. Tissue hardness and gender difference

Mean value (SD) of the KEM tissue hardness at knee extended position was 51.4 (3.2) [N=40; right 52.4 (2.6), left 50.4 (3.4)]. Also, gender differences of tissue hardness were male; 51.2 (2.8) [N=20; right

Table 1 Mean (SD) values of the KEM tissue hardness in knee extended position (males: n=10, females: n=10).

	Males	Females
Right	52.1 (2.7)	52.6 (2.7)
Left	50.4 (2.8)	50.4 (4.1)
Total	51.2 (2.8)	51.5 (3.5)

Table 3 P values of standard partial regression coefficients for possible factors to influence the measurement of the KEM tissue hardness at knee extended position.

Factor	P value
BMI	0.59
Thigh circumference	0.32
Skinfold thickness	0.45
Knee extensor peak torque	0.74

Table 2 Mean (SD) values of BMI, thigh circumference (cm), skinfold thickness (mm) and knee extensor peak torque (%) (males: n=10, females: n=10).

	Males	Females	Total (n=20)
BMI	23.4 (1.7)*	20.9(1.8)	22.2(2.1)
Thigh circumference			
Right	52.4 (1.9)*	49.0 (3.3)	50.7 (3.2)
Left	52.1 (2.0)*	48.4 (2.9)	50.3 (3.1)
Skinfold thickness			
Right	16.1 (7.5)	18.7 (6.4)	17.4 (6.9)
Left	15.7 (9.7)	17.7 (7.6)	16.7 (8.5)
Knee extensor peak torque			
Right	303.5 (48.2)	277.4 (31.6)	290.5 (41.9)
Left	312.4 (43.9)*	265.1 (38.0)	288.8 (46.8)

* Significantly greater than females ($P<0.05$)

52.1 (2.7), left 50.4 (2.8)], female; 51.5 (3.5) [N=20; right 52.6 (2.7), left 50.4 (4.1)]. No significant difference in the KEM tissue hardness between the male and female groups was observed (**Table 1**).

3.2. Factors influenced tissue hardness measurement

Measurement of factors assumed to influence tissue hardness measurement such as BMI, thigh circumference (cm), skinfold thickness (mm) and knee extensor peak torque per weight (%) showed gender differences of BMI, bilateral thigh circumference and left knee extensor peak torque per weight (**Table 2**). Tissue hardness in knee extended position did not correlate with BMI, thigh circumference, skinfold thickness or extensor peak torque per weight (**Table 3**).

3.3. Relation between the KEM length and tissue hardness

As the knee flexed, the KEM length significantly increased and so did the KEM tissue hardness (**Table 4**). In addition, there was significant correlation between length and tissue hardness of the KEM (correlation coefficient 0.35, $p<0.01$). Furthermore, there was significant correlation between relative length (compared with an extended knee position) and relative tissue hardness of the KEM (compared with an extended knee position; correlation coefficient 0.70, $p<0.01$; **Figure 3**).

4. Discussion

Although sports injury risk is multifactorial, flexibility of the muscle-tendon unit is assumed to be one of the most important intrinsic risk factors. Preparticipation warm-up, including stretching exercise, is common to most sports endeavors

Table 4 The KEM length and the KEM tissue hardness in five knee positions (n=40).

Knee angle	0	30	60	90	fully flexed
KEM length (cm)	47.9 (3.2)	50.6 (3.5)*	53.2 (3.4) *	55.2 (3.5) *	56.4 (3.8) *
KEM tissue hardness	51.4 (3.2)	52.4 (3.1)	55.1 (3.3) *	57.6 (3.4) *	59.0 (3.6) *

* Significantly different from the knee angle 0 degree (knee extended) position (p<0.05).

