Torque-velocity Patterns of Hip, Knee and Ankle Flexors and Extensors during Concentric and Eccentric Actions

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Abstract

The torque-velocity relations in the eccentric and concentric actions of extensors and flexors around hip, knee, and ankle joints were examined in 13 untrained males (21-46 years) using Loredan's LIDO isokinetic dynamometer. The peak torques developed during eccentric actions (ECC) showed large value in comparison with maximal static torques (Po): knee extensors (108-112% of Po) ; knee flexors (101-105 % of Po) ; dorsiflexors (109-120% of Po) ; plantarflexors (102-112% of Po); hip extensors (100-118% of Po) ; and hip flexors (108-113% of Po). In all muscle groups, torques developed in ECC did not significantly change with increasing velocity, although the maximal ECC was significantly greater ($p<.05$) than the static torque. The static torque was significantly greater ($p<.05$) than the concentric torque which decreased with increasing velocity. The large difference between the in vivo eccentric torque-velocity profiles obtained in this experiment and those reported for muscle isolated from animals could be due to the presence of neural inhibitory mechanism (Wickiewicz et al, 1984 and Westing et al, 1990).

Introduction

Torque-velocity curves in muscle contraction have been studied extensively for intact human lower body muscle, though few studies have described eccentric muscle action. Isolated skeletal muscle preparations from animals have consistently shown to produce eccentric force larger than isometric force, sometimes twice as large, with increasing lengthening velocity(3,9). On the other hand, voluntary contractions of human skeletal muscles eccentric torque remaining constant(1,4,6,7,13, 14,15,16), increasing(1,8), decreasing(1,2), or increasing initially and then decreasing(5,12) with increasing lengthening velocity. Even though these studies have been carried out for only extensors and flexors of knee and elbow, the results are not conclusive mentioned above.

The purpose of this investigation was to evaluate the joint kinetics of the hip, knee, and ankle in both isokinetic lengthening and shortening muscle actions. Examining the eccentric torque-velocity patterns of the extensors and the flexors of these joints would help to account for the discrepancy in eccentric torque-velocity data currently presented. A torque-velocity curve was first drawn for each joint. Then the data were discussed with special reference to the discrepancy between the results by Cybex II (10,17) and those by SPARK System(13,14,15).

Methods

Subjects 13 males gave their written consent to participate (mean$\pm$SD for age, body mass and height : 26.5$\pm$8.2 years, 75.0$\pm$11.3kg, 177.5$\pm$10. 4cm,respectively). The subjects had not previously been trained on an isokinetic device.

Experimental apparatus. The LIDO Active Isokinetic Rehabilitaion System (Model # 100303-01; Loredan Co., Ltd.) was used to measure eccentric (ECC) and concentric (CON) torques at constant angular velocities. For the measurements on the knee extension (KE) and flexion (KF), the subjects were seated on a sturdy test chair provided. The angle between the backrest and the base was 105 deg, while the base was 10 deg up in its front from the horizonatal line. The subjects were stabilized by a seat belt placed around their waist, and an adjustable thigh pad held their thigh on the chair base. They maintained their backs against the seat and used hand grips on each side of the base to further stabilize the upper body position. Lateral femoral condyle was aligned with the LIDO lever arm's axis of rotation. A cuff was attached just proximal to the maleolus for recording torque. Shoes were optional for the subjects.

For dorsiflexion (DF) and plantarflexion (PF), the subjects kneeled on the test chair with their addomen pressed against the backrest. The angle between the seatback and the base was 105 deg. A strap was placed around the seatback and across the hamstrings, and another belt was placed over the calves to secure the lower leg. The subjects grasped the back of the chair for further support. LIDO was connected to the foot by aligning the lateral maleolus with the lever arm's axis of rotation and securing the bottom of the foot to a plate with two straps-one across the metatarsals and the other wound around the calcaneous through the maleolae.

Hip extension (HE) and flexion (HF) measurements were made with the subjects laid on their back. The axis of rotation of the dynamometer was aligned with the greater trochanter. Knee angle was kept at 90 deg by placing a Bledsoe Sports Rehab Knee Brace (Medical Technology Co.) on the right leg. The body position was adjusted on the table so that the right leg was fully extended over the end of the table. The angle between the backrest and the base was 175 deg, so that the hip angle was elevated by 5 deg above the horizontal line. Each subject was secured to the chair by a belt wound around the waist and two belts crossing over the shoulders. A lower thigh cuff was attached and connected to the LIDO lever arm for recording of hip joint torque.

