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TORQUE-VELOCITY RELATION AND MUSCLE FIBRE CHARACTERISTICS OF FOOT DORSIFLEXORS AFTER LONG-TERM OVERUSE OF RESIDUAL MUSCLE FIBRES DUE TO PRIOR POLIO OR L5 ROOT LESION

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ABSTRACT. Isokinetic foot dorsiflexion strength and muscle biopsy data from eight patients with overuse of tibialis anterior muscle (TA) fibres due to weakness after prior polio or L5 root lesion were compared to data from age and sex matched, healthy subjects. Concentric peak torque at an angular velocity of 30°/s was 6–24 Nm in the patients and 15–34 Nm in the controls ($p<0.01$). Muscle biopsies from TA showed a significantly higher proportion of type 1 fibres in the patients as compared to the controls ($p<0.005$). The type 1 fibres in the patients had a significantly larger cross-sectional area than in the controls ($p<0.005$). The type 1 fibre proportion and relative area were inversely correlated to the relative concentric torque produced at 180°/s ($p<0.05$) and 240°/s ($p<0.05$) compared to that produced at 30°/s in the controls but not in the patients. However, the relative concentric torque produced at 180°/s and 240°/s compared to that produced at 30°/s was not significantly different in the patients and the controls. This indicates that the contractile properties of the overused muscle fibres do not change in parallel with the histochemical fibre type.

Key words: isokinetic, torque-velocity, muscle fibre histochemistry, post-polio syndrome, L5 root lesion.

Skeletal muscle fibres are classified according to the myosin ATPase-based histochemistry in type 1, slow-twitch and type 2, fast-twitch fibres. There is a close correlation between the functional properties of the muscle fibres and their motor neurons in normal muscle (5).

Animal experiments have shown muscle fibre type transformation in response to long-term electrical stimulation (15, 17, 19) while fibre transformation in response to physiological stimulation by exercise has not been shown in normal man. However, in paretic foot dorsiflexors due to prior polio or a fifth lumbar root lesion, long-term overuse of remaining muscle fibres during locomotion correlated with a strong predominance of type 1 muscle fibres probably due to transformation of type 2 to type 1 muscle fibres (2). The aim of the present study was to examine whether this change of the histochemical muscle fibre properties was correlated with a change in the torque-velocity relation of isokinetic, concentric work of the foot dorsiflexors.

MATERIAL AND METHODS

Five women and three men with paresis of the tibialis anterior muscle (TA) due to prior polio (seven cases) or chronic L5 root lesion (one case) aged 46–74 (63 ± 9, M ± SD) years were studied. One polio patient used two crutches, one polio patient used one stick; the other patients used no walking aids. The latency between the acute illness and the investigation was 21–49 years for the polio patients and 12 years for the L5 root lesion patient. All polio patients complained of recent functional deterioration due to pain or muscle weakness or muscle fatigue but not specifically in the foot dorsiflexors. Eight healthy subjects, aged (63 ± 9 years) and sex matched to the patients, served as controls. All patients exhibited a moderate foot dorsiflexor paresis (Kendal 3–4) and an excessive use of the TA during locomotion as previously determined (2). The control subjects were sedentary or normally active. All participating subjects had given informed consent. The study was approved by the ethics committee at the Karolinska Hospital.

Strength measurement. Maximal voluntary foot dorsiflexor strength was measured in isokinetic concentric and eccentric movements with a dynamic dynamometer (KIN-COM 500H, Chattecx Corp., 101 Memorial Drive, P.O. Box 42887, Chattanooga TN 37405, USA). The tests were performed with the trunk leaned back and the hip and knee of the examined extremity flexed as shown in Fig. 1. The foot wearing a flat jogging shoe was fixed to a standard heel and foot sole support with the talo-crural joint axis (10) carefully aligned to the axis of rotation of the dynamometer. In this position the antagonistic gastrocnemius activity is reduced by 10–20% (7). At fixation of the foot care was taken not to interfere with foot dorsiflexor activity to avoid an inhibitory effect by pressure of the straps on the muscle tendons. The ankle joint position was defined as the angle between a line through the medial tibial condyle and the medical malleolus and a line in

