Effects of Aging on Force, Velocity, and Power in the Elbow Flexors of Males

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Abstract The effect of aging on muscular power development was investigated by determining the force-velocity relationship. The muscle cross-sectional area (CSA) was estimated by the thickness of the elbow flexors. The subjects were 19 elderly males aged 69.1±3.7 years old (G-70 group), 15 middle-aged males aged 50.9±3.5 years old (G-50), and 19 young males aged 21.2±1.3 years old (G-20). The G-70 group had the slowest shortening velocities under various load conditions, resulting in the lowest force-velocity relationship. The maximum values for force (Fmax), velocity (Vmax), power (Pmax), dynamic constants (a, b), and the a/Fmax ratio were determined using Hill's equation. The a/Fmax ratio determines the degree of concavity in the force-velocity curve. The a/Fmax ratio was greatest in G-70, followed by those in G-50 and G-20, while the maximum values for force (Fmax), velocity (Vmax), and power (Pmax) were significantly lower in G-70 than in the other groups. Fmax and Pmax per CSA were lowest in G-70, and Vmax per unit muscle length was also lowest in G-70 as compared to the other age groups. The ratio of G-70/G-20 was greatest in Pmax (69.6%), followed by Fmax (75.3%) and Vmax (83.4%). However, there were no significant differences in CSA among the 3 age groups. Our findings suggest that muscle force and shortening velocity may decline gradually in the process of aging attributed to declining muscle function rather than CSA. J Physiol Anthropol 26(6): 587–592, 2007 http://www.jstage.jst.go.jp/browse/jpa2

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Keywords: aging, force-velocity relationship, muscle power

Introduction

The effects of aging on muscle function are often represented by isometric muscle contraction. For this context, many proofs have been shown by dealing with the isometric strength of various muscle groups: grip strength (Izquierdo et al. (1999b), elbow flexor strength (Viitasalo et al., 1985; Doherty et al., 1993), ankle plantar strength (Vandervoort and McComas, 1986), and knee extensor strength (Larsson et al., 1979; Häkkinen and Häkkinen, 1991; Häkkinen et al., 1995; Akima et al., 2001). According to Klitgaard et al. (1990), reduction due to aging in isometric strength was greater in the lower limb muscles than those in the upper limbs.

On the other hand, there is little information about isotonic (dynamic) contraction regarding aging effects. Izquierdo et al. (1999b) reported that the 1RM values for half squat and bench press exercises in an aged group were significantly lower than those in a middle aged group. It was also reported that aging effects were obvious in the force-time curves during isometric and isotonic maximum contractions (Häkkinen and Häkkinen, 1991; Häkkinen et al., 1996b; Izquierdo et al., 1999b). The squat jump and standing broad jump performances were also reduced with aging (Häkkinen et al., 1996a; Izquierdo et al., 1999a). Some studies have been performed by using an isokinetic machine to obtain the torque, velocity, and power relationship (Roman et al., 1993; Pousson et al., 1999; Ferri et al., 2003), but it is difficult to obtain the muscle power under high velocity of muscle contraction with that machine (Perrine and Edgerton, 1978). However, there are few studies using the force-velocity (F-V) relationship (Hill, 1938) with regard to aging.

The effects of aging on power seem to lead to a decrease in force and velocity in elderly people, because power is a function of force and velocity. The purpose of the present study was to quantify the effects of aging on the Pmax of the elbow flexor muscle and to determine the impact on force and velocity in an aged group using the after-load method.

Materials and Methods

Subjects

The subjects were 53 healthy males who were divided into 3 age groups: 1) young (G-20, n=19, 22–24 years old), 2) middle-aged (G-50, n=15, 45–56 years old), and 3) the elderly (G-70, n=19, 65–77 years old). None were involved in a specific physical training program. The physical characteristics of the subjects in each group, who are all right-handers, are shown in Table 1. The subjects received explanations regarding
the experiments verbally and written materials, then signed an informed consent statement. Approval for the experiment was obtained from the University of Hyogo Ethics Committee on Human Research.

