Paper : Sports Medicine and Rehabilitation

Changes in Muscle Hardness and Electromyographic Response for Quadriceps Muscle during Repetitive Maximal Isokinetic Knee Extension Exercise

Gang Sun[*], Shumpei Miyakawa[*], Hiroaki Kinoshita[**], Hitoshi Shiraki[*], Naoki Mukai[*], Masahiro Takemura[*] and Hajime Kato[*]

[*]Doctoral Program of Sports Medicine, Graduate School of Comprehensive Human Sciences, University of Tsukuba, Japan
Laboratory of Advanced Research D 1-1-1 Tennodai, Tsukuba, Ibalaki 305-8577 Japan
sungang@med.taiiku.tsukuba.ac.jp
[**]Faculty of Heath Science, Tsukuba University of Technology, Japan
4-3-15,Tuskuba, Ibalaki 305-8520, Japan
[Received September 24, 2008 ; Accepted February 12, 2009]

There are many cases of Osgood-Schlatter disease (OSD) in soccer players. It's disturbs their activity in playing soccer. It is necessary to protect them from OSD. It's known that quadriceps muscle tightness and hardness are increasing before OSD would occur. Because muscle fatigue makes it's muscle harden. Measuring muscle hardness, we can detect the symptom of OSD. The purpose of this study was to investigate changes in muscle hardness and mean frequency (MNF) of surface electromyography (EMG) during 100 repetitions of maximal isokinetic knee extension. Nineteen healthy subjects performed 100 isokinetic knee extensions at 90°/s using a calibrated isokinetic device. Peak Torque (PT) was determined for each extension (90°-0°), and MNF were recorded from the vastus lateralis (VL), rectus femoris (RF) and vastus medialis (VM) of the right thigh at the same time. Quadriceps muscle hardness of the anterior thigh was measured with knee extended both before- and after-exercise. MNF of each muscle and PT decreased with increasing repetitions. MNF showed higher correlation coefficients with PT for RF than for VL or VM (r=0.59, p<0.01). Muscle hardness for each muscle was increased after exercise (VM, 49.6±3.9; RF, 54.9± 3.6; VL, 62.6±5.4) compared with before exercise (VM, 47.1±4; RF, 47.1±4.2; VL, 56.7± 5.4) (p<0.01 each). Reductions in MNF and PT showed the characteristics of muscle fatigue during repetitive maximal isokinetic knee extension exercise, and a correlation between these values was recognized in RF. Muscle hardness showed consistent increases after exercise in all muscles and can thus be used as a marker of muscle fatigue in the RF.

Keywords: muscle hardness, mean frequency (MNF), muscle fatigue, Osgood-Schlatter Disease (OSD)

[Football Science Vol.6, 17-23, 2009]

1. Introduction

The knee extensor mechanism (KEM) is one of the most common sites for overuse disorder that occurs in athletes involved in excessive jumping or kicking, such as football player. Overuse disorders of the KEM include patellar tendinitis (jumper's knee), patellarfemoral stress syndrome and traction apophysitis such as Osgood-Schlatter's disease (Ekstrand, 1994; Krivickas, 1997). It is important to check the muscle fatigue by the overuse for the prevention of the KEM disorder, a simple and quantitative measurement yet to be established (Gilbeert & McHugh, 1997). Kinoshita, et al., (2006) cleared that the KEM flexibility could be evaluated by measurement of tissue hardness. We hypothesized that the KEM fatigue could be evaluated using a tissue hardness meter.

Measuring muscle fatigue, the fast Fourier transform (FFT) technique is widely used to analyze mean frequency (MNF) of surface electromyography (EMG) to fatigue (Gerdle & Elert, 1994; Lindström, et al., 1997; Gerdle, Larsson, & Karlsson, 2000; Crenshaw et al., 2000; Larsson et al., 2003; Babault et al., 2005). Larsson, et al., (2003) reported a good reliability to test-retest relationship of MNF and peak

