Effect of Age and Gender on Muscle Function—Analysis by Muscle Fiber Conduction Velocity—

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Abstract. The effect of age and gender on muscle fiber conduction velocity (MFCV) was examined. Subjects were 216 healthy persons (369 limbs), of which 102 were males (180 limbs) and 114 were females (189 limbs). The method of evoked potential was used for measuring MFCV. The muscles measured were the vastus medialis of the right and / or left limbs. The measurement was taken in a sitting position with the hip and knee joints flexed at 90°. On the effect of aging, a significant correlation between MFCV and age was observed in males (r=0.63, p<0.01) and in females (r=0.52, p<0.01). There was a tendency of delay in MFCV due to aging. On the gender difference, male MFCV showed a faster rate, compared with that of females in the age group from 20’s to 40’s. However, no gender difference was observed in the age group of more than 50 years. Based on these results, age and gender differences must therefore be considered when determining standard values of MFCV.

Keywords: Muscle fiber conduction velocity, Aging, Gender

INTRODUCTION

Disuse muscle atrophy due to arthrodesis performed after fracture or orthopedic surgery and due to general hypoactivity represents a very serious dysfunction in the execution of physical therapy. Determining muscle strength is the most common method of evaluating disuse muscle atrophy. However, this method is inappropriate, as muscle strength is influenced by factors such as pain and neurological and articular function, rather than purely muscle atrophy. As a physical morphological method, changes in muscle fiber cross-sectional area due to muscle atrophy can be indirectly assessed using muscle circumference, but this method is affected by factors such as swelling, edema and thickness of subcutaneous fat, rather than just muscular cross-sectional area. Other relatively simple methods include; 1) histological methods using muscle biopsy; 2) measurement of muscle cross-sectional area using computed tomography (CT) and magnetic resonance imaging (MRI); and 3) measurement of muscle tissue thickness by ultrasonography. As CT and MRI are costly, frequent use of these techniques is not preferable. Moreover, CT is associated with X-ray exposure problem, and MRI cannot be employed for patients with metal fixation from orthopedic operations. Furthermore, ultrasonography is unable to differentiate between affected muscle and...
associated connective and fatty tissues, due to fibrosis of muscular fibers or increased fat tissue following disuse.

Although each of the above methods has some drawbacks, muscle fiber conduction velocity (MFCV) has been employed as a method of measuring muscular function, and has been clinically used to evaluate muscular conductivity in patients with neuromuscular disease. MFCV represents the propagation velocity of action potentials traveling from a neuromuscular junction along the muscular fiber. Despite the lack of standardization for use of this method and difficulties in learning the measuring technique, this method offers the advantages of non-invasiveness and low cost.

Results of animal experiments\textsuperscript{1, 2)} suggest that MFCV is related to the diameter of muscle fibers, and increases with increasing muscle fiber thickness. In human tests\textsuperscript{3), 4)}, MFCV in the affected limb of patients with disuse atrophy of the quadriceps femoris due to osteoarticular disease was delayed compared with the intact side. MFCV in atrophied muscle due to denervation also reportedly showed delays, but recovered on reinnervation\textsuperscript{4)}, and MFCV in the atrophied muscle due to CNS paralysis showed delays\textsuperscript{5)} that improved with increased cross-sectional area of muscle during rehabilitation\textsuperscript{6)}. These results suggest that MFCV may be useful as a parameter for non-invasive and cheap evaluation of muscular atrophy following hypoactivity, denervation or CNS paralysis.

MFCV is not yet a common method for evaluating muscular atrophy due to disuse. Widespread clinical use would require the establishment of standard values, but some differences in clinical reports have been identified concerning the effects of age and gender on MFCV. Some studies have reported no influence of age\textsuperscript{7, 8)}, while others have indicated age-related delays in MFCV\textsuperscript{9, 10)}. The effects of gender also appear contentious, with MFCV identified as faster in males than in females by some studies\textsuperscript{8, 11)}, while other researchers have found no effect of gender\textsuperscript{12, 13)}. The present investigation therefore examined the effects of age and gender on MFCV, with an aim of determining standard values for MFCV.