**Experimental procedures**

Testing of the force, velocity, and power during elbow flexion was performed using a Wilkie’s arm ergometer (Toji and Kaneko, 2004). As shown in Figure 1, in a seated position, the subject placed his right upper arm on a table and flexed the elbow joint from 40° to 140° with maximum effort. The long iron arm of the apparatus rotated in parallel with the forearm during elbow flexion, so that a weight suspended on the short iron arm was lifted. The maximum isometric strength (Fmax) of the elbow flexor was measured at an elbow angle of 90° using a force transducer (Kyowa Corporation, LUR-A-S1). Force-time curves were digitized online with a sampling frequency of 1000 Hz using a personal computer. Force, velocity, and power were determined with loads of 0%, 10%, 20%, 30%, 45%, 60% and 100% of Fmax. The measurements were carried out using a series and reverse method (Hill, 1938), with the first trials performed twice for each load, in which the loads were increased step by step, followed by the second trials performed twice for each load in reverse order. The four velocity values so obtained for each load were averaged, with the velocity at 0% Fmax used to indicate the maximum velocity with no load, and the force at 100% Fmax used to indicate the maximum isometric strength. For these measurements, the angle-time curve was recorded with an electro-goniometer attached to the rotation axis of the iron arm to confirm an angle of 90°. The velocity of elbow flexion was measured at an elbow angle of 90° by the elbow joint using a linear velocity transducer (TRANS·TEK: 0122-0001) connected to the long iron arm of the apparatus. The force equal to the loads and velocities under various %Fmax load conditions were fitted to Hill’s characteristic equation to calculate the force (F)-velocity (V) relationship as follows (Hill, 1938):

\[
(F + a)(V + b) = (F_{\text{max}} + a)b 
\]

where F is force, V is velocity, Fmax is maximum strength, and a and b are dynamic constants. Power (P) was calculated using equation (2), and optimal velocity (Vopt) and optimal force (Fopt), at which the maximal power appeared, were calculated from equations (3) and (4):

\[
P = b \cdot F \left\{ (F_{\text{max}} + a)/(F + a) - 1 \right\} \quad (2)
\]

\[
F_{\text{opt}} = a \sqrt{1 + (F_{\text{max}}/a) - 1} \quad (3)
\]

\[
V_{\text{opt}} = b \cdot F_{\text{max}} - b \cdot F_{\text{opt}} / F_{\text{opt}} + a \quad (4)
\]

Measurements of muscle thickness by ultrasonography

The thickness of the elbow flexor muscles in the right upper arm was determined using a B-mode ultrasonic apparatus (Nihon-Koden Corporation, USD-N500) with a linear scanner (scanning frequency 5 MHz). The measurements were performed with the subjects in a standing position with the arm muscles relaxed. The measurement point was 60% distal above the lateral epicondyle of the humerus from the acromion process of the scapula in the upper arm. The muscle volume was calculated from the muscle thickness measured at the arterioles, as this single measurement is reported to be well correlated with magnetic resonance imaging (MRI) measurements (Miyatani, et al., 2000). Therefore, we estimated the cross-sectional area (CSA) of the upper arm using the value for the square of muscle thickness measured by the ultrasonic apparatus.

Statistical analysis

Statistical methods were used to calculate the mean values and standard deviations. One-way ANOVA with repeated measures and a Bonferroni post hoc test were used to determine the differences among the 3 different age groups. The probability level for statistical significance was set at \( p < 0.05 \).

**Results**

Height and upper-arm length were significantly lower in G-70 than in G-20 and G-50. However, no significant differences were observed for muscle thickness (Table 1). Thus, the muscle cross-sectional area (CSA), estimated from muscle thickness, was not significantly different among the groups (5.55 m² in G-20, 6.66 m² in G-50, and 6.40 m² in G-70).

The velocities under various %Fmax load conditions and statistical differences among those values are shown in Table 2, while F-V curves calculated by equations (1) and (2) are shown in Fig. 2. The dynamic constants a and b, and the a/Fmax ratios related to F-V relationship are listed in Table 3 with statistical proofs.

The F-V curve of G-70 tended to be lower than that of G-20 and G-50 (Fig. 2). There were significant differences among the 3 age groups for Vmax, V10 and V20 (Table 2), though not for the dynamic constants a and b (Table 3). The a/Fmax ratio of G-70 was significantly greater than that of G-20 (Table 3);
Table 1  Age and physical characteristics of subjects in 3 age groups