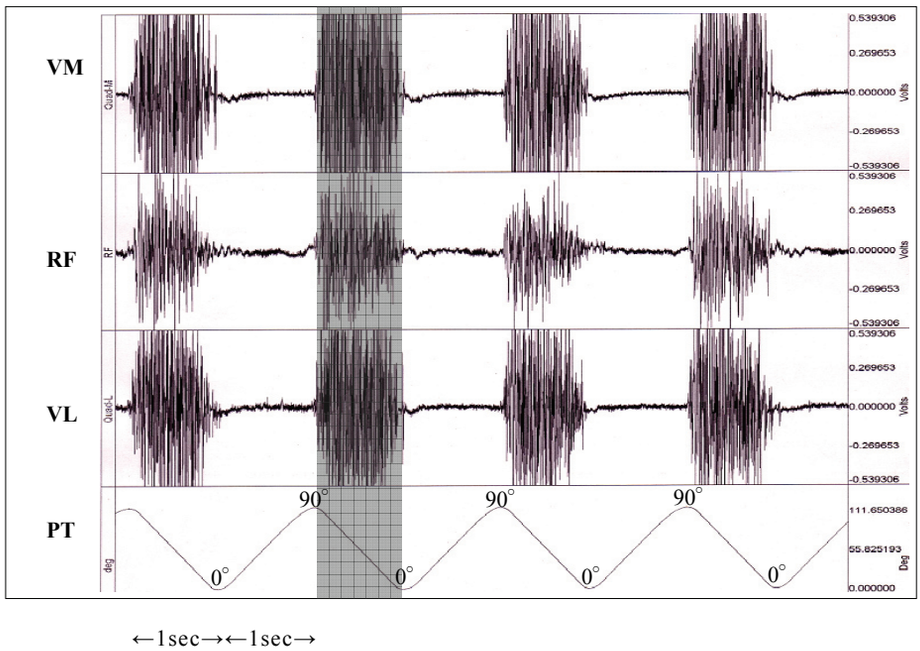


Figure 1 EMG of each muscle and peak torque (PT) on extension exercise.
MNF was calculated every 100 ms using the FFT method (black screen band at **Figure 1**).

torque (PT) during 100 isokinetic knee extensions at 90°/s. MNF can become an index of the muscle fatigue in isokinetic contractions in constant quantity of load exercise (Gerdle & Elert, 1994). To the best of our knowledge, no reports have described relationships between muscle hardness and muscle fatigue (as MNF) of the quadriceps muscle during repetitive maximal isokinetic knee extension exercise

The aim of the present study was to investigate changes in muscle hardness and the MNF of the quadriceps muscle during repetitive maximal isokinetic knee extension exercises, to examine the possibility of using muscle hardness as an index of muscle fatigue.

2. Methods

2.1. Subjects

Participants in this investigation were 19 men (mean age, 28.5±2.3 years; mean height, 173±4.4 cm; mean body mass, 67.4±8.5 kg). Each subject provided written informed consent before participation and signed a consent form approved by the Human Research Ethics Committee of the University of Tsukuba.

2.2. Testing procedures

A calibrated Biodex System 3 isokinetic device (Biodex Medical Systems, New York) was used to measure PT and knee-joint position throughout 100 repetitions of maximal isokinetic knee extension. During testing, the subject was seated on the Biodex System 3 with 90° hip flexion, and restraining straps were placed across the waist and chest in addition to a rigid sternal stabilizer. The dynamometer was motor driven at a constant velocity of 90°/s. Each subject performed a series of 100 isokinetic contractions using the knee extensors of the right leg from 90° of flexion to 0° (full extension). As the arm of the dynamometer moved up from 90° to 0°, subjects were encouraged to perform maximally for each contraction throughout the full range of motion (ROM) (i.e., active phase of the contraction cycle). Subjects relaxed as the dynamometer arm moved back to 90° (passive phase of the contraction cycle). Each contraction and relaxation period lasted 1 s and the total length of the contraction cycle was thus 2 s. All subjects were able to complete the full 100 contractions.

