短　報

Dynamic characteristics of muscle in preadolescent boys

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Abstract

The purposes of this study were to determine dynamic characteristics of muscle in preadolescent boys from relationship of isometric, concentric and eccentric torque, and effects of growth and development in dynamic characteristics of muscle. Thirteen healthy boys performed maximal efforts of elbow flexion to obtain maximal torque during isometric, concentric and eccentric action. Electromyographic activities of biceps brachii and brachioradialis were also recorded to measure motor unit activation (MUA) during maximal efforts. To determine the dynamic characteristics of muscle in preadolescent boys, maximal isometric (P_0), concentric (P_{CON}) and eccentric torque (P_{ECC}) were analyzed by Hill equation and repeated one-way ANOVA. As a result, relative eccentric torque (P_{ECC}/P_0), which showed 1.19±0.23, was obviously lower than that of adults, and it appeared to stem from the fact that the boys showed less than 1.0 P_{ECC}/P_0. To determine the individuality of P_{ECC}/P_0, subjects were divided into two groups by P_{ECC}/P_0 above 1.0 (high group) or under 1.0 (low group) and then MUA of both groups were compared by repeated two-way ANOVA (group × region of muscle). Consequently the activation level in both regions of muscles of the low group was significantly lower than the high group, and there was no significant interaction. Therefore, it is suggested that the dynamic characteristics of muscle in preadolescent boys are similar to those of adults during isometric and concentric action, and there are effects of growth and development on characteristics of muscle in boys during eccentric action.

Key words : torque, angular velocity, eccentric action, electromyography

1. Introduction

Deterioration in physical fitness among Japanese youth has become an important issue (Nishijima et al., 2003). Because it has become clear through the results of study in recent years that physical fitness is a function of physical activity (Haskell and Kiernan, 2000), it has become necessary to analyze the physical activity of youth in order to solve this problem.

Physical activity has been classified functionally into skeletal muscle activity types: isometric action, concentric action and eccentric action (Haskell and Kiernan, 2000). Study on adults has revealed the dynamic characteristics of muscle, i. e., that maximal torque is exhibited during eccentric action (Westing et al., 1988; Akima and Katsuta, 1999). Meanwhile, Fuchimoto and Kaneko (1981) and Asai and Aoki (1996) have reported in regard to children as subjects that maximal torque in children is far below adult levels and that there is a large difference in maximal angular velocity between children and adults. Differences between children and adults in torque and angular velocity decrease dramatically at the border of the growth spurt (Fuchimoto and Kaneko, 1981). As a result, it is thought that differences in morphological structure such as muscle cross-section (Kanehisa et al., 1994), muscle length (Ito, 1994) and muscle fiber composition (Lexell et al., 1992) influence the differentials in torque and angular velocity between children and adults.

Most study on children has focused on the dynamic characteristics of muscle through comparison of average values with adults (Asai and Aoki, 1996; Marginson and Eston, 2001). However, there has been no study

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reported that has studied the dynamic characteristics of muscle in relationship to torque in isometric, concentric and eccentric action. Great individuality of some 4 to 5 years has been determined in adolescent maturity (Tanner, 1955), so that in order to study the dynamic characteristics of children in greater detail it is necessary to consider individual maturity if study is to be made on the dynamic characteristics of muscle in relationship to torque in isometric, concentric and eccentric action.

The methodology for studying the dynamic characteristics of muscle has been to take either force or contraction speed as the standard and then measure the other (Asai and Aoki, 1996; Perrine and Edgerton, 1978). With force as the standard, isotonic strength was measured; with muscle contraction speed as the standard, isokinetic strength was measured. However, neither maximal eccentric torque nor maximal angular velocity can be accurately measured using an isokinetic dynamometer. Previous study in children have studied the dynamic characteristics of muscle, such as maximal eccentric torque and maximal angular velocity, using isokinetic dynamometers (Perrine and Edgerton, 1978; Seger and Thorstensson, 2000), but there have been no reports of the use of isotonic dynamometers.

Thus the purposes of this study were to determine the dynamic characteristics of muscle in relation to torque in preadolescent boys using an isotonic dynamometer to measure the isometric, concentric and eccentric actions of the elbow flexor muscles, and to study the influence of maturity on the exhibition of muscle strength.