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Body mass (kg)</th>
<th>L (cm)</th>
<th>MT (mm)</th>
<th>CSA (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elderly</td>
<td>19</td>
<td>69.1±3.7 a</td>
<td>161±6.2 a</td>
<td>58.9±7.4 a</td>
<td>30±2.1</td>
<td>2.50±0.40</td>
<td>6.40±1.91</td>
</tr>
<tr>
<td>Middle-aged</td>
<td>15</td>
<td>50.9±3.5 b</td>
<td>170±4.2 b</td>
<td>65.8±5.9 b</td>
<td>32.7±1.2</td>
<td>2.56±0.31</td>
<td>6.66±1.60</td>
</tr>
<tr>
<td>Young</td>
<td>19</td>
<td>21.2±1.3 c</td>
<td>171.7±3.8 c</td>
<td>60.8±6.4</td>
<td>32.6±1.7</td>
<td>2.33±0.34</td>
<td>5.55±1.65</td>
</tr>
</tbody>
</table>

Mean values±SD; L:upper-arm length; MT:anterior muscle thickness; CSA:cross-sectional area estimated from MT²

*significant difference between elderly and midle-aged (p<0.05); ²significant difference between midle-aged and young (p<0.05)
³significant difference between elderly and young (p<0.05)

Table 2  Velocities (Vmax, V₁₀, V₂₀, V₃₀, V₄₅, V₆₀; m·s⁻¹) under 10%Fmax, 20%Fmax, 30%Fmax, 45%Fmax and 60%Fmax

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>Vmax</th>
<th>V₁₀</th>
<th>V₂₀</th>
<th>V₃₀</th>
<th>V₄₅</th>
<th>V₆₀</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elderly</td>
<td>19</td>
<td>3.707±0.246 a</td>
<td>2.511±0.238 a</td>
<td>1.998±0.272 a</td>
<td>1.539±0.201</td>
<td>0.945±0.216</td>
<td>0.501±0.195</td>
</tr>
<tr>
<td>Middle-aged</td>
<td>15</td>
<td>3.64±0.367</td>
<td>2.954±0.191</td>
<td>2.245±0.174</td>
<td>1.719±0.207</td>
<td>1.102±0.205</td>
<td>0.534±0.169</td>
</tr>
<tr>
<td>Young</td>
<td>19</td>
<td>4.444±0.296 c</td>
<td>2.950±0.345 c</td>
<td>2.251±0.290 c</td>
<td>1.636±0.218</td>
<td>0.963±0.225</td>
<td>0.512±0.162</td>
</tr>
</tbody>
</table>

Mean values±SD

*significant difference between elderly and midle-aged (p<0.05); ²significant difference between midle-aged and young (p<0.05)

Table 3  Maximal isometric strength (Fmax), dynamic constant (a, b and a/Fmax), maximal power (Pmax), optimal force (Fopt), optimal velocity (Vopt) and Fopt/Fmax

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>Fmax (N)</th>
<th>a</th>
<th>b</th>
<th>a/Fmax</th>
<th>Pmax (W)</th>
<th>Fopt (N)</th>
<th>Vopt (m)</th>
<th>Fopt/Fmax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elderly</td>
<td>19</td>
<td>244.3±37.7 a</td>
<td>97.8±23.1</td>
<td>1.49±0.42</td>
<td>0.407±0.117</td>
<td>107.8±21.3 a</td>
<td>84.3±11.9 a</td>
<td>1.27±0.12 a</td>
<td>0.35±0.02</td>
</tr>
<tr>
<td>Middle-aged</td>
<td>15</td>
<td>285.2±35.8 b</td>
<td>106.0±26.4</td>
<td>1.61±0.35</td>
<td>0.373±0.086</td>
<td>143.3±22.7</td>
<td>97.1±12.9</td>
<td>1.47±0.12</td>
<td>0.34±0.02</td>
</tr>
<tr>
<td>Young</td>
<td>19</td>
<td>324.6±76.0 c</td>
<td>102.7±93.0</td>
<td>1.42±0.41</td>
<td>0.319±0.068</td>
<td>155.0±31.3</td>
<td>105.8±16.1</td>
<td>1.46±0.14</td>
<td>0.33±0.02 c</td>
</tr>
</tbody>
</table>

Mean values±SD

*significant difference between elderly and midle-aged (p<0.05); ²significant difference between midle-aged and young (p<0.05)
³significant difference between elderly and young (p<0.05)

Fig. 2 Force-velocity and force-power relationships in the elderly, middle-aged, and young groups.

thus, the F-V curve of G-20 showed a more concave pattern than that of G-70. Further, the values for optimal force (Fopt) and velocity (Vopt) at which Pmax appeared were significantly smaller in G-70 than in G-20 and G-50 (Table 3).