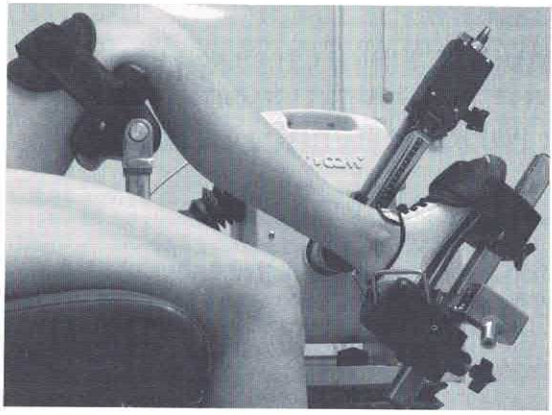

Fig. 1. Test position used in determinations of torque in isokinetic foot dorsal flexions; the hip fastened to the examination couch with a non-elastic strap across the anterior superior iliac spines (not seen), and the thigh of the extremity to be examined fixed to a rigid arm carrying the leg with the knee lifted above the actuator of the dynamometer. Hip and knee flexions approx. 70° and 90°, respectively. The heel and sole of foot resting on a standard adaptor with the talo-crural joint axis aligned to the rotational axis of the dynamometer and the foot firmly fixed to the adaptor with a strap over the dorsum of the foot.

parallel with the sole of the flat jogging shoe. At foot plantar flexions the angle was set as larger than 90°.

Voluntary strength was measured in concentric and eccentric movements at five different velocities, 30, 60, 120, 180 and 240°/s, during perpetual, verbal encouragement to maximal performance. The largest possible active range of motion was used. At each speed movements were repeated three times with intervening one minute rest periods. Measurements were accepted only when the reproducibility was good. Common errors due to uncontrolled acceleration, i.e., torque "overshoot" (18) and reach of maximum contractile tension later than peak tension (8) could be excluded by using computer controlled acceleration after an adequate preloading adapted to each subject. In healthy subjects, the preload was approx. half of the peak torque at 30°/s. In the patients, the preload varied highly due to difference in capacity. The analysis was based on computed mean torque for each angular position. Peak torque was determined at an angular velocity of 30°/s. The torque produced at a high speed relative to that produced at low speed was determined within a range where movement speeds were constant at both angular velocities. Determinations of such relative torque values were restricted to comparisons of torque at highest possible difference in velocity. Thus, relative torque was determined from torque at 180°/s or 240°/s as compared to torque at 30°/s.

EMG. The electromyographic activity of the tibialis anterior and the gastrocnemius muscles was recorded with surface electrodes over the muscle bellies. The signals were amplified

Table I. *Peak torque at 30°/s in concentric and eccentric isokinetic foot dorsal flexions and concentric torque at 4 different velocities relative to concentric torque at 30°/s. Relative torque determined in movement range 102–103°*

	Peak torque (Nm)		Relative torque (%)			
Subject no.	Concentric 30°/s	Eccentric 30°/s	Concentric 60°/s	120°/s	180°/s	240°/s
Patients						
1	8	15	75	31	3	–
2 (L5)	18	29	82	46	31	26
3	8	13	81	51	35	6
4	11	16	75	29	11	–
5	24	38	61	47	26	–
6	8	17	86	76	–	–
7	6	12	84	60	8	–
8	14	20	77	50	42	21
Mean ± SD	12.1 ± 6.2	20.0 ± 9.0	77.6 ± 7.9	48.8 ± 15.0	22.3 ± 15.0	17.7 ± 10.4
Controls						
1	17	24	59	42	18	12
2	26	33	80	43	19	12
3	15	24	77	41	30	28
4	28	45	78	49	27	16
5	34	60	79	52	–	28
6	16	28	70	41	29	16
7	22	31	81	50	35	29
8	34	59	81	53	39	21
Mean ± SD	24.0 ± 7.7	38.0 ± 14.8	75.6 ± 7.6	46.4 ± 5.1	28.1 ± 7.7	20.3 ± 7.3
	$p<0.01$	$p<0.05$	NS	NS	NS	NS