2.3. EMG procedures

Electrodes were connected to a WEB-500 4-channel frequency-modulation transmitter (Nihon

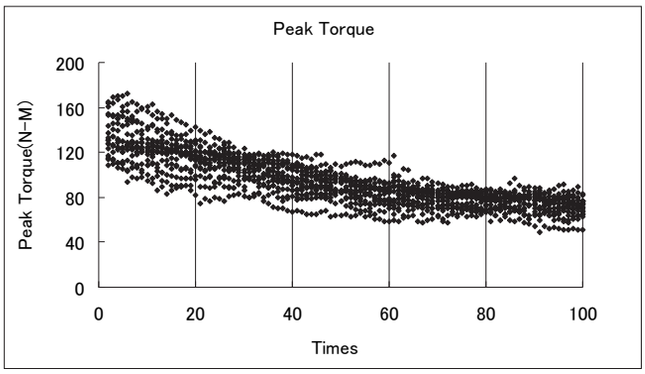


Figure 2 Changes in PT of quadriceps muscles during 100 isokinetic knee extensions in each subject.
PT decreased with increasing number of extensions.

Kohden, Tokyo, Japan). Acetabuliform Ag/AgCL bipolar surface electrodes (5-mm diameter recording surface, NT-511G; Nihon Kohden) were placed on the vastus lateralis (VL), rectus femoris (RF) and vastus medialis (VM) along the main direction of muscle fibers with an inter-electrode center-to-center distance of 20 mm [as suggested by the European Recommendations for surface EMG (Hermens et al., 1999)]. Accuracy of the differential amplifier was measured using a common mode rejection ratio (CMRR) of 110 dB at 60 Hz, a gain of 1000Hz, and noise <0.2 μV (EMG 100; BIOPAC System, Santa Barbara, USA). Amplitude of the raw EMG signal from the receiver was interfaced with a computer using 16 channels through a 16-bit A/D card (UIM100; BIOPAC System). During the test, the System 3 device and Biopac system were connected to accurately determine ROM simultaneous with EMG. All data were stored on a personal computer and the FFT function in Acknowledge 3.7.5 software (BIOPAC System) was used for data processing and analysis. EMG signals were band-pass filtered at 10-500 Hz. EMG data were recorded individually from each muscle and PT values were extracted for each test from torque curves once, and so the Biodex and Biopac were synchronized (**Figure 1**). To calculate MNF of the EMG, every duration of 1 s (full extension: 90°~0°) was divided into 100-ms sections by FFT.

2.4. Muscle hardness procedures

Muscle hardness was measured at VM, RF, VL both before and after-exercise in the bed. Subjects were facing up position, and values of quadriceps muscle hardness (VM, RF, VL) were examined for each of the knee-extended positions. The measurement point was the pasting position of each electrode. A PEK-1 biotissue spring-meter (Imoto, Tokyo, Japan) was used for measurements. Subjects were required to relax during measurement. Each measurement was made 3 times and means were determined (Kinoshita, et al., 2006).

2.5. Statistical analysis

Analysis were made using StatView for Windows software (StatView 5.0, Japanese Edition; HULINKS, Tokyo). All values are shown as mean ± standard deviation. PT, MNF of EMG was measured every 20 (1-20, 21-40, 41-60, 61-80, & 81-100) muscular contractions by one-way analysis of variance (ANOVA). Multiple comparisons were performed using Scheffe's method when significant differences were identified. Linear regression analysis was used to analyze the relationship between PT on the one hand and MNF on the other hand. Muscle hardness before- and after-exercise was compared by paired t-test. Values of $P \leq 0.05$ were considered statistically significant.

3. Results

3.1. Changes in PT during 100 contractions

Figure 2 showed changes in PT of the quadriceps muscle during 100 isokinetic knee extensions. PT gradually decreased from the start of exercise to end.

3.2. Distribution of PT every 20 contractions

The distribution of PT every 20 contractions is shown in **Figure 3**. PT displayed the differences between all groups ($p<0.01$ each). PT was found to have decreased markedly during the initial 40-60 contractions, followed by a phase with little or no change.