Procedures. Torque-velocity patterns were examined for the following joint movements: KE, KF, DF, PF, HE, and HF of the right leg. Testing for each joint was done on separate days where there was no soreness in other muscle groups caused by previous testings. Torques in maximal voluntary ECC, static, and CON actions were measured at velocities of 0, 30, 60, 90, 120, 180, 210, 240, 270 (for CON only), 300 (CON), 350 (CON), and 400 (CON) deg/s. For each muscle group, static trials (each lasting for 3s) were performed at four different angles. The highest torque among those at the four angles was regarded as the maximum static torque (Po). The joint angles used were within the following range: KE (60-90 deg), KF (10-40 deg), PF (130-100 deg), DF (180-150 deg), HE (110-80 deg), HF (10-40 deg), where 0 deg means full extension for hip and knee joint. These angles were chosen on the basis of the optimal angle for maximum force production as follows. For each subject, the angle at which maximum isometric torque was generated was first determined. The motion of each joint was limited within the range over which the subjects did not feel any uncomfortableness. The subjects then performed generated maximal isokinetic contractions over the range around this maximum torque-producting angle. This technique was proposed originally by Wickiewicz et al. (1984) since contractions over too wide range require pro-longed efforts that are "fatiguing" if held maximally throughout the arc of motion (17). The order of measurements was randomized for each subject. A minimum of three ECC and two CON trials at each velocity were performed. One or two additional trials were performed if torque continued to increase. The highest torque recorded among a series of trials at a given velocity was adopted.

Statistics. Absolute torque at each velocity was converted to a value relative to static torque (Po). Paired t-tests were done within each muscle group to determine the significance of difference between torques developed at varied velocities. An alpha level of $p<0.05$ was required for statistical significance.

Table 1. Mean SD of isometric and eccentric torques (Nm) for extensors and flexors of hip, knee and ankle joints.

	Velocity (deg/s)	HE	HF	KE	KF	PF	DF	KE#
Isometric								
	0	226 ± 71	181 ± 55	295 ± 56	146 ± 25	182 ± 30	46 ± 6	269 ± 40
Concentric								
	30	221 ± 60	161 ± 46	258 ± 54	129 ± 29	140 ± 33	33 ± 6	269 ± 42
	120	174 ± 54	131 ± 47	174 ± 32	103 ± 21	83 ± 21	21 ± 3	186 ± 31
	270	128 ± 41	102 ± 25	139 ± 31	74 ± 11	50 ± 13	18 ± 4	127 ± 18
Eccentric								
	30	303 ± 53 *	196 ± 54	305 ± 44 *	147 ± 27	183 ± 30	54 ± 6 *	287 ± 53
	60	309 ± 57 *	198 ± 45	299 ± 40 *	150 ± 24	193 ± 32 *	54 ± 8 *	- -
	90	285 ± 80 *	191 ± 46	300 ± 40 *	153 ± 25 *	200 ± 36 *	56 ± 8 *	- -
	120	283 ± 88 *	191 ± 41	307 ± 43 *	153 ± 24	200 ± 36 *	55 ± 8 *	288 ± 59
	150	262 ± 76	196 ± 59	285 ± 56	156 ± 30	199 ± 45 *	51 ± 9 *	- -
	180	239 ± 63	196 ± 59	291 ± 54	152 ± 30	195 ± 47	52 ± 9 *	- -
	210	240 ± 75	195 ± 59	288 ± 49 *	150 ± 30	192 ± 45	50 ± 9 *	- -
	240	229 ± 60	199 ± 56 *	279 ± 51	151 ± 25	191 ± 49	49 ± 8	- -
	270	- -	- -	- -	- -	- -	- -	299 ± 60

HE: hip extension (n=8), HF: hip flexion (n=8), KE: knee extension (n=10), KF: knee flexion (n=11), PF: plantarflexion (n=8), DF: dorsiflexion (n=8)
* significantry ($p<.05$) greater than static torque.
KE#: data from Westing et al., 1988.

Results

Peak ECC torques in KE, KF, PF, DF, HE, and HF were significantly greater than their static torques.

