SPECIFICITY OF TORQUE PRODUCTION TO MUSCLE CONTRACTION AT HIP, KNEE AND ANKLE JOINTS

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Ten male college students performed the simple strength test of the lower limb with using isokinetic dynamometer. The values of flexion and extension torques tended to be the largest at the hip and smallest at the ankle joint in both ECC and CON. However, the ratio of ECC/CON (%) was significantly greater at ankle joint compared with the hip and knee. These finding indicate that ankle joint produce torque more efficiently by ECC than by CON. Also, the correlation coefficients between the values of torques were not significant among three joints. These finding indicate that the ability of torque production is independent in each joint. These results suggest that the characteristics of torque production by the hip, knee and ankle joint vary considerably, reflecting their structural and functional properties.

KEY WORDS: lower limb joint, torque, muscle contraction, specificity

INTRODUCTION: The torques of flexion and extension at each joints of the lower limb during running and jumping are the results of the tension generated by the muscle-tendon complex (MTC) acting on the joints. While muscles that constitute this MTC contract and produce tension, tendon themselves do not produce tension but are dependent on muscle contraction for their tension. However, tendons store elastic energy as they are stretched and shorten explosively in a manner resembling a spring and generate extremely large tension. Also, as the MTC and various tissues around the joint execute complex maneuvers during physical exercise, the performance of physical exercise is not determined simply by characteristics of the muscles per se. Therefore, the torque generated by each joint of lower limb largely reflects the structure and function of MTC constituted by muscles, which are the primary source of tension, and tendons, which absorb, store, and release this tension. Characteristics of a MTC, therefore, are expected to vary widely with the position of the joint in the kinetic chain of the body, which is a serial multi-joint system, and the main function of the joint. For example, the hip joint is located in the center of this system, very large muscle groups such as the extensors including the gluteal muscle and adductor muscles of the thigh insert to it, and the trunk with large mass ratio and moment of inertia moves around this joint. For this reason, it can generate the greatest power among the three joints of the lower limb and is considered to be a major source of power. The knee, which is located between the ankle and hip, not only generates a large power but also efficiently transmits a large power generated by the upper hip joint to the lower ankle joint. In contrast, the ankle, located most distally among the three joints of the lower limb, is a terminal point of transmission of the power generated by the upper joints and is considered to efficiently convey it to the ground. Therefore, in comparison with the MTC of hip and knee, tendinous components occupy a larger percentage in the MTC of ankle, suggesting high capacities of storage and reuse of elastic energy. Also, to efficiently carry out this function, the MTC of ankle must have torque-generating characteristics in which eccentric muscle contraction is stronger than concentric muscle contraction compared with the knee and hip. Thus, torque-generating characteristics of three joints of the lower limb are considered to vary widely depending on the position of the joint in the kinetic chain, its motion range, dynamic characteristics of somatic segments related to it, the thickness and length of the muscle groups involved, the thickness and length of the tendons involved, and the muscle-tendon ratio. In this study, therefore, differences in the torque-generating characteristics of serial multi-joint system at the three joints of the lower limb corresponding to their structure and functional properties were evaluated with particular reference to the differences in type of muscle contraction.

METHODS: The subjects were 10 male college students majoring in physical education (age, 20.0 ± 2.1 years; height, 1.75 ± 0.06 m; body weight, 65.8 ± 4.35 kg). The subjects were explained in advance about the procedures of measurements and the risk in details. The isokinetic dynamometer (BIODEX) was used for the measurement of the torques at the hip, knee, and ankle joints. The subjects were seated in a chair of the measurement apparatus and immobilized tightly with special belts so that only the region of measurement remained movable, and the position of the lever arm was adjusted so that its rotation axis became uniform to the rotation axis of the joints. The movements measured were flexion and extension of the hip and knee and dorsiflexion and plantar flexion of the ankle. Each movement was performed at 3 angular velocities of 30, 60, and 120 °/ sec by both concentric and eccentric contractions. Measurement trials were performed 3 times each with maximum exertion, and the peak torque was calculated. Trials were interposed with sufficient rest to eliminate the effect of fatigue on the measurements. The results of measurement were expressed as the mean±SD. The differences in flexion and extension torques of the hip, knee, and ankle joints were examined by one-way analysis of variance. The relationships among the torques of the three joints were examined using Pearson's correlation analysis. The level of signification was $p<0.05$ in all test.