Differences in Fmax, Vmax, and Pmax were compared, and the results shown in Fig. 3 (upper). The reduction in Fmax due to aging was 324.6 N in G-20, 285.2 N in G-50 and 244.3 in G-70. Taking the value of G-20 as 100%, Fmax was reduced to 87.9% in G-50 and 75.3% in G-70. Vmax was highest in G-20 (4.44 m/s=100%), followed by G-50 (4.36 m/s=98.2%) and G-70 (3.71 m/s=83.4%). Likewise, Pmax decreased from 155.0 W (100%) in G-20, to 143.3 W (92.4%) in G-50 and 107.8 W (69.6%) in G-70. Among the Pmax values, that of G-70 was significantly smaller than those for G-50 and G-20. In the case of Fmax, a significant difference (p<0.01) was found between G-20 and G-50, while there were no significant differences for Vmax and Pmax among the groups.

Figure 3 (lower) shows the maximum values for unit CSA or upper-arm length (L). The Fmax/CSA ratios were 61.8 N/cm² for G-20, 44.7 N/cm² for G-50, and 42.7 N/cm² for G-70, while the ratios of Vmax/L were 13.6 m/s/cm for G-20, 13.4 m/s/cm for G-50, and 12.4 m/s/cm for G-70. In addition, the Fmax/CSA ratios in G-50 and G-70 were significantly smaller than in G-20, while the Vmax/L ratio was significantly lower in G-70 as compared to the other two age groups.

Discussion

To investigate the effects of aging on the power of the elbow flexors, the force-velocity relationship of the elbow flexors was determined using a modified Wilkie's ergometer,
and the cross-sectional area of muscle (CSA) was measured using an ultrasonic apparatus.

As shown in Fig. 2, the F-V curve of G-70 was considerably lower than that in G-20 and G-50. Valour et al. (2003) reported that velocities under light loads, including Vmax, were lower in the elderly than in young subjects. These findings suggest that aging has an effect on muscle shortening velocity, particularly velocity under light loads. In the present study, Fmax was significantly different among the 3 groups (G-70/G-20/G-50). Similar results have been obtained with regard to elbow flexor strength (Viitasalo et al., 1985; Doherty et al., 1993; Valour et al., 2003) and grip strength (Izquierdo et al., 1999b). Aging effects have also been reported for leg extensor strength (Larsson et al., 1979) and ankle dorsi-flexor strength (Vandervoot and McComas, 1986). All of these reports emphasized that rapid strength reduction occurred after the age of 50. Regarding the onset of muscle strength loss with aging, the significant difference observed between G-20 and G-50 in the present study suggests that strength reduction may begin prior to 50 years old.

Fmax/CSA was lower in the elderly and middle-aged than in the young group, which was similar to the results obtained by Klitgaard et al. (1990) regarding elbow flexors and Izquierdo et al. (1999b) regarding leg extensors. As for the effects of aging on CSA, Frontera et al. (1991) and Klein et al. (2001) observed apparent decrements with age, whereas, Klitgaard et al. (1990) and Miyatani et al. (2003) did not note any changes due to aging. In the present study, we noted that CSA in the G-70 group was not different from those in G-50 and G-20. These discrepancies indicate that the effects of aging toward morphological changes, such as in muscle mass, are not always accompanied by a neuromuscular function, as in muscle strength. Thus, the reduced Fmax/CSA ratio seen in the present study may have more strongly reflected the functional deterioration, as in the number of motor units (Young et al., 1985; Doherty et al., 1993) and/or the firing rate (Esposito et al., 1996; Connelly et al., 1999) during muscle contractions. It was previously noted that morphological changes, such as muscle atrophy, have a relatively smaller effect (Larsson et al., 1979; Lexell et al., 1988).