3.3. Changes in MNF during 100 contractions

Figure 4 showed changes in MNF of the quadriceps muscle during 100 isokinetic knee extensions. RF gradually decreased from the start of exercise to end, but little tendency to decrease was found in VL, and, MNF of the VM did not display

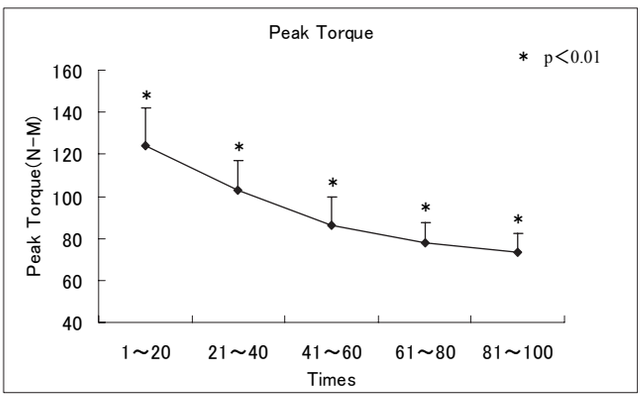


Figure 3 PT every 20 extensions among 100 isokinetic knee extensions.
PT tended to decrease, with significant decreases in each case (p<0.01).

decreases anymore.

3.4. Distribution of MNF every 20 contractions

The distribution of MNF every 20 contractions is shown in **Figure 5**. In the VM, significant differences were only seen between 1-20 and both 61-80 and 81-100 contractions (p<0.01 each). RF displayed the differences between all groups (p<0.01 each). Significant differences were not recognized only during 41-60 and 61-80 contractions compared to another groups in the VL (p<0.01). MNF was found to have decreased markedly during the initial 40-60 contractions, followed by a phase with little or no change.

3.5. Correlation of MNF and PT

Correlations between MNF and PT in each muscle are shown in **Figure 6**. In the RF, changes in MNF closely resembled those in PT, and a significant relationship was apparent (r=0.59, p<0.01). Not such relationships were noted for the VL or VM.

3.6. Changes in muscle hardness before and after-exercise

Muscle hardness before and after-exercise are shown in **Table 1**, with significant increases recognized in all muscles (p<0.01). Muscle hardness increased by about 5% in VM, compared to ≥10% in RF and VL.

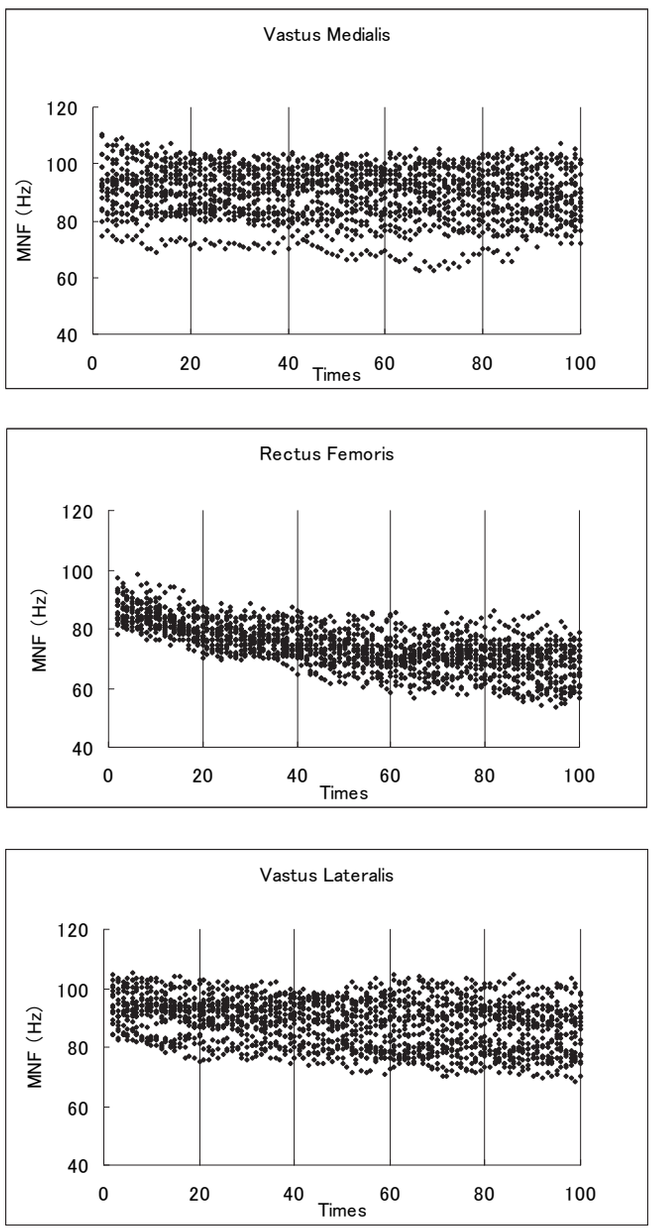
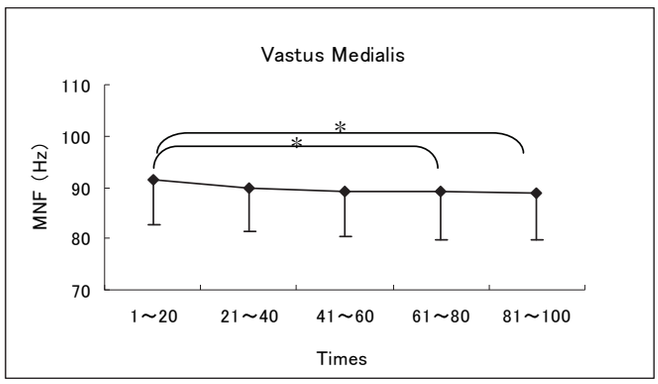