Table 1 shows the mean absolute torques of all the muscle groups, with asterisks(*) denoting those significantly greater than the static torques. Comparison between ECC torques measured at different velocities for each joint movements lead to the following results; 1. In HE and HF, ECC torque did not change with increasing velocity; 2. In KE, ECC torques at 90, 180, and 210 deg/s were significantly greater than that at 240 deg/s; 3. In KF, ECC torque at 90 deg/s was significantly greater than that at 30 deg/s; 4. In DF, ECC torque at 30 deg/s was significantly greater than that at 240 deg/s, 90 deg/s was significantly greater than those at 60, 210, and 240 deg/s, that at 120 deg/s was significantly greater than those at 150

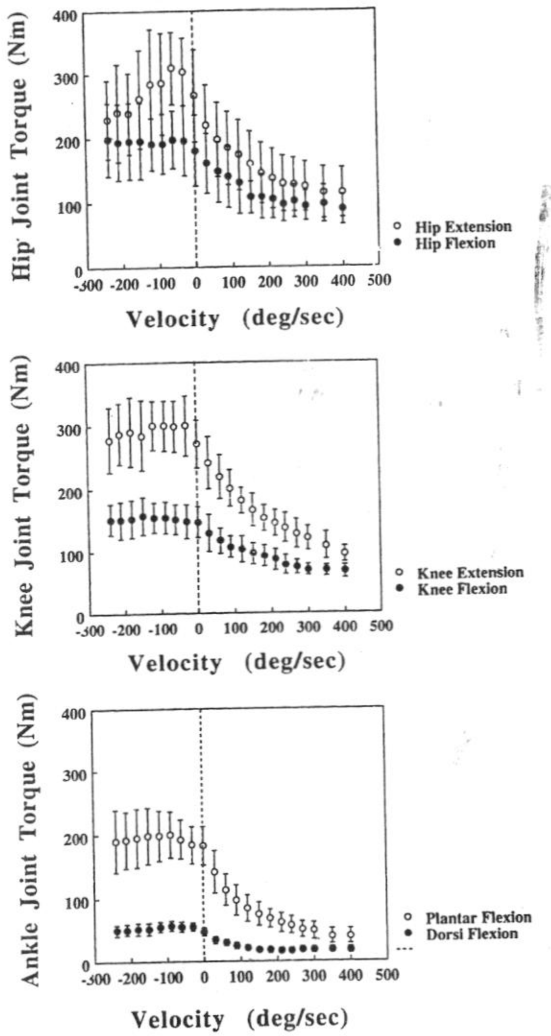

Fig.1 Joint torque-velocity profiles in hip extension and flexion, knee extension and flexion, planter flexion and dorsilexion (mean±SD).

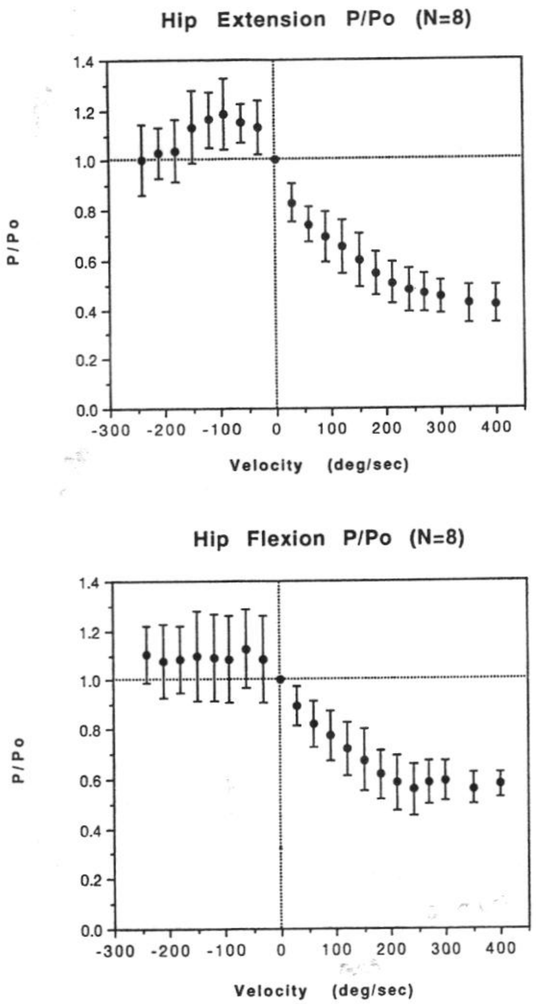

Fig.2 Relative values (mean±SD) in torque to maximal static torque (Po) in relation to velocity in hip extension (upper) aud flexion (lower).

and 240 deg/s and that at 180 deg/s was significantly greater than that at 240 deg/s, 5. In PF, ECC torques at 60, 90, 120, and 150 deg/s were significantly greater than that at 30 deg/s.

In each muscle group, ECC torques were within the following ranges (%Po): KE (108-112%), KF (101-105%), PF (102-112%), DF (109-120%), HE (100-118%), HF (108-113%), ECC torques were always significantly greater ($p<0.01$) than CON torques, with larger differences seen as velocity increased. CON torques were always significantly smaller than the static torques in all six muscle groups, and decreased with increasing velocity.