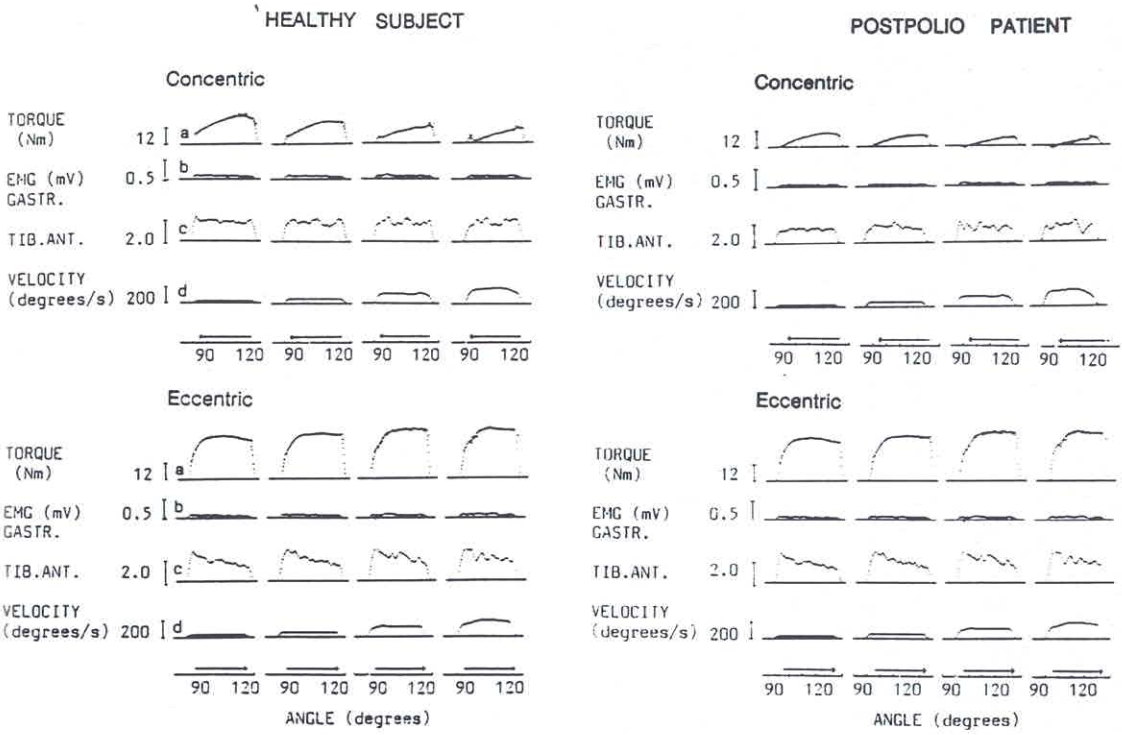

Fig. 2. Torque and EMG in isokinetic ankle movements at maximal voluntary contractions of foot dorsal flexor muscles in a postpolio patient and a healthy subject. Concentric and eccentric actions of the muscles at movements reaching 4 different constant angular velocities (30, 60, 120, 180°/s) in columns from left to right. Each curve gives an average from 3 tests. EMG activity in the gastrocnemius and the tibialis anterior muscles given by means of rectified EMG activity. Direction of concentric and eccentric movements indicated by arrows at bottom of each column.

(1 000×) in miniature preamplifiers fixed to the skin close to the surface electrodes and the signals fed to an EMG integrator (KIN-COM 500H, Chattecx Corp.) where they were rectified and time-averaged. Mean integrated EMG was calculated for each angular position in repeated tests at the same velocity.

Muscle biopsy. TA muscle biopsies were performed by the percutaneous conchotome method originally described by Radner (16) and slightly modified (9, 12). The biopsy material obtained was freshly frozen in freon 13 kept at its melting point (−190°C) by liquid nitrogen and kept at −75°C until further processed.

Serial transverse sections of 10–15 µm were cut in a cryostat operating at −25°C and stained with myosin-adenosintriphosphatase (ATPase) according to the original method of Padykula & Herman (14) and the modifications by Brooke & Kaiser (4).

The muscle fibre nomenclature was based on the ATPase stainability according to Brooke & Kaiser (4). Thus fibres with high content of acid stable ATPase and low content of alkali stable ATPase were termed "type 1" while fibres with the opposite staining pattern were termed "type 2". All fibres on a muscle biopsy cross section were classified and the total number of fibres of each type estimated. Fibre cross-sectional areas of at least 200 muscle fibres were measured by a semiautomatic technique applied on black and white photographs (MOP Videoplan, Kontron, Bildanalyse GMBH, Munich, FRG). Statistical analysis was based on Wilcoxon rank sum test and Spearman rank correlations.

RESULTS

Fig. 2 shows the recordings from one of the patients and one of the control subjects. Table I shows the torque-velocity data for all patients and control subjects.