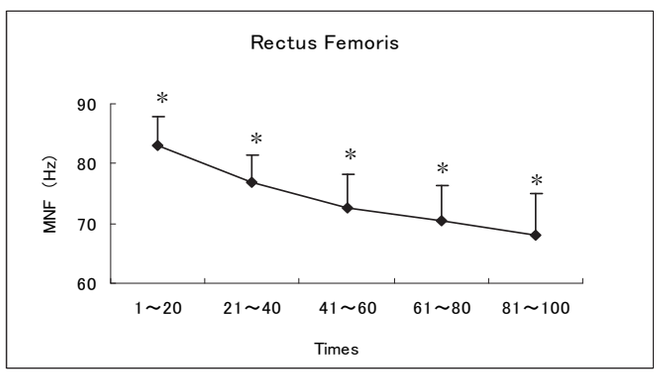
Figure 4 Changes in MNF of quadriceps muscles during 100 isokinetic knee extensions in each subject.
MNF decreased with increasing number of extensions.

4. Discussion

4.1. PT and MNF

Changes in MNF activity are frequently used as physiological indicators of muscle fatigue (Gerdle & Elert, 1994; Lindström, et al., 1997; Gerdle, Larsson, & Karlsson, 2000; Crenshaw, et al., 2000; Larsson, et al., 2003; Babault, et al., 2005). FFT was used by MNF analysis of Larsson (Larsson, et al., 2003) in this study. Namely, MNF synchronized with knee extension movement (90-0 degrees) that Biodex depends on, so for each section (knee





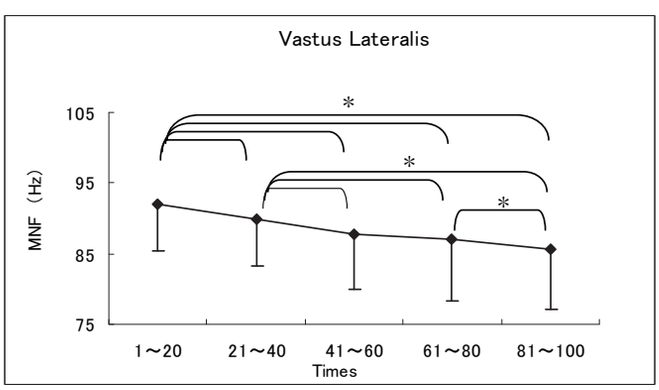
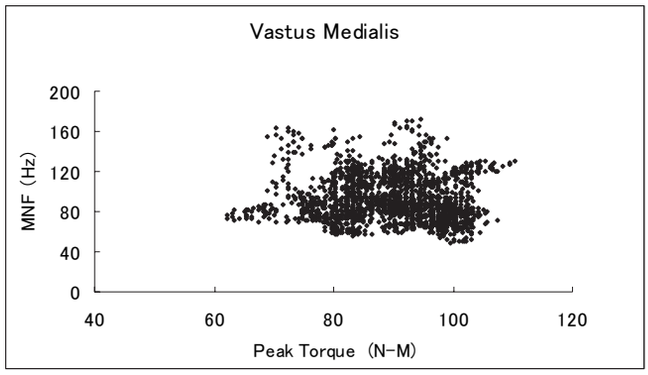
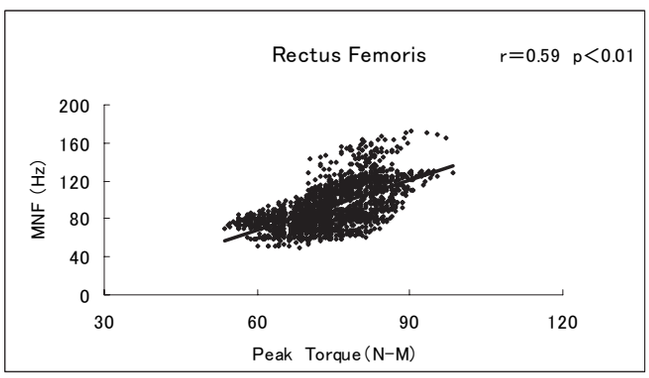