### SUBJECTS

Subjects comprised 216 healthy individuals (369 limbs; 180 men, 189 women) with no disability in activities of daily living (Table 1). Mean age was 47.6 years (range, 20–79 years). Prior to participation in the study, informed consent was obtained from all subjects.

### METHOD

MFCV was measured using a modification of the methods of Kondo et al.\textsuperscript{6)}, but our method induces many more electromyograms (EMG) from muscle fibers and appears to enhance measurement precision, due to visual observation of action potentials traveling along 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 EMGs, negative peaks in evoked potential were easily recognized.

*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 electrostimulator (Nicolet, USA) with rectangular waves of 0.5-ms duration at 1 Hz. 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*

### Table 1. Subjects

<table>
<thead>
<tr>
<th>Cases</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>20–29 years</td>
<td>19 (36 limbs)</td>
<td>18 (33 limbs)</td>
</tr>
<tr>
<td>30–39 years</td>
<td>20 (38 limbs)</td>
<td>18 (32 limbs)</td>
</tr>
<tr>
<td>40–49 years</td>
<td>15 (30 limbs)</td>
<td>17 (31 limbs)</td>
</tr>
<tr>
<td>50–59 years</td>
<td>15 (25 limbs)</td>
<td>19 (33 limbs)</td>
</tr>
<tr>
<td>60–69 years</td>
<td>15 (24 limbs)</td>
<td>20 (31 limbs)</td>
</tr>
<tr>
<td>70–79 years</td>
<td>18 (27 limbs)</td>
<td>22 (29 limbs)</td>
</tr>
<tr>
<td>Mean age ± SD (years)</td>
<td>46.6 ± 17.4</td>
<td>48.7 ± 17.2</td>
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medialis, 3–5 cm from the superior margin of the patella (Fig. 2). Using the electro-stimulator, 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 the 1st to 7th waveforms displayed sizable potentials with similar shapes and time differences between any 2 adjacent waveforms. 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:

\[
\text{MFCV (m/s)} = \frac{\text{inter-electrode distance (30 mm)}}{\text{delay time (ms)}}
\]

When the placement angle of the electrodes did not coincide with the length of muscle fibers, discrepancies such as the following were observed: 1) scattering of latent time differences among EMGs and 2) amplitude of evoked potentials from the 1st waveform to the 7th waveform decreased markedly, or shapes changed. When these discrepancies occurred, measurements were conducted only after having corrected the electrode placement angle with the longest latent time difference, least scattering and smallest changes in shape and amplitude of the waveforms.

For statistical analysis, Spearman’s rank correlation coefficient test was used to determine correlations between MFCV and age. Gender differences in MFCV for each generation were first tested using 2-factor analysis of variance (ANOVA), followed by the Fisher’s PLSD test to determine differences among each level of significance. Gender differences with age for MFCV were tested using multiple regression analysis. For all statistical processing, a value of the risk function less than 5% was fixed as the level of significance.

**RESULTS**

Table 2 shows mean (± standard deviation) MFCV in each generation by gender. In each generation, males showed a significantly faster
velocity than females in the age groups from the 20’s to the 40’s, but no significant differences were apparent between genders in the 50’s and 70’s.

Regarding the effect of aging, a significant negative correlation was noted between age and MFCV in both males \((r=0.63, p<0.01)\) and females \((r=0.52, p<0.01)\), and MFCV is delayed with aging in both males and females (Fig. 3). Examination on gender differences in delays by regression analysis revealed a significant difference between males and females.