Fig. 1 shows the torque-velocity curves for the HE, HF, KE, KF, PF, and DF. These are replotted on the torque axis normalize to Po in Fig. 2-4. In Fig. 5, data from all the muscle groups were averaged.

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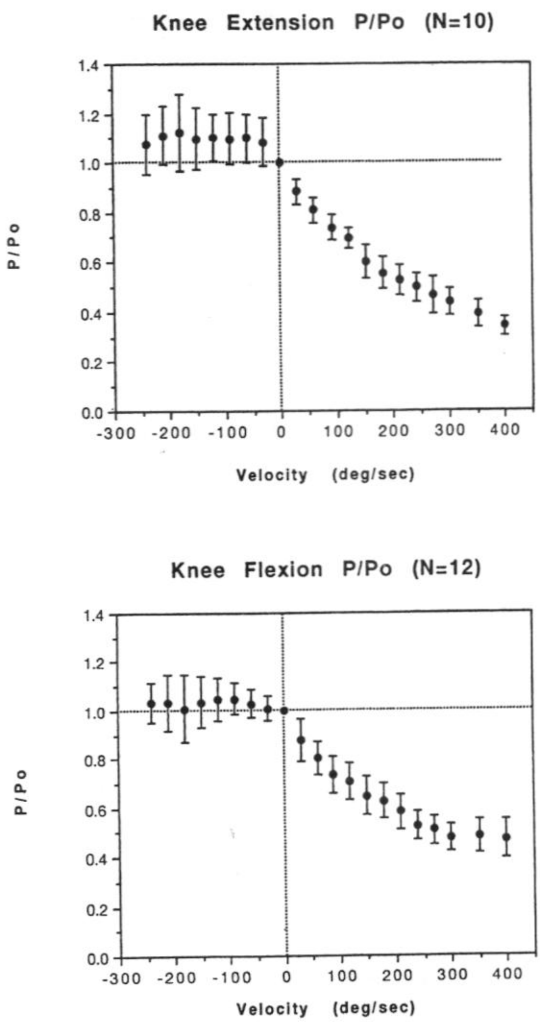

Fig.3 Relative values (mean±SD) in torque to maximal static torque (Po) in relation to velocity in knee extension (upper) and flexion (lower).

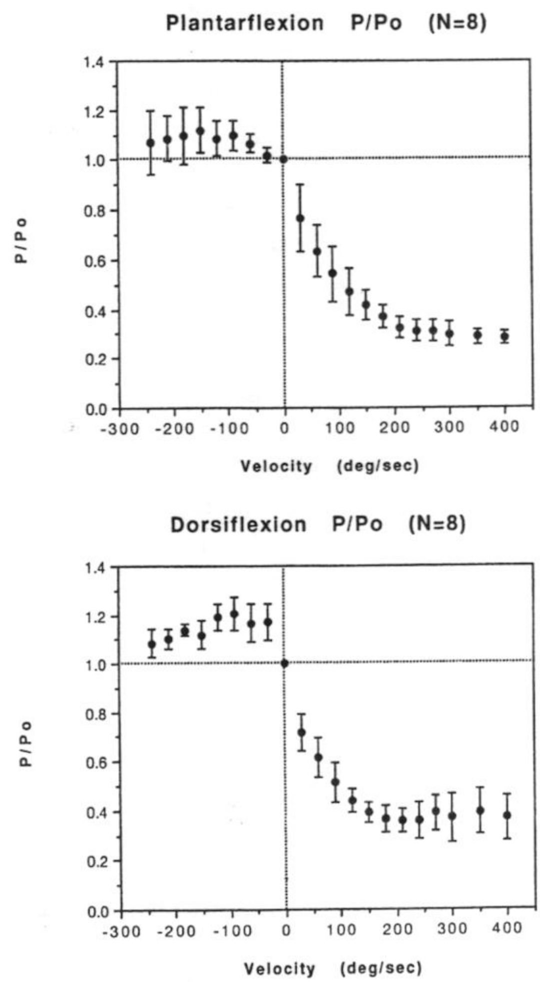

Fig.4 Relative values (mean±SD) in torque to maximal static torque (Po) in relation to velocity in plantarflexion (upper) and dorsiflexion (lower).