RESULTS AND DISCUSSION: The values of flexion and extension torques generated by the three joints of the lower limb tended to be the largest at the hip and smallest at the ankle joint in both eccentric (CON) and concentric (ECC) contraction types (Fig.1). Major muscle groups including the flexor muscles of the thigh such as the gluteal muscle and adductor muscles are involved in the hip joint located in the center of the serial multi-joint system, while small muscle groups such as the triceps surea muscle and anterior tibial muscle are involved in the ankle joint located in the distal part of this system. Characteristics of the cross-sectional areas of these lower limb muscles have been studies initially by anatomy of corpses and more recently by the ultrasound, CT, and MRI techniques. As a result, a significant positive correlation has been

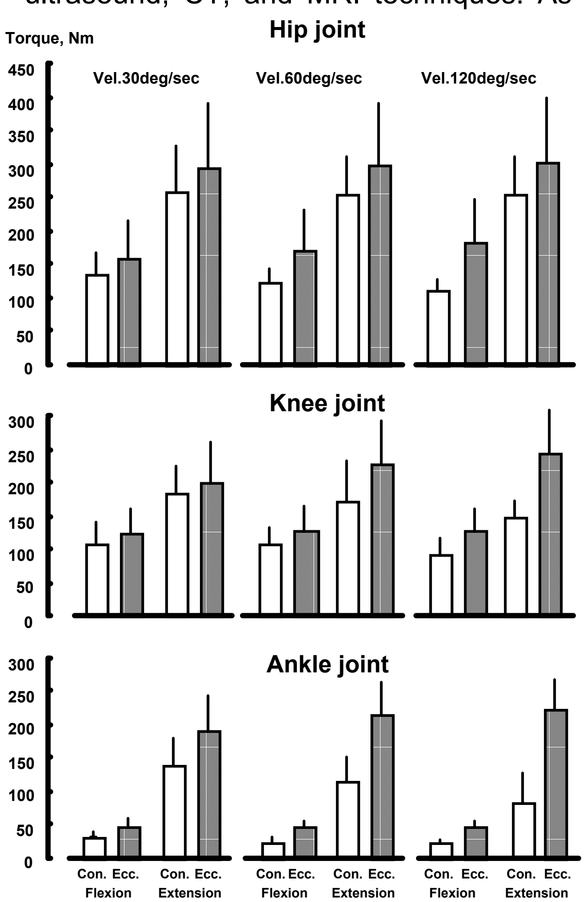

Figure 1. Average peak torques of extension and flexion at the hip, knee and ankle with concentric and eccentric contraction.

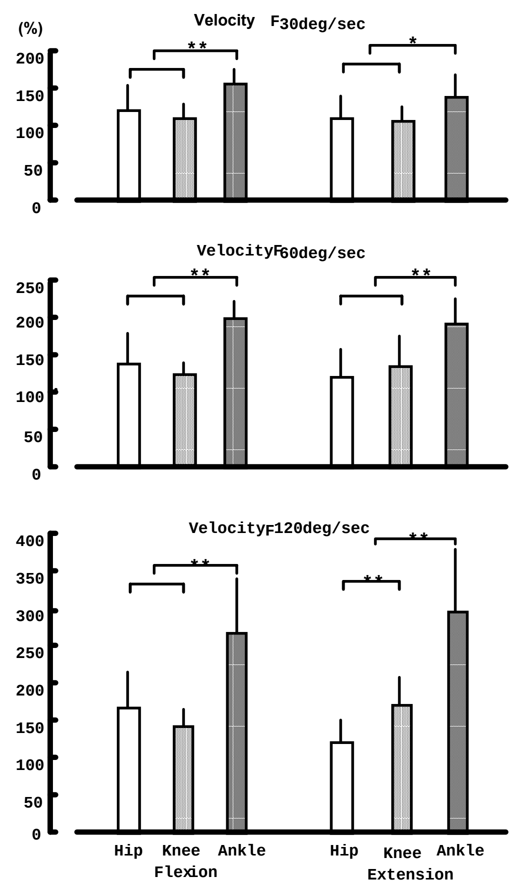

Figure 2. Ratios (%) of peak eccentric to concentric torque of extension and flexion at the hip, knee and angle.