Figure 5 MNF every 20 extensions among 100 isokinetic knee extensions.
MNF tended to decrease, with significant decreases in MNF of rectus femoris muscle in each case (p<0.01).





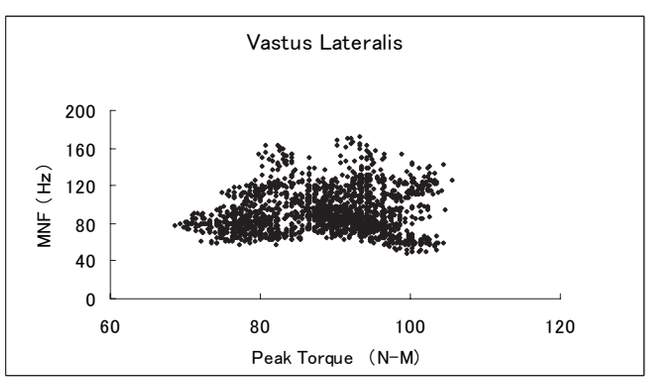


Figure 6 Correlation between MNF and PT in quadriceps muscle during 100 isokinetic knee extensions. A significant correlation was seen between MNF and PT in rectus femoris muscle.

extension every once) of the MNF was performed by frequency analysis on time. There were few changes of the normal deviation value of MNF every 20 times (**Figure 5**), so that, the EMG analysis can be reliable.

Isokinetic dynamometers (PT) are commonly used for assessing dynamic muscle strength, muscle endurance and muscle fatigue. During repeated maximum isokinitic contractions, biomechanical output (PT) will decrease prominently during the initial 40-60 contractions, followed by a phase with no further decrease (**Figure 2**) (Gerdle, Larsson, & Karlsson, 2000). In the present study, patterns of change in MNF closely resembled falls in PT (**Figure 3** and **Figure 5**), PT and MNF were found to decrease markedly during the initial 40-60 contractions, followed by a phase with little or no change. The result supported preceding studies (Gerdle, Larsson, & Karlsson, 2000; Larsson, et al., 2003).

MNF and PT showed a significant correlation only in the RF (r=0.59, p<0.01; **Figure 6**). During repeated maximum isokinitic contractions, RF was more used and easier to reach the fatigue state than VM and VL.

Table 1 Changes in quadriceps muscle hardness between before and after-exercise.
Muscle hardness increased significantly between before and after-exercise.