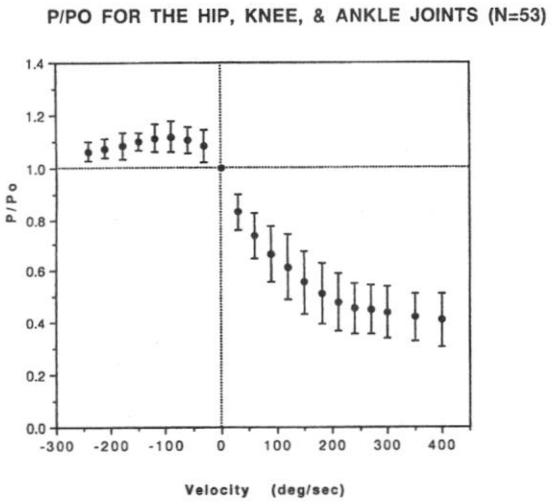

Fig.5 Relative values (mean±SD) in torque to maximal static torque (Po) in relation to velocity. Each mean and SD were averaged from the data obtained in hip extension and flexion, knee extension and flexion, planterflexion and dorsiflexion.

each diagram is due to misrecordings in some subjects producing torques that exceeded the LIDO's upper limit torque setting: for the safety of the testing, the movement of lever arm of the LIDO was automatically set to stop when the torque exceeds over 400 Nm for HE, HF, KE and KF, and over 300 Nm for PF and DF.

Discussion

The results of this study revealed that the torque-velocity patterns are similar for the extensors and the flexors in each hip, knee, and ankle joint. The peak eccentric torque of each muscle group was significantly greater than the static torque, but no pattern where eccentric torque increased with velocity was observed. The results generally agree with previous studies with male and female subjects, in which knee and elbow extensors and flexors generated eccentric torque greater than static torque(1,5,7,8), and eccentric torque did not increase with velocity(1,4,6,7,13,14,15,16). However, the results differ from earlier studies on elbow flexors(8) and female knee extensors and flexors(1), which showed that eccentric torque increased with velocity. In addition, several studies reported no significant differences between static and eccentric torques(4,13,15).

Studies on female elbow flexors (Griffin et al., 1987) and female knee extensors (Rizzardo et al., 1988) agree with our data. These studies reported an initial insignificant increase in eccentric torque up to 120 deg/s, followed by a significant decrease at 210 and 180 deg/s respectively(5,10). Although Griffin et al. only measured torques at three velocities (30, 120, and 180 deg/s) and Rizzardo et al. reported data at 60, 120, and 180 deg/s, the tendency of showing significant decreases at the highest velocity is consistent with our results for KE and DF.

Previous researches concerning eccentric torques of both the knee and elbow extensors and flexors has shown inconsistencies between those of flexors and extensors. In this experiment, the eccentric data of extensors and flexors of the hip, knee, and ankle are consistent to each other, in that the eccentric torques were greater than the static torques, and the eccentric torque did not increase with velocity.

Westing et al. (1990) reported that direct electrical stimulations given additionally to the maximal voluntary contractions evoked consistently eccentric forces greater than isometric forces. This suggests that the electrical stimulation overrides the neural inhibition(15). Therefore, skeletal muscle has the ability of attaining supra-isometric eccentric torques, but is limited by a neural inhibition as suggested by Perrine et al (1978). Strong motivation may be one voluntary mechanism for overriding this neural inhibition. For example, the subject's motivation may influence the setting of the alpha motonueron's sensitivity to feedback from muscle spindles and golgi tendon organs. The central nervous system may increase the motonueron's sensitivity to the Ia code while decreasing sensitivity to the Ib code. Even though it could not be measured, we feel subject's motivation played a role in eccentric torque output. However, such a psychological effect would be so small that the voluntary eccentric torques in this experiment did not increase with velocity as Westing et al (1990) reported.

In comparing eccentric torques developed by each muscle group, that by PF group exhibited a specific pattern. The eccentric torques at velocities from 60 to 150 deg/s are all significantly higher than that at 30 deg/s. This may implies that the PF is able to increase eccentric torque as the lengthening velocity increases. Although a paired t-test does not support this, the mean values in Fig. 4 appear to show this tendency.

In muscles acting against gravity, such as the PF, it would be important to produce increasing eccentric torques as lengthening velocity increases. This would be reflected in the profiles of eccentric force shown in PF group. In landing movements, the PF are the first muscles to encounter ground reaction forces after a flight phase and subjected to various lengthening velocities. Therefore, the PF plays an important role in absorbing energy during the landing, so as to the landing is smooth. This is accomplished by producing large eccentric torque that is a function of velocity. As stated before, this experiment did not show that, in PF, eccentric torque significantly changes with increases in lengthening velocity. However, the subtle tendency of the data has lead to this speculation and its supporting arguments.

Perhaps the in vivo eccentric torque-velocity pattern of PF is unique among other muscle group, due to its particular architecture, location, and function.

More researches are needed on PF lengthening contractions and on the other lower limb muscles.

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