2. Methodology

2.1. Subjects

Subjects were 13 healthy boys in 5th grade of elementary school, age 10.6±0.21 years. Physical characteristics were shown in Table 1. Height was 140.4 ±5.97 cm, and weight was 34.2±6.03 kg. Subjects were relatively active youth, in the habit of exercising 2 to 3 hours about 3 times per week above mid-level (3 METs to 7 METs). In addition, all the subjects and their guardians were fully informed of the purposes, contents and dangers of the study, and their consent was obtained.

Table 1 Physical characteristics of the subjects (N=13)

Variables (unit)	Mean	SD
Age (years)	10.6	0.21
Height (cm)	140.4	5.97
Weight (kg)	34.2	6.03

2.2. Measurement methods

Measurements were conducted of maximal torque and maximal angular velocity on all subjects in isometric, concentric and eccentric action. Eccentric action load was set at twice the maximal isometric torque. After first conducting the measurement of isometric action, measurement of concentric action and eccentric action was made by random arrangement.

Figure 1 showed the arm-ergometer. A force transducer (LU-100KSB34D, Kyowa Electric Instruments Co., Ltd.), an angle transducer (JC40S, Copal), and an accelerometer (AS-20GB, Kyowa Electric Instruments CO., Ltd.) were attached, and the transducer signals were passed through an amplifier and A/D converter to be entered into a computer. Subjects were seated, idle arm placed flat on the tabletop, and the upper arm fixed. The arm to be used was defined as the arm most frequently used in daily life, selected by the subject himself. In all cases, subjects chose the right arm. Measurement was conducted after warm-up in concentric action of 1 kg load lifted 10 times, and subjects were admonished to exert maximum effort.

The angle of measurement of isometric action was set at 90°, and the maximal value of torque exerted was

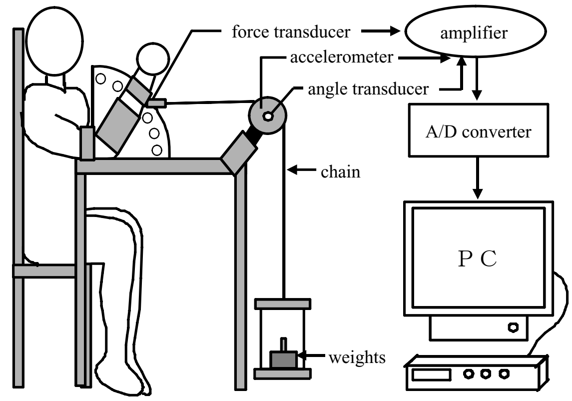

Figure 1 Experimental device

determined to be the maximal isometric torque. In the measurement of concentric action, stoppers were used to limit movement of the elbow joint to the range of 150° to 70°. Lifting load was increased from 1 kg in 1kg increments until subject could not lift load. In the measurement of eccentric action, a load greater than the maximal isometric torque was held at an elbow angle of 80° with the aid of a helper. At a signal, the helper's support was removed, and the subject resisted the load with all his strength; the average value obtained from 3 repeated measurements was determined to be the maximal eccentric torque. Further, to avoid the effects of fatigue, a period of at least 3 minutes of rest was given per traction. Demonstrated eccentric torque (P_{ECC}) was shown as a value (P_{ECC}/P_0) relative to maximal isometric torque (P_0).

2.3. Torque-angular velocity curve

Torque and angular velocity measured through isometric and concentric action were substituted into Hill's equation (Hill, 1938) and a torque-angular velocity curve was drawn.

$$(P + a) \quad (V + b) = (P_0 + a)\, b$$

Here, P is the weight of the load, V is the angular velocity, a is the heat constant and b is the energy isolation rate constant (a, b are Hill constants); P_0 is the maximal isometric torque. a and b are coefficients estimated through nonlinear regression analysis, and both coefficients are known to show the dynamic characteristics of muscle. This equation is based on measurement values of heat production in frog skeletal muscle during isotonic muscle action. It has been reported that Hill's equation is applicable to human muscle using an isotonic dynamometer (Wilkie, 1950; Kaneko, 1970; Kojima, 1991).

Elbow angle, force and acceleration were measured by an angle transducer, force transducer and accelerometer, respectively. Measurement value acceleration = 0 was used, based on the method of Kojima (1991). For force, torque (Nm) was sought by capitalizing on the acceleration of gravity 9.8 m/s^2 and forearm length. Forearm length was taken to be the distance from the desktop to the wrist (carpus) at measurement of maximal isometric torque. Angular velocity was sought by elimination of the elbow angle when acceleration = 0.