* ; p < 0.05,** ; p < 0.01

noted between the cross-sectional area of the muscle and torque. From these reports, the torque was expected to be greater as the joint had more muscles with a large cross-sectional area, i.e. hip>knee>ankle. The moment arm, mass ratio, and moment of inertia of the body segments involved in each joint are also considered to increase in the same order. Therefore, if a joint with small moment arm, mass ratio, and moment of inertia produces a torque from the relaxed state, the rotational movement of the segment is accelerated instantaneously, and the limit of the motion range is reached immediately, so that there may not be sufficient time for the joint to produce a large torque. That is, there is the possibility that a joint in which these factors are small may not be able to produce a large torque due to the restriction of the dynamic characteristics of the body segments involved in the joint. The difference between the ECC torque and CON torque tended to increase from the hip to the ankle (Fig.1). When the rations of ECC torque to CON torque (ECC/CON, %) were evaluated in the hip, knee, and ankle joints, ECC/CON was significantly greater in the ankle joints compared with the hip or knee, and this tendency was greater as the angular velocity was higher (Fig.2). These findings suggest that the MTC of ankle joint produce torque more efficiently by ECC than by CON. Therefore, the MTC of the ankle joint constituted by small muscle groups such as the triceps surea muscle and anterior tibial muscle is considered to have small contraction factors and is inferior in CON torque roduced by its own contraction. However, the ECC torque generated as it is extended was suggested to be considerably greater than that estimated from its small contraction factors and low CON torque. The following factors are considered to be related to the development of such torque production characteristics. First, the hip is located in the center of the serial multi-joint system and receives insertions of large muscle groups so that it can produce a large power concentrically by contraction of its own muscles. This large power is known to be transmitted via the interarticular forces and bi-articular muscles to the knee and further to the ankle (Bobbert, 1986a, b). The ankle joint absorbs the power transmitted from the upper hip and knee joints by ECC and stores it also in the tendinous components and conveys the power efficiently to the ground as these structures act as springs rather than produces a large power by contraction of its own muscles. For this reason, it is important for the MTC of the ankle joint to be highly elastic for efficient storage and reuse of this elastic energy. Also, the capacity of storage and reuse of this elastic energy has been shown to be greater as the ECC muscle strength is larger, and as the time needed for the shift from ECC to CON is shorter (Asmussen,1974 ; Bosco, 1981). The above results that the MTC of the ankle joint is better in exertion of ECC torques are what the ankle joint needs for smooth execution of this function. In addition, the MTC of ankle includes a large tendon, i.e. AchIlles tendon, which increases the percentage of the tendinous components in the complex, to a major advantage for execution of this function. The results obtained in this study suggest that the characteristics of torque production by the ankle joint are closely associated with its structural and functional properties such as (1) that it is located at the end of the kinetic chain of the body as a serial multi-joint system, (2) that it is responsible for efficient exchange of a large power it receives from the upper structures with the ground, and (3) that it has a greater percentage of tendinous components and is the most liable to the effect of storage and reuse of elastic energy. The above findings indicate that the characteristics of torque production by the hip, knee, and ankle joint vary considerably, reflecting their structural and functional properties. Therefore, we further studied interrelations between the flexion and extension torques in each joint. The correlation coefficients between ECC and CON torques were significant in each joint, but no significant correlation was observed among the three joints. This tendency was more notable as the angular velocity of the motion was greater. Tab.1 is the results of 60°/ sec. These results suggest that the MTC of ankle is not necessarily strong individuals with strong MTC of hip and knee and that the ability of torque production is independent in each joint.

Table 1. Correlation coefficients among eccentric and concentric torques at the hip, knee and ankle with angle velocity of 60 deg/sec.

Flexion movement

		Hip		Knee		Ankle	
		con.	ecc.	con.	ecc.	con.	ecc.
Hip	con.		0.748*	0.330	0.457	-0.032	-0.245
	ecc.			0.354	0.635	0.189	0.183
Knee	con.				0.839**	0.443	0.233
	ecc.					0.407	0.270
Ankle	con.						0.885**
	ecc.						

Extension movement

		Hip		Knee		Ankle	
		con.	ecc.	con.	ecc.	con.	ecc.
Hip	con.		0.700*	0.233	0.405	0.514	0.620
	ecc.			0.273	0.587	0.456	0.461
Knee	con.				0.697*	0.297	0.172
	ecc.					-0.038	-0.056
Ankle	con.						0.938 **
	ecc.						

CONCLUSION: These results suggest that methods suited for the characteristics of the joint and its MTC shown by this study must be created and selected to effectively conduct muscle strength and power training of the MTC involved in a given joint. In the MTC of the hip, for example, the contraction force of the muscle, i.e. the ability to generate CON torque, must be developed. For this purpose, methods to increase the muscle strength by inducing muscle hypertrophy and those to increase the power by improving the neural function as well as inducing muscle hypertrophy are considered to be useful. On the other hand, in the MTC of the ankle joint, it is considered necessary to increase the ability to generate ECC torque, i.e. the tolerability to muscle extension, and to develop the restitution the tendons connected to the muscles. This will be achieved efficiently by the use of plyometric training combined with conventional methods of muscle strength and power training. Further studies are considered to be needed to clarify more appropriate methods for muscle strength and power training and to evaluate their training effects.

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