Peak torque at 30°/s angular velocity

Concentric peak torque at an angular velocity of 30°/s ranged 6–24 Nm (12.1±6.2) for the patients and 16–34 Nm (24±7.7) for the controls. The difference was statistically significant ($p<0.01$). Peak torque was <15 Nm in six patients and above this level in all the controls. Eccentric peak torque values at 30°/s ranged 13–38 Nm (20.0±9.0) in the patients and 24–60 Nm (38.0±14.8) in the controls. The difference was statistically significant ($p<0.05$). Peak torque was <21 Nm in six patients and above this

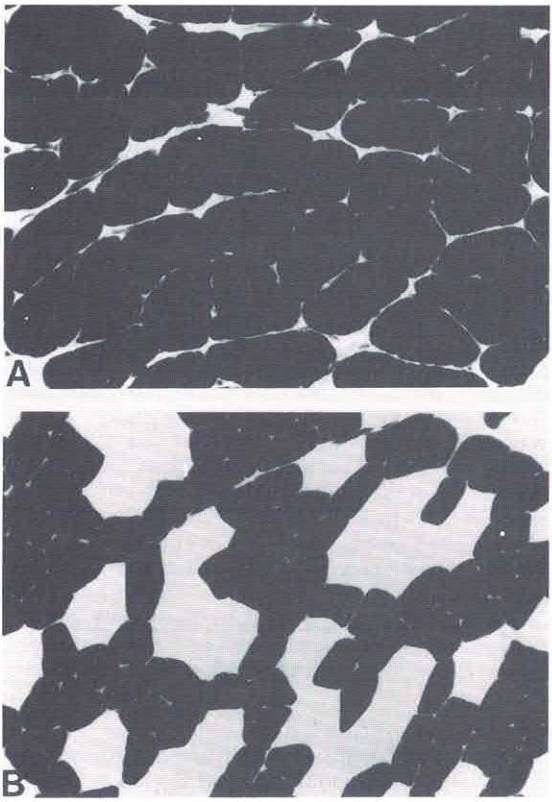

Fig. 3. Photomicrographs of tibialis anterior muscle biopsies from a polio patient (A) and a healthy subject (B). Cryostat cross-sections were stained for myosin-ATPase after acid preincubation of pH=4.3. Note the predominance of large diameter, type 1 fibres in A as compared to a normal distribution of type 1 and type 2 fibres with normal cross-sectional diameters in B.

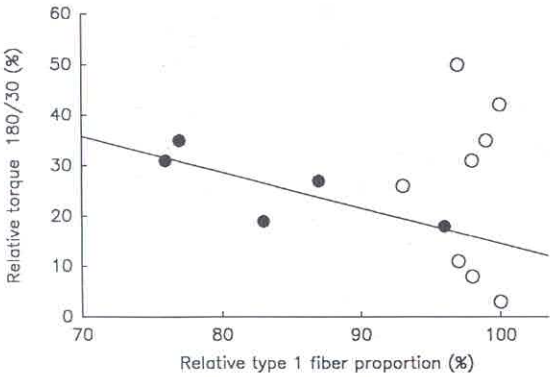

Fig. 4. Relative torque 180°/s as compared to torque at 30°/s given against type 1 muscle fibre proportions in the control subjects (*filled circles*) and in the patients (*open circles*). Regression line refers to data from the control subjects.

level in all controls. The ratio between eccentric and concentric peak torque was not significantly higher in the patients (1.71 ± 0.25) than in the controls (1.57 ± 0.18).

Relative concentric torque

In the patients, the angular range in which the different velocities of foot dorsal flexions were kept constant and thus allowed comparison of torque produced at different velocities was narrow. All patients could reach the velocity 180°/s in foot dorsal flexions and keep this velocity within the movement range 102–103°. In this range, the movement velocity was constant also at all lower velocities tested. The highest angular velocity, 240°/s, could be reached by five patients but only in three of them this velocity was kept within the defined movement range. In all control subjects, a velocity of 180°/s as well as 240°/s could be reached and kept constant in a range at least including 102–103°. This range was judged optimal for comparing torque in fast movements to torque in slow movements and was thus used to calculate the relative torque at velocities of 180 and 240°/s as compared to the torque at a velocity of 30°/s in both patients and healthy controls (Table I).

The relative torque produced at velocities of 180 and 240°/s as compared to torque at 30°/s was not significantly different in the patients and the controls.