	Before-exercise (mean±SD)	After-exercise (mean±SD)	Rate change (%) (Bef/Aft*100)	Significant difference (*)
VM	47.1±4	49.6±3.9	105.6±4.8	p<0.01
RF	47.1±4.2	54.9±3.6	111.7±3.9	p<0.01
VL	56.7±5.4	62.6±5.4	110.8±6.3	p<0.01

4.2. Muscle hardness

In recent years, the PEK-1 biotissue spring-meter (Imoto) has allowed easy measurement of muscle hardness as an indicator of muscle fatigue in clinical and sports situations (Howell, et al., 1993; Chleboun, et al., 1998; Holikawa, et al., 1997; Murayama, et al., 2000; Miyakawa, et al., 2005; Kinoshita, et al., 2006; Sun, et al., 2007). Muscle hardness has been measured based on bounce of the spring coefficient since ancient times, and some studies have examined changes in muscle hardness after soccer games (Holikawa, et al., 2003; Sun, et al., 2008). However, these studies did not clarify quantity of load, which is regarded as an important factor when muscle hardness increases, and various methods were used to achieve muscular contraction. Muscle hardness has been reported to rise after isometric contractions (Holikawa, et al., 1997), but not isokinetic contractions like dynamic exercises in soccer.

In this study, 100 repetitions of maximal isokinetic knee extension were used. As a result, muscle hardness increased by about 5% in VM, compared to ≥10% in RF and VL (**Table 1**). This reflected the result of the correlation between MNF and PT (**Figure 6**). Muscle hardness can be useful as a physiological predictor of muscular fatigue.

Kinoshita, et al., (2006) reported muscle hardness was examined at the same result for each of the knee-extended and flexure positions. In this study, muscle hardness was measured in bed before and after exercise immediately. MNF fall concerned with muscle conduction velocity CV) closely (Moritani, 1986; Gerdle & Elert, 1994; Potvin & Bent, 1997; Gerdle et al., 2000; Crenshaw et al., 2000; Larsson et al., 2003), which would be affected by the change of the intramuscular liquids when repetitions of maximal isokinetic knee extension (Crenshaw & Gerdle et al., 2000; Yamada, et al., 2003). When intramuscular liquids temporarily accumulate, muscle hardness will be increasing at the same time in reverse relation to the MNF decreasing. Therefore, MNF can be considered as one cause of increased muscle hardness. Measuring muscle hardness, we would detect muscle fatigue. So We can see symptoms of Osgood-Schlatter disease in football players.

5. Conclusion

The present study examined the characteristics of muscle hardness and MNF with 100 repetitions of maximal isokinetic knee extension. A significant correlation with MNF and PT was found only in the RF, an agonist muscle of knee extension. Muscle hardness increased significantly in all muscles (ML, RF, VL) as MNF decreased. The present study thus suggests that muscle hardness can be useful as a physiological predictor of muscular fatigue in the RF for the prevention of the KEM disorder in sports filed such as soccer.

References

Babault, N., Desbrosses, K., Fabre, M.S., Michaut, A., & Pousson, M. (2005). Neuromuscular fatigue development during maximal concentric and isometric knee extensions. Journal of Applied Physiology 100 (3): 780-785.

Chleboun, G.S., Howell, J.N., Conatser, R.R., & Giesey, J.J. (1998). Relationship between muscle swelling and stiffness after eccentric exercise. Medicine and Science in Sports and Exercise 30: 529-535.

Crenshaw, A.G., Gerdle, B., Heiden, M,, Karlsson, S., & Fridé n, J. (2000). Intramuscular pressure and electromyographic responses of the vastus lateralis muscle during repeated maximal isokinetic knee extensions. Acta Physiologica Scandinavica 170: 119-126.

Ekstrand, J.(1994). Injuries.In Ekbblom B (Eds.) Handbook of Sports Medicine and Science-Football (Soccer). Oxford: Blackwell Scientific Publication: 175-194.

Gerdle,B., & Elert, J. (1994). The temporal occurrence of the mean power frequency shift of the electromyogram during maximum prolonged dynamic and static working cycles. International Journal of Sports Medicine 15: 32-37.

Gerdle ,B., Larsson, B., & Karlsson, S. (2000). Criterion validation of surface EMG variables as fatigue indicators using peak torque-A study of repetitive maximum isokinitic knee extensions. Journal Electromyography and Kinesiology 10: 225-232.

Gerdle, B., Karlsson, S., Crenshaw, A.G., Elert, J., & Fridén, J. (2000). The influences of muscle fibre proportions and areas upon EMG during maximal dynamic knee extensions. European Journal of Applied Physiology 81: 2-10.