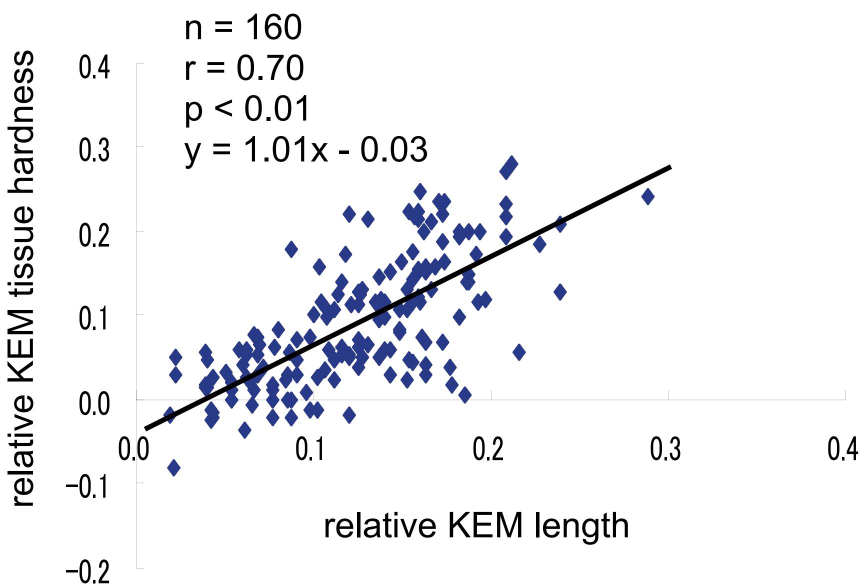

Figure 3 Correlation between relative length and relative tissue hardness of the KEM.

(Gilbert & McHugh, 1997). The KEM is one of the most common sites for overuse disorder, such as patellar tendinitis and patellofemoral stress syndrome, that occurs in athletes involved in excessive jumping or kicking, such as football players (Ekstrand, 1994; Krivickas, 1997). Also, there are several overuse injuries unique to adolescent athletes during the growth spurt period, which is called the traction apophysitises (Micheli, 1987). These injuries are associated with the presence of growth cartilage in adolescents and, additionally, the growth process itself. The main etiology of these disorders is assumed to be related to the rapid growth of skeletal bone, which causes decrease in flexibility of muscle-tendon units (muscle tightness) attached to the apophyseal insertions. The traction apophysitises are assumed result from repetitive microtrauma caused by repetitive sports training and competition under this decrease in flexibility of muscle-tendon units (Micheli, 1987; Hawkins & Metheny, 2001; Hirano, et al., 2001). One of the most common sites for traction apophysitises are the insertion of the patella tendon on the tibial tubercle, resulting in Osgood- Schlatter's disease, due to an avulsion of the secondary ossification center (Ogden & Southwick, 1976; Hirano, et al., 2002). Several cohort studies have examined the relationship between flexibility and sports injury (Ekstrand, et al., 1983; van Mechelen, et al., 1993; Witvrouw, et al., 2001).But there is no strong evidence proving that flexibility is associated with rates of sports injury. Debates about flexibility result from lack of consensual definitions and measurements (Gilbert & McHugh, 1997). Measurements of the flexibility, both static and dynamic, are performed to assess the ability of muscle-tendon units to lengthen. In preparticipation check-ups of sports activities, static flexibility is often evaluated by measuring the range of motion (ROM) available to a joint or series of joints. The Ely test is a useful method to detect the severe tightness of the KEM (Micheli, 1987; Krivickas, 1997), but it is difficult to predict occurrence of disorders. In addition, it is sometimes difficult to distinguish between a reduced ROM caused by a short muscle-tendon unit versus a tight joint capsule or arthritic joint (Gilbert & McHugh, 1997). The important measurement in dynamic flexibility is tissue stiffness, which is defined as the instantaneous dependence of tension on length. Stiffness increases with the same course as tension (Woledge, 1985). Dynamic flexibility can be measured actively or passively. Passive dynamic flexibility is documented by qualifying joint angle as passive torque generation, but it also seems be affected by joint structures (Gilbert & McHugh, 1997; Lamontagne, et al., 1997; Koga, et al., 1999). Active flexibility is measured by the damped oscillation technique, assessing the ability to transiently deform contracted muscle, which seems difficult to measure on sports fields (Gilbert & McHugh, 1997).