2.4. Electromyography

Integral electromyographic activity was measured as an indicator of motor unit recruitment at the same time that measurement was made of torque and angular velocity. Action potential was recorded from the elbow muscle group (biceps brachii, brachioradialis) with surface electrodes at 20 mm intervals. Electromyography was amplified, and, after A/D conversion, read into a computer through a 50kHz low-cut filter. In the computer, the data were subjected to full-wave rectification, and after time integration, the time element was eliminated. The data used in this study were in the range from 90° to 110° elbow angle during eccentric action.

2.5. Statistical analysis

All measurement results are shown in average values ±SD. In the comparison of maximal torque of isometric, concentric and eccentric action, repeated measures one-way layout ANOVA was conducted, and whenever a significant main effect was confirmed, post-hoc test was conducted using the Tukey HSD test. In addition, the goodness of fit of Hill's equation was determined from the coefficient of correlation, and the dynamic characteristics in preadolescent boys during isometric and concentric action were determined from the assumed Hill constants a and b. The Hill constants were assumed using the nonlinear least square method (Levenberg-Marquardt method).

In order to determine maximal eccentric torque characteristics, maximal eccentric torque was divided into two groups, one in which it was greater than maximal isometric torque and one in which it was less. Integral electromyographic activity at each measurement site (biceps brachii, brachioradialis) was compared by means of repeated measures two-way layout ANOVA (group 2 level x site 2 level). Whenever significant main results were determined and significance of interaction was not determined, post-hoc test was conducted using the Tukey HSD test. SPSS 11.5 for Windows was used in all statistical analyses. Significance level was taken to be $\alpha = 0.05$.

3. Results

Table 2 Descriptive statistics (N=13)

Variables (unit)	Mean	SD	Max	Min
Maximal concentric torque (Nm)	10.6	2.61	13.1	7.3
Maximal isometric torque (Nm)	20.0*	3.62	23.0	13.6
Maximal eccentric torque (Nm)	22.0*,**	4.73	36.1	16.4
Maximal eccentric torque (P_{ECC}/P_0)	1.19	0.23	1.60	0.87

*: higher than maximal concentric torque (p<.05)
**: higher than maximal isometric torque (p<.05)

Table 2 showed the descriptive statistics for maximal torque of the various types of muscle action. The maximal concentric torque of the elbow flexor muscles was 10.6 ±2.61 Nm, the maximal isometric torque 20.0±3.62 Nm, and the maximal eccentric torque 22.0±4.73 Nm (P_{ECC}/P_0 = 1.19±0.23). Maximal angular velocity was 592.4 deg/sec. As a result of the repeated measures one-way layout ANOVA, significant main results were significant, so comparison of the various types of action was conducted using post-hoc test. Maximal isometric torque was significantly higher than maximal concentric torque, and maximal eccentric torque showed significantly higher values than either maximal isometric torque or maximal concentric torque.

Figure 2 showed the torque-angular velocity relationship. Goodness of fit to the Hill equation was coefficient of correlation r = 0.91. The Hill constants were a = 0.76, b = 452.9.

Table 3 showed comparison of the integral electromyographic activity of the group in which maximal eccentric torque was greater than the maximal isometric torque with the group in which it was smaller. As a result of the repeated measures two-way layout ANOVA, main results showed significant values in 2 factors, and significant interaction could not be determined. Therefore,

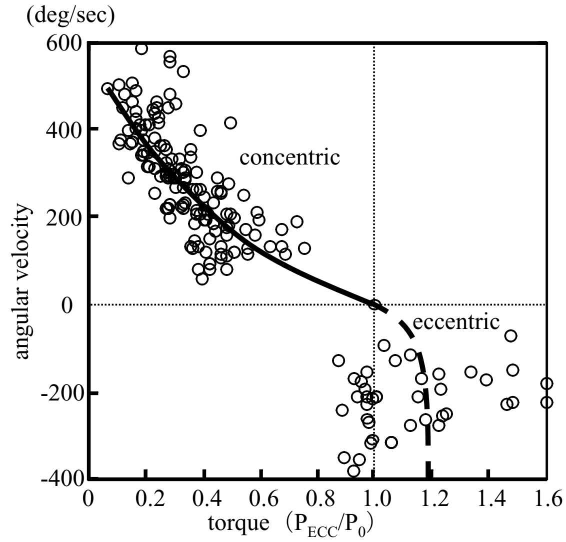

Figure 2 Torque-angular velocity relationship in preadolescent boys

comparison was carried out on the various average values by means of post-hoc test (Tukey HSD test). The group in which maximal eccentric torque was higher than maximal isometric torque showed significantly high integral electromyelographic activity in the biceps brachii and in the brachioradialis.

