Relationship between Muscle Fiber Conduction Velocity and Muscle Strength in Patients with Joint Disorder of the Lower Limb

KYOUSHI MASE1), HIROMITSU KAMIMURA2), SHIGEYUKI IMURA3), KAORU KITAGAWA4)

1)Department of Rehabilitation, Hyogo College of Medicine Sasayama Hospital:
75 Yamauchi-cho, Sasayama, Hyogo 669-2337, Japan. TEL +81 79-552-7381
2)Department of Rehabilitation, Hyogo College of Medicine Hospital
3)Ibaraki Prefectural University of Health Sciences
4)Laboratory for Exercise Physiology and Biomechanics, Graduate School of Health and Sport Sciences, School of Health and Sport Sciences, Chukyo University

Abstract. The relationship between muscle fiber conduction velocity (MFCV) of the vastus medialis and muscle strength of knee extensors was observed in patients with joint disorder of the lower limb, and the feasibility of MFCV as an index for evaluating the condition of muscular disuse was examined. MFCV was significantly slower in patients with joint disorder (2.91 ± 0.27 m·s⁻¹) than in healthy subjects (3.22 ± 0.22 m·s⁻¹; p<0.01). Muscle strength of knee extensors was significantly lower in patients (198.1 ± 72.2 N) than in healthy subjects (311.2 ± 79.6 N; p<0.01). Muscle strength displayed a significant positive correlation with MFCV in patients with joint disorder (r=0.63, p<0.01). In patients after joint surgery of the lower limb, MFCV increased with muscle strength recovery. Reduced MFCV in patients with joint disorder appears to primarily reflect muscle atrophy of type II fibers. MFCV of patients with joint disorder of the lower limb may thus reflect changes in muscle fiber type and diameter.

Key words: Muscle fiber conduction velocity, Disuse, Muscle weakness

(INTRODUCTION)

Muscle fiber conduction velocity (MFCV) represents the propagation velocity of action potentials traveling from a neuromuscular junction along the muscular fiber. Since MFCV reportedly declines during muscle fatigue and MFCV is propagated at a higher rate in type II fibers than in type I fibers, MFCV is used as an index of muscle fatigue and muscle fiber type. MFCV is also available as an index of muscle fiber diameter. In myogenic disorders such as Duchenne muscular dystrophy, inflammatory myopathy, myotonic dystrophy, and neurogenic disorders such as amyotrophic lateral sclerosis, myasthenia gravis and hypokalemic periodic paralysis, MFCV is reportedly reduced with muscle atrophy.

Stalberg and Cruz-Martinez reported MFCV of patients with joint disorder. Stalberg measured MFCV of the quadriceps femoris immobilized in a plaster cast for 3 weeks after operation on a meniscus, and MFCV was reduced in the operated leg with decreased thigh circumference in comparison with the normal leg. Cruz-Martinez found that in patients after traumatic lesions of a unilateral knee and immobilization with quadriceps
atrophy, MFCV of quadriceps femoris on the immobilized side was reduced compared with the uninjured side, and MFCV recovered after removing immobilization and initiating physical therapy.

Few studies have examined MFCV in patients with joint disorder rather than neuromuscular disease, and MFCV is not generally applied in clinical situations to such patients. The present study examined the availability of MFCV for evaluating the disuse condition of muscles in patients with joint disorder of the lower limb.

SUBJECTS

Relationship between MFCV and muscle strength in patients with joint disorder of the lower limb, and comparison between joint disorder and healthy subjects

Relationships between MFCV and disuse muscle weakness were examined in 68 patients with osteoarthrosis (OA) of the lower limb who experienced disuse muscle atrophy following hypoactivity with joint pain and deformity (disuse group). The underlying pathologies were OA of the hip (n=33) and OA of the knee (n=35). No patient reported pain during measurement of muscle strength, so the effects of pain inhibition on muscle strength were eliminated from this study. All subjects were women, and their mean age was 69.0 ± 10.0 years. Healthy controls comprised 51 healthy women with no disability in activities of daily living, and their mean age was 68.1 ± 9.0 years.

Changes in MFCV with increasing muscle strength

Changes in MFCV with increasing muscle strength were examined for patients after surgery of the lower limb. Subjects were 12 patients (2 men, 10 women: mean age, 69.6 ± 10.1 years) who showed postoperative muscle weakness and underwent rehabilitation (postoperative group). Operations involved total hip arthroplasty (n=7), intramedullary hip screw (n=2), compression hip screw (n=1), valgus femoral osteotomy (n=1) and hemiarthroplasty (n=1) (Table 1).

METHODS

Measurement of MFCV

MFCV was measured according to Kondo et al. 11), but our method of inducing many more electromyograms (EMG) from muscle fibers appeared to enhance measurement precision, due to visual observation of the action potential traveling along the muscle fibers. The micro-surface electrode array used 8 copper electrodes (1 mm × 10 mm each) aligned on a plastic plate (20 mm × 50 mm) at intervals of 5 mm (Fig. 1). By inducing bipolar EMG, negative peaks in evoked potentials were easily recognized.

The vastus medialis muscle was used for measurement, and subjects were in a sitting position with both hip and knee joints flexed at 90°. Electric stimulation was given using a Viking IV electro-stimulator (Nicolet, America) with rectangular waves of 0.5-ms duration at 1 Hz. The site of electric stimulation was a peripheral part of the vastus medialis just above the patella. Prior to placement of the micro-surface electrode array, electric stimulation at the peripheral part of the vastus medialis just above the patella was visually observed on the skin surface to confirm that muscle fibers contracted on impulse and that the stimulus was traveling along these fibers. Next, the micro-surface electrode array was placed across the length of the muscle fibers at the center of the vastus medialis 3–5 cm from the superior margin of the patella (Fig. 1). Using the Viking IV (Nicolet), 7 bipolar EMGs were obtained from each electrode adjacent to each other (Fig. 1). For intensity of electric stimulation, the waveform derived from the electrode nearest to the stimulation site was called the 1st waveform, whereas the waveform derived from the electrode furthest from the stimulation site was called the 7th waveform, and stimulus intensity was increased until 1st to 7th waveforms had sizable potentials of similar shape and similar time difference between two adjacent waveforms 11). An averaged waveform was obtained from 10 measurements, from which the delay time of negative peaks in the 1st and 7th waveforms was obtained, then MFCV was calculated using the following equation:

$$MFCV \ (m \cdot s^{-1}) = \frac{\text{inter-electrode distance (30 mm)}}{\text{delay time (ms)}}$$

In some patients displaying severe muscle atrophy of the vastus medialis, the amplitude decreased markedly for waveforms away from the site of electric stimulation between the 1st and 7th waveforms, and negative peaks could not be distinguished or the latency was markedly long.
Waveforms with such changes were excluded from the analysis, and MFCV was calculated using data before such changes were observed.

**Measurement of muscle strength for knee extensors**
Muscle strength was measured using a Digital Dynamometer (Takei Scientific Instruments, Japan). As with MFCV measurement, each subject was instructed to sit with hip and knee joints in 90° flexion, and then to fully extend the knee joint isometrically 3 times. The highest value was used in analysis as muscle strength of the knee extensors.

**Postoperative measurements**
In 12 patients, chronological changes in postoperative muscle strength and MFCV were ascertained using 2–4 measurements. The number of postoperative measurements was 2 in 5 patients, 3 in 6 patients and 4 in 1 patient. The first postoperative measurement was taken when physical therapy was begun, and muscle strength could be measured at a mean of 25.7 ± 4.6 days after surgery. The last measurement was taken at the time of discharge. The mean duration of exercise therapy was 53.3 ± 18.1 days (Table 1).

**Statistical analysis**
For statistical analysis, Spearman’s rank correlation coefficient test was used to ascertain relationships between muscle strength and MFCV for the disuse group, Student’s t-test for differences in muscle strength and MFCV between control and disuse groups, and a paired t-test for postoperative changes in muscle strength and MFCV.

**RESULTS**

**Comparison of the muscle strength and MFCV between disuse and control groups**
MFCV of vastus medialis was significantly faster in the control group (3.22 ± 0.22 m·s⁻¹) than in the disuse group (2.91 ± 0.27 m·s⁻¹; p<0.01). Muscle strength of knee extensors was significantly higher in the control group (311.2 ± 79.6 N; p<0.01) than in the disuse group (198.1 ± 72.2 N; p<0.01).

**Relationship between MFCV and muscle strength of disuse group**
A significant positive correlation (r=0.63, p<0.01) was shown between muscle strength of knee extensors and MFCV in the disuse group (Fig. 2).

**Postoperative changes in MFCV and muscle strength**
Table 2 shows postoperative changes in MFCV as muscle strength increased in the 12 patients. Mean muscle strength for the first postoperative measurement was 133.6 ± 72.2 N, but significantly increased to 212.3 ± 82.0 N at the time of discharge (p<0.01). Muscle strength increased in all patients. Mean MFCV was 2.75 ± 0.23 m·s⁻¹ for the first postoperative measurement, and significantly improved to 3.06 ± 0.24 m·s⁻¹ at time of discharge (p<0.01). MFCV improved in all patients. Figure 3
shows chronological changes in MFCV and muscle strength for the 7 patients in whom ≥3 measurements were taken MFCV improved in many patients as muscle strength increased.

DISCUSSION

Reduced muscle strength and MFCV in patient with joint disorders of the lower limb

In patients with joint disorder of the lower limb, motor disability due to pain and reduced muscle strength would clearly reduce activity in comparison to healthy individuals, and muscle atrophy is also likely. The present results showed that muscle strength was clearly lower for the disuse group than for the healthy group.

Animal studies have shown that when activity is reduced by recumbency, joint fixation or hind limb suspension to relieve load, atrophy of type I fibers predominates\(^\text{12}\). Clinical studies have shown that this type of inactivity in humans causes atrophy of mainly type I fibers\(^\text{13}\), or both type I and II fibers\(^\text{14}\). The results of a long-term recumbency study clearly showed atrophy of mainly type II fibers\(^\text{15}\). Bloomfield\(^\text{16}\) reported that: 1) in a normal state, type II fibers are thicker than type I fibers in humans, but type I fibers are thicker in rats; and 2) muscle atrophy caused by suspension or inactivity is more likely to affect thick muscle fibers. Type I muscle atrophy is more likely to occur in animal studies while type II muscle atrophy is more likely to occur in clinical studies. As far as reports on patients with joint disorders of the lower limb are concerned, Reardon et al.\(^\text{17}\) reported that atrophy of type II fibers is dominant for the quadriceps femoris of patients with OA of the hip, and Tanaka et al.\(^\text{18}\) documented that in severe cases, atrophy of type I fibers is also seen. As a result, both type I and II fibers become atrophied. Atrophy of mainly type II fibers in patients with OA of the hip has been reported not only in the quadriceps femoris, but also in gluteal muscles near the hip joint\(^\text{19}\). Many studies have reported atrophy of mainly type II fibers in the quadriceps femoris of patients with knee joint disorders\(^\text{20, 21}\), and in severe patients,
atrophy of type I fibers has been reported, as in patients with OA of the hip\textsuperscript{18, 20}. We therefore believe that, in the vastus medialis of patients with hip or knee joint disorders, atrophy of type I and II fibers occurs in severe cases and atrophy of type II fibers predominates in other cases.

MFCV is affected by physiological factors such as muscle fiber type, muscle fiber thickness, discharge frequency and muscle fatigue. With the present MFCV measurement method, the effect of discharge frequency was low because electric stimulation was applied at a stimulation frequency of 1 Hz. Furthermore, the 10 stimulations performed in this study might not induce muscle fatigue. Differences in MFCV of the vastus medialis thus seem likely to primarily reflect differences in muscle fiber thickness and type. In the present study, muscle strength was significantly lower for knee extensors in the disuse group than in the control group, and MFCV was significantly

| Table 2. | Comparison of first and last tests |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|               | Muscle strength (N) | MFCV (m·s$^{-1}$) |                |                |
|                | First test | Last test | First test | Last test |
| Subject 1     | 136.2     | 340.0     | 2.75       | 2.91       |
| Subject 2     | 75.4      | 198.0     | 2.75       | 2.91       |
| Subject 3     | 275.4     | 336.1     | 2.73       | 3.37       |
| Subject 4     | 82.3      | 181.3     | 2.75       | 2.91       |
| Subject 5     | 96.0      | 150.9     | 2.83       | 3.30       |
| Subject 6     | 213.6     | 242.1     | 3.19       | 3.53       |
| Subject 7     | 60.8      | 100.9     | 2.54       | 2.83       |
| Subject 8     | 165.6     | 267.5     | 2.78       | 2.91       |
| Subject 9     | 166.6     | 204.8     | 2.54       | 2.88       |
| Subject 10    | 208.7     | 280.3     | 2.97       | 3.22       |
| Subject 11    | 52.9      | 137.2     | 2.88       | 3.13       |
| Subject 12    | 70.6      | 108.8     | 2.27       | 2.78       |
| Mean          | 133.6     | 212.3*    | 2.75       | 3.06*      |
| SD            | 72.2      | 82.0      | 0.23       | 0.24       |

\*p<0.01

Fig. 3. Chronological changes in MFCV and muscle strength for the 7 patients for whom $\geq$3 measurements were taken.
slower. In addition, a significant positive correlation was seen in the disuse group between muscle strength and MFCV, and lower muscle strength thus means slower MFCV. This suggests that MFCV delay in the disuse group might reflect atrophy of type II fibers.

Chronological changes in postoperative MFCV and muscle strength of the lower limb

In the present study, MFCV improved as muscle strength increased among patients who underwent surgery for joint disorders of the lower limb. Based on chronological changes in muscle strength and MFCV, MFCV improved as muscle strength increased in each patient. These results show that MFCV reflects changes in muscle strength to some degree in each patient.

Muscle strength cannot be measured after surgery while the joints are immobilized or systemic condition is poor. Conversely, MFCV can be measured even when patients are resting in bed and cannot move joints, and can thus be used to assess muscle disuse during such periods.

In many patients with joint disorders of the lower limb, muscle strength does not recover to normal levels. Some studies with long follow-up of patients after total hip replacement surgery who displayed less pain after surgery and underwent rehabilitation therapy have shown that muscle strength continues to remain low\(^{17, 22}\). Reduced voluntary muscle activity has been reported as one reason for poor muscle strength\(^{23}\), and rehabilitation programs to improve voluntary muscle activity are needed\(^{17, 23}\). However, no common methods have been defined to ascertain how and to what degree reduced muscle strength is affected by muscle atrophy, reduced voluntary muscle activity and pain. In general, computed tomography (CT), magnetic resonance imaging (MRI) and ultrasonography are used to objectively assess muscle atrophy. However, CT and MRI are expensive and cannot be performed frequently. Voluntary muscle activity is also very important for assessing reduced muscle strength, and this parameter is measured by applying electrical stimulation during voluntary contractions\(^{22}\), but since this electrical stimulation is very painful, use in clinical settings is difficult. MFCV offers a noninvasive, convenient and inexpensive alternative for assessing disuse muscle atrophy and represents a clinically useful technique.

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