Gilbert, W.G., McHugh, M.P. (1997). Flexibility and its effects on sports injury and performance. Sports Med 24: 289-299.

Holikawa, H., Sato, M., et al (1997). The change of muscle hardness during maximal isometric knee extension exercise. The journal of clinical sports medicine 14: 573-578. (in Japanese)
Holikawa, H., Asahina, S., Sato, M., (2003). The change of muscle hardness during the consecutive soccer game. Bulletin of general culture, Showa University 34: 19-23. (in Japanese)
Howell, J.N., Chleboun, G., & Conatser, R. (1993). Muscle stiffness, strength loss, swelling and soreness following exercise-induced injury in humans. The Journal of Physiology 464: 183-196.
Hermens, H.J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., Disselhorst-Klug, C., Hagg, G., SENIAM. (1999). European recommendations for surface electromyography. Roessingh Research and Development, Enschede, Holland.
Kinoshita, H., Miyakawa, S., Mukai, N., & Kono, I. (2006). Hardness in Knee Extensor Mechanism in Adolescent Male Soccer Players. Japanese journal of orthopaedic sports medicine 25 (4): 399-402.
Kinoshita, H., Miyakawa, S., Mukai, N., Kono, I. (2006): Measurement of tissue hardness for evaluating flexibility of the knee extensor mechanism. Football Sci, 3:15-320.
Krivickas, L.S. (1997). Anatomical factors associated with overuse sports injuries. Sport Med, 24:132-146.
Larsson, B., Karlsson, S., Eriksson, M., & Gerdle, B. (2003). Test-test reliability of EMG and peak torque during repetitive maximum concentric knee extensions. Journal Electromyography and Kinesiology 13: 281-287.
Lindström,L., Kadefors,R., & Petersén, I.(1997). An electromyographic index for localized muscle fatigue. Journal of Applied Physiology 43(4): 750-754.
Miyakawa, J., Mukai, N., & Shiraki, H. (2005). The construction of the medical check system of the athlete in Tsukuba University. Bulletin of Institute of Health and Sport Science, the University of Tsukuba 28: 57-66. (in Japanese)
Moritani, T., Muro, M (1986). Intramuscular pressure and surface electromyogram changes during muscle fatigue. Journal of Applied Physiology 60(4):1179-1185.
Murayama, M., Nosaka, K., Yoneda, T., & Minamitani, K.(2000). Changes in hardness of the human elbow flexor muscles after eccentric exercise. European Journal of Applied Physiology 82: 361-367.
Potvin, J.R., & Bent, L.R. (1997). A validation of techniques using surface EMG signals from dynamic contractions to quantify muscle fatigue during repetitive tasks. Journal Electromyography and Kinesiology 7: 131-139.
Sun, G.., Miyakawa, J., Kinoshita, H., Takemura, M., Shiraki, H. & Mukai, N. (2008). Changes of quadriceps muscle stiffness of young female soccer players during the game. Japanese journal of clinical sports medicine 16 (1): 68-71. (in Japanese)
Yamada, E., Kato, H., Miyamoto, K., Tanaka, S., Morita, S., Tanaka, S., & Norimatsu, H. (2003).The frequency analysis of surface electromyography during dynamic contractions using wavelet transform. The frequency characteristics of muscle fatigue during 30 repetitive maximum isokinetic contractions. Japanese Physical Therapy Association 30 (7): 391-396. (in Japanese)

Name:
Gang Sun

Affiliation:
Doctoral Program of Sports Medicine, Graduate School of Comprehensive Human Sciences, University of Tsukuba, Japan

Address:
Laboratory of Advanced Research D 1-1-1 Tennodai, Tsukubashi, Ibaraki 305-8577 Japan

Brief Biographical History:
2000- Master Program of Physical Education, University of Tokai, Japan
2004- Doctoral Program of Sports Medicine, University of Tsukuba Japan

Main Works:
• "Changes of quadriceps muscle stiffness of young female soccer players during the game" JPN J Clin Sports Med, Vol.16 (1), 68-71, 2008.

Membership in Learned Societies:
• Japanese Society of Clinical Sports Medicine
• Japanese Society of Physical Fitness and Sports Medicine
• European College of Sports Science