### DISCUSSION

**Measurement of MFCV**

For measuring MFCV, two methods are available: to measure potential propagation velocity during voluntary contraction; and to measure the propagation velocity of a potential directly evoked by electric stimulation of muscle fibers. MFCV is also influenced by physiological factors other than the diameter of the muscle fiber. Reports have described phenomena such as slower MFCVs of Type I fibers belonging to smaller motor units in comparison to Type II fibers belonging to larger motor units\(^5,\,14\), faster MFCVs with increased frequency of discharge\(^1,\,5\), and delayed MFCV due to muscle fatigue\(^16\). Measurement of MFCV during voluntary contraction is affected by all these factors, and measured values are likely to become unstable and display poor reproducibility compared with measurement using evoked potentials. In our method using evoked potentials, however, stimulation frequency was fixed at 1 Hz, to avoid the effects of excessive discharge frequency or muscle fatigue. MFCV measured using evoked potential thus seems to reflect the characteristics of the diameter of a muscle fiber activated mainly by electric stimulation and of the motor unit that the muscle fiber belongs to. With the present method, mean potential propagation velocity of muscle fibers activated by action potential due to electric stimulation is thought to be measured. When disorders are present in bones and joints or the nervous system, subjects are often unable to perform sufficient voluntary muscular activities, due to the influence of factors such as pain, motor paralysis and voluntary-activation deficits\(^17\), which in turn may greatly affect the test results. However, if evoked potentials are used, these influences are thought to be avoided. The evoked potential method may thus be more appropriate than methods using voluntary contractions for measuring MFCV when disorders of the bones, joints or nervous system are present.

In our measurements, the site for stimulation was a peripheral part of the vastus medialis muscle just above the patella. When using evoked potential, the stimulation site should be situated away from nerves or neuromuscular junctions to avoid nerve stimulation, to ensure direct electrical stimulation of muscle fibers. The vastus medialis muscle contains numerous neuromuscular junctions, and in sites other than those used this time, the possibility of directly electrically stimulating not only muscle fibers, but also nerves or neuromuscular junctions, was considered high. The peripheral part of the vastus medialis muscle just above the patella was thus chosen.

No changes in MFCV values have been reported, even under increased stimulus intensity, during MFCV measurement using a surface EMG with

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**Table 2.** The mean values and SDs for MFCV in each age group by gender

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>20–29**</td>
<td>3.75</td>
<td>3.55</td>
</tr>
<tr>
<td>30–39*</td>
<td>3.58</td>
<td>3.49</td>
</tr>
<tr>
<td>40–49**</td>
<td>3.57</td>
<td>3.38</td>
</tr>
<tr>
<td>50–59</td>
<td>3.46</td>
<td>3.37</td>
</tr>
<tr>
<td>60–69</td>
<td>3.27</td>
<td>3.27</td>
</tr>
<tr>
<td>70–79</td>
<td>3.22</td>
<td>3.16</td>
</tr>
</tbody>
</table>

\(m\cdot s^{-1},\ *: p<0.05,\ **: p<0.01\)
percutaneous electrical stimulation at the muscle\(^6\)).

Stimulus intensity was thus increased until the 1\(^{\text{st}}\) to 7\(^{\text{th}}\) waveforms displayed sizable potentials with similar shape and time differences between adjacent waveforms\(^6\)).

**Effect of aging on MFCV**

Few reports have examined the influence of aging on MFCV using a large number of clinical cases. To examine effects due to aging, as many clinical cases as possible must be accumulated, but most reports have only used 20~30 cases\(^6,8,9\)). This seems likely to be the reason behind the differing results reported by various physicians. Among the papers dealing with relatively many cases, Okada et al.\(^10\)) examined 99 women and reported that MFCV was delayed with aging. In this study of 216 subjects, the results showed a tendency toward delayed MFCVs due to aging in both males and females. Indeed, most studies reporting no effect on MFCV of aging have confirmed that, despite the lack of significant differences from a statistical perspective, MFCVs tended to be delayed in the elderly compared with younger subjects.

Muscle deteriorates both structurally and functionally with age. The most common phenomenon is a decrease in muscle volume and strength. Muscle strength is reportedly highest in the 20’s to 30’s, gradually decreasing until around the 50’s, then the rate of decrease accelerates from around the 60’s\(^18\)). Muscle volume has also been reported to decrease from around 25 years, to be decreased by about 10% at 50 years, with the rate of decrease accelerating after around 60 years\(^39\)).

Decreases in muscle volume with age are attributed to factors such as decreased motor unit counts\(^20\)), decreased activity and increased slow activity\(^21\)), serious muscular injuries\(^10\)), malnutrition and hormonal changes\(^22\)). Denervation with aging reportedly causes fibrosis of muscle and decreases the number of muscle fibers. Furthermore, denervation appears more likely to occur in Type II fibers than in Type I fibers, and slower activity is more often observed with increased age, causing atrophy mainly found in Type II fibers\(^23\)) and decreases in numbers of muscle fibers, then shifting from Type II to Type I fibers\(^24\)).