4. Discussion

The subjects, whose height and weight were nearly the same as the height of 139.0±6.11 cm and weight of 34.5± 6.77 kg reported in Sports and Youth Bureau in Ministry of Education, Culture, Science and Technology (2003), can be deemed normal 10 year-old boys.

In comparison of maximal isometric torque, concentric torque and eccentric torque averages, isometric torque showed significantly higher values than concentric torque, and eccentric torque significantly higher values than isometric torque (Table 2). These results are in agreement with previous study on adults (Westing et al.,

Table 3 Comparison of activation level between low and high group of relative eccentric torque (P_{ECC}/P_0)

group	number	sample	P_{ECC}(Nm)	P_{ECC}/P_0	biceps brachii(mV)	brachioradialis(mV)
			Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
$P_{ECC}/P_0 \geqq 1.0$	10	30	24.8 ± 4.33	1.26 ± 0.14	0.064 ± 0.096*	0.053 ± 0.105*
$P_{ECC}/P_0 < 1.0$	3	9	19.4 ± 3.22	0.96 ± 0.03	0.010 ± 0.011	0.008 ± 0.004

*: higher than low group (p<.05)

1988; Seger and Thorstensson, 2000). Torque and angular velocity in isometric and concentric action showed very good goodness of fit with the Hill equation of coefficient of correlation r = 0.91 (Figure 2). The assumed Hill constants, a = 0.76, b = 452.9, showed almost the same values as Asai and Aoki (1996). Fuchimoto and Kaneko (1981) reported that they could not determine great differentials in comparison of Hill constants a, b between preadolescent boys and adults. From the above results, it can be speculated that the dynamic characteristics of preadolescent boys in isometric and concentric action are similar to those of adults.

In this study, maximal eccentric torque in preadolescent boys showed values about 120% of maximal isometric torque. In previous study on adults, maximal eccentric torque has been reported to be from 140% to 180% of maximal isometric torque (Ishii, 1994). Maximal eccentric torque obtained in this study had a lower value in comparison to previous study on adults. According to the measurement data plot, 3 subjects had smaller values for maximal eccentric torque than for maximal isometric torque (Table 3). It is speculated that this is caused by the large individuality observed in eccentric torque. As a result of comparison of integral electromyographic activity, significant main effects were observed between the groups that were divided by the amount of maximal isometric torque and maximal eccentric torque. Significance of interaction was not observed. This result shows that differences in integral electromyographic activity between the groups are not affected by the location of the active muscle.

Integral electromyographic activity is an indicator of motor unit recruitment. The strength of muscle activity is regulated by the number of motor unit recruitments and the firing rate of action potential of the α motor neuron (Burke et al., 1981; Henneman and Mendell, 1981). It is speculated that a reason why maximal eccentric torque showed lower values than maximal isometric torque is that in exercise at maximum effort motor unit recruitment was undeveloped, and no increase in motor unit recruitment was possible. Motor units are broadly classified according to contraction velocity in the controlling muscular fibers, strong contraction tension, histological and biochemical characteristics, etc. Muscles in preadolescent children have fast-twitch fibers that are undeveloped in comparison with those of adults (Lexell et al., 1992); it is speculated that the motor units that control fast-twitch fibers could not contribute to maximal torque or maximal angular velocity as in adults.

From the above it was speculated that the dynamic characteristics of muscle in preadolescent boys are similar to those of adults in isometric action and concentric action, and that degree of maturity affects motor unit recruitment in eccentric action of preadolescent boys.

However, it is thought that the small sampling size of 13 boys in this study, and the fact that comparisons are made with untested persons taking the integrated burst discharge value as a dependent variable, place limits on generalizing the results of this study. Remaining tasks include the avoidance of statistical error in tests of differentials in average values, using a larger sample to ensure robustness in the tests, proper design of experiments, and choosing a statistical model to study conspicuous differences in eccentric muscle action.

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