We found that Vmax and Vmax/L in G-70 were lower than those in the G-50 and G-20 groups, while there was no apparent difference between G-50 and G-20. These results suggest that the effects of aging on muscle shortening velocity might become apparent after 50 years of age. Using male and female subjects ranging in age from 20 to 84 years old, Akima et al. (2001) measured velocity values at 0, 60, 180 and 300 degrees per second by the leg extensor and flexor muscles using an isokinetic machine, and they reported that all velocity values decreased with aging. Similar results were also reported by Frontera et al. (1991) with male and female subjects aged 45–78 years old. The present findings clarified that the
shortening velocity decreases with 0% (Vmax), 10% and 20% of Fmax (Table 2). Regarding these aging effects, Viitasalo and Komi (1978) found that the slope of the developing force in a force-time curve was positively correlated to the ratios of the fast twitch fibers (FT)/slow twitch fibers (ST). Thorstensson et al. (1976) noted that the cause of aging in shortening velocity may be attributed to reduced Type II fibers and their atrophy. Likewise, Narici et al. (1991) and Lexell et al. (1988) emphasized the effects of aging on type II fibers, while Larsson (1978) reported an increase in Type I fibers, and suggested an indirect reduction in Type II fibers. There were no significant differences in CSA among the 3 groups. From these results, the effects of aging on Vmax and Vmax/L seem to be attributable to a decreased recruitment of motor units rather than reduced FT fibers or their atrophy in elderly people.

The relative force (Fopt) at which Pmax appeared was 34.6% in G-70, 34.0% in G-50, and 32.6% in G-20, which were similar to the optimum values presented earlier (Kaneko, 1970; Kaneko et al., 1983; Duchateau and Hainaut, 1984, Moritani et al., 1993; Toji et al., 1997), suggesting a good correlation between force and velocity with Hill’s characteristic equation (1938). In our study, Pmax in G-70 was obviously lower than that in G-50 and G-20, whereas, no significant difference was found between G-50 and G-20, suggesting that the onset may take place after the age of 50, as in the case of Vmax and Vmax/L. The cause of decrement associated with aging has been discussed from the viewpoints of a reduction in FT fibers, their atrophy, and/or reduced recruitment in power development (Häkkinen and Häkkinen, 1991; Häkkinen et al., 1996a; Häkkinen et al., 1996b; Izuierdo et al., 1999b). Valour et al. (2003) examined the ability to produce muscle power in elderly male subjects and compared the results to younger males, for which they used the F-V relationship of the elbow flexors measured with an isokinetic machine. In that study, if the results of the younger group were considered to be 100%, then the elderly group showed 63% for Pmax, 80% for Fmax, and 83% for Vmax. Similarly, as compared to the G-70/G-20 ratio in the present study, the percent values for Pmax, Fmax, and Vmax were 69.6%, 75.3%, and 83.4%, respectively. Likewise, using the relative index of G-70/G-20, the percent values for Pmax/CSA, Fmax/CSA, and Vmax/CSA were 64.2%, 69.1%, and 90.9%, respectively. The larger percent values indicate smaller differences between G70 and G-20. In this regard, the age difference was smallest in Vmax and largest in Fmax. The reason for Pmax being intermediate was considered to be based on the fact that power is derived from both force and velocity. The ratios for Fopt and Vopt for G70/G-20 were 79.8% and 87.1%, respectively, which suggests that Pmax was more strongly influenced by Fmax than Vmax. However, Valour et al. (2003) analyzed both men and women, and reported 72% for Fmax, 69% for Vmax, and 55% for Pmax. This % Vmax value was much lower than ours. Consequently, these differences may reflect the different ideas regarding the effects of Vmax and Fmax on Pmax with aging. In a comparison between G-50 and G-20, it was interesting to note that the greatest decrease due to aging was seen in Fmax, and its reduction started before the age of 50 years old.

The ratio of a/Fmax, which determines the concavity of the F-V curve, may represent the ratio of the internal friction load (a) relative to Fmax (Hill, 1938). Those ratios in G-70, G-50, and G-20 were 0.394, 0.373, and 0.319, respectively, in the present study. Regarding the a/Fmax ratio, earlier studies have shown ranges of 0.20–0.48 (Wilkie, 1950) and 0.45–0.47 (Kaneko, 1970, 1974), and no consistent changes (0.39–0.49) were found in subjects ranging in age from 10 to 19 years old (Fuchimoto and Kaneko, 1980). In the present study, the a/Fmax ratio was greatest in G-70, with G-50 greater than G-20 and a significant difference between G-70 and G-20. Valour et al. (2003) also reported a greater a/Fmax ratio in aged (0.51) as compared to young (0.39) subjects. An age-related increase in the a/Fmax ratio may indicate that the internal resistance of the muscle increases to reduce the shortening velocity of muscle during aging.

From these observations, we concluded that muscle force and shortening velocity may be affected more by muscle function than by CSA in the process of aging.

References

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