It has been reported that muscle becomes harder in a pathological condition such as spasm, cramps, myopathy, and edema. Several non-invasive methods of measuring human muscle hardness have been reported, such as quick-release method, an impedance method, and a pressure method. The pressure method is used to measure the tissue hardness of a stiff tissue which may produce greater resistance when pressure is applied to the fiber transcutaneously, just like pressing a tight string (Murayama, et al., 2000). Recently, several devices have been developed to quantify tissue hardness (Horikawa, et al., 1993; Komiya, et al., 1996; Murayama, et al., 2000; Leonard, et al., 2003; Arokoski, et al., 2005). Using the pressure method tissue hardness meter, tissue hardness changes according to the joint angle and hardness of elbow flexor tissues was larger at the elbow-extended position than at the elbow-flexed position (Komiya, et al., 1996; Murayama, et al., 2000). As elbow flexor tissues are elongated when elbow is extended, we hypothesized that the KEM flexibility (tissue stiffness) could be evaluated using the pressure method tissue hardness meter. A tissue hardness meter, Muscle Meter PEK-1 (Imoto Machinery Co. Ltd., Japan) used in this investigation, is characterized as non-invasive, quantitative, portable (340g in weight), easy to measure, and can be used on sports fields. Furthermore, in evaluating muscle-tendon unit flexibility, the measurement of tissue hardness, especially in joint extended position, is less affected by joint structure than the measurement of static flexibility (ROM) or passive dynamic flexibility. In this study, as there was a significant positive correlation between elongation and tissue hardness of the KEM, tissue hardness would be an indicator evaluating the KEM flexibility. As the mechanical property of muscle-tendon unit shows viscoelastic behavior, the relationship between elongation and tissue hardness may not be linear (Woledge, 1985; Alter, 1988; Lamontagne, et al., 1997). Further study, using an animal model, is needed to clarify the relationship between tissue hardness, tensile stress, and tissue stiffness (elongation) of the muscle-tendon unit.

In the tissue hardness measurement, there are several factors which may influence the data obtained, such as age, gender, the soft tissues surrounding the muscles (skin, subcutaneous and muscle), muscle situations (tone, fatigue, blood circulation, edema, temperature), and measurement points (Alter, 1988; Horikawa, 1993; Murayama, 2000; Arokoski, 2005). In this study, the measurement of the KEM tissue hardness was not influenced by gender difference, BMI, thigh circumference, skinfold thickness and knee extensor peak torque. As subjects were told to relax their thighs during the measurement, influence of muscle tone may be negligible. But the measurement with EMG would add credence to exclude the influence of muscle tone. Although other factors, such as fatigue, blood circulation, edema, temperature of muscle were not taken into consideration, influence of these factors might be less important. As measurement point of skin was midpoint of the KEM in all knee positions, the measuring point of underlying muscle might be different when the knee angle had been changed. Further investigation in the animal model may clarify which factors are influencing the measurement.

We conclude that KEM flexibility can be evaluated using a tissue hardness meter, which indicates that the value of tissue hardness can be a predictor for the occurrence of the KEM overuse disorders. Further study to investigate the relation between the KEM tissue hardness, the KEM flexibility, and the incidence of the KEM overuse disorders in athletes will not only clarify the etiology, but also contribute to the prevention of these disorders.

5. Conclusion

- The KEM flexibility can be evaluated using a tissue hardness meter.
- The measurement of the KEM tissue hardness was not influenced by gender difference, body mass index, thigh circumference, skinfold

thickness, and knee extensor peak torque.
- Further investigation is needed to clarify the relation between the KEM tissue hardness, the KEM flexibility, and the incidence of KEM overuse disorders in athletes for the prevention of these disorders.

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