Electromyographic recordings

The mean amplitude of the electromyographic activity was determined within the widest possible range with constant movement velocity for each of the different angular velocities. The electromyographic recordings from TA showed no systematic change during concentric or eccentric movements at increasing angular velocities in the patients or the controls. Thus, there were no signs of reduced central drive at high velocities. The electromyographic recordings showed low activity in the antagonists and no systematic changes at different angular velocities in the patients or the controls.

Muscle biopsy data

Fig. 3 shows the predominance of hypertrophic type 1 muscle fibres in a biopsy from one patient (No. 3). Table II shows the muscle fibre type 1 proportions and cross-sectional areas. A significantly higher ($p<0.005$) proportion of type 1 muscle fibres were seen in the TA of the patients ($97.8 \pm 2.3\%$) than in

Table II. *Torque at 180°/s relative to torque at 30°/s in concentric isokinetic foot dorsal flexions and type 1 fibre proportions and areas in biopsies from tibialis anterior muscles*

Subject no.	Relative torque 180°/s (%)	Type 1 fibres		
		Proportion (%)	Mean area (μm^2)	Relative area (%)
Patients				
1	3	100	7 865	100
2 (L5)	31	98	6 883	99
3	35	99	9 923	99
4	11	97	13 249	98
5	26	93	12 380	92
6	50	97	8 927	99
7	8	98	9 913	99
8	42	100	6 440	100
Mean ± SD	25.8 ± 17.0	97.8 ± 2.3	9 447 ± 2 446	98.3 ± 2.6
Controls				
1	18	96	4 546	93
2	19	83	5 731	85
3	31	76	3 761	76
4	27	87	4 044	75
5	–	81	4 834	77
6	29	–	–	–
7	35	77	4 184	78
8	39	–	–	–
Mean ± SD	28.3 ± 7.8	83.3 ± 7.4	4 516 ± 704	80.7 ± 7.0
	NS	$p<0.005$	$p<0.005$	$p<0.005$

the controls (83.3 ± 7.4%). The cross-sectional areas were significantly larger ($p<0.005$) in the patients (9 447 ± 2 446 μm) than in the controls (4 516 ± 704 μm). The relative area of type 1 muscle fibres was significantly larger ($p<0.005$) in the patients (98.33 ± 2.6%) when compared with the controls (80.7 ± 7.0%).

Torque-velocity relation and muscle fibre characteristics

Table II shows the mean values of type 1 fibre proportion, fibre area, relative fibre area and relative torque produced at 180°/s as compared to torque at 30°/s. Fig. 4 shows the relative torque at 180°/s against type 1 fibre proportions in the control subjects (*filled circles*) and the patients (*open circles*). The type 1 fibre proportion was inversely correlated to the relative concentric torque produced at 180°/s ($r=-0.80$, $p<0.05$) and also to the relative torque at 240°/s ($r=-0.77$, $p<0.05$) in the controls but not in the patients. The relative area of the type 1 muscle fibres was inversely correlated to the relative concentric torque produced at 180°/s ($r=-0.6$, $p<0.05$) and 240°/s ($r=-0.43$, $p<0.05$) in the controls but not in the patients. The type 1 muscle fibre proportion or fibre area was not significantly correlated to peak torque values in the patients or the controls. Muscle fibre area was not correlated to relative concentric torque at high angular velocities in the patients or the controls.

DISCUSSION

This study has shown an inverse correlation between relative torque produced at high angular velocities compared to that at low angular velocity and the type 1 muscle fibre proportion of foot dorsiflexor muscles in healthy subjects, which is in accordance with previous findings in the quadriceps muscles of healthy subjects (11, 20). Such a correlation was not seen in the patients with overuse of residual muscle fibres due to a neurologic loss. Compared to the control subjects, the patients produced a higher relative torque at 180°/s than expected from the high proportion of type 1 fibres. This indicates that the contractile properties of the excessively used s.c. type 1 muscle fibres differ from normal type 1 fibres. This might

be due to a change of the contractile properties of the excessively used fibres towards an intermediate type. Although these fibres are of type 1 according to conventional ATPase stainability, many of them appears to have atypical myosin contents since they showed binding of antibodies against both fast and slow myosin heavy chains (3). This might explain the altered contractile properties of the muscle fibres.

The torque-velocity data are in agreement with previous findings that the motor neuron firing properties and axonal conduction velocities are differentiated in the same way in the muscles with type 1 fibre predominance as in muscles with a normal type 1