Severe muscular injuries also decrease the number of muscle fibers. These phenomena appear differently, depending on the body site. Galea\(^25\)) reported that changes in peripheral muscle due to aging were strongly affected by decreases in motor unit counts, and that, in the case of central muscles, myogenic changes, rather than the effect of decreased motor unit counts, strongly affect decreases in muscle volume. Tomonaga et al.\(^26\)) also suggested that myogenic changes are much stronger in peripheral muscle than in central muscle.

On the other hand, Klein\(^27\)) noted that, in biceps brachii of both young and elderly subjects, no changes were observed in numbers of muscle fiber, but selective atrophy of Type II fibers was apparent, and decreased muscle volume of an upper extremity muscle due to aging was predominantly caused by atrophy of Type II fibers rather than decreases in

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**Fig 3.** The relationships between age and muscle fiber conduction velocity (MFCV) of the vastus medialis.

![Graph showing the relationships between age and muscle fiber conduction velocity (MFCV) for Males and Females.](image)
numbers of muscle fibers. However, in quadriceps femoris, decreases in numbers of muscle fibers reportedly represent the main cause of decreased muscle volume as a result of aging, and atrophy of Type II fibers is involved. The factors affecting decreases in muscle volume may thus differ between the upper and lower limbs.

Judging from these reports, changes in vastus medialis due to aging are likely to include myogenic changes, decreased numbers of muscle fibers due to the denervation likely to occur in Type II fibers rather than in Type I fibers, atrophy centering around Type II fibers and increases in Type I fibers. All these changes will cause delays in MFCV. As a result of these changes, MFCV appears to be delayed with the advancement of age.

Effect of gender on MFCV

Few reports using large numbers of clinical cases have examined the effects of gender on MFCV. The present study reports the largest number of the subjects. Zwarts et al. reported on a comparative study using 7 males and 8 females, and found no gender difference in MFCV. In other reports, total subjects for each test have been very few, even after combining numbers of males and females, with only 10~50 persons. This seems to account for the differences observed in MFCV due to gender, depending on the reporters.

As a result of this study, MFCV was faster in males than in females for subjects in their 20’s to 40’s. Males reportedly display a larger muscle cross-sectional area than females, for both Type II and Type II fibers. In females, Type I fibers are reportedly larger than Type II fibers. Most papers have reported that differences by gender are observed in diameter of muscle fibers. However, regarding the ratio of Type I and II fibers in quadriceps femoris, one report indicated that females display a higher ratio of Type I fibers, another showed that males display a higher ratio of Type I fibers, and a third report found no gender differences. This may indicate that no clear differences by gender exist. The region to be occupied by Type I and Type II fibers in quadriceps femoris is determined by the diameter of such fibers, and in males, the thickest Type II fibers occupy a larger region, while in females, Type I fibers occupy a larger region. Based on these reports, the cause of faster MFCVs in males compared with females in the age group from the 20’s to 40’s appears attributable to the fact that males display larger cross-sectional areas of both Type I and II fibers compared with females, and also to the fact that males display a larger region to be occupied by Type II fibers, compared with females.

In the present study, MFCV did not show any differences by gender in the age groups of the 50’s to 70’s, probably influenced by the fact that females had slower MFCVs when young, compared with males, and that the degree of delay in MFCV was low with advancement of age. We have already noted that aging causes decreases in numbers or atrophy of Type II fibers, and increases of Type I fibers, resulting in delays to MFCV. However, in females, Type I fibers that increase with age among muscle fibers are thick, occupying a large region, whereas in males, Type II fibers that are thick decrease in number or show atrophy, occupying a large region. Delays in MFCV due to aging are thus less likely to occur in males than in females. Trappe described that, particularly in elderly females, motion speed of daily living becomes slower in most of the cases, and that as Type I fibers are often mobilized at the time initiating motion, the function of Type I fibers is maintained. This may account for why the degree of delay in MFCV due to aging is lower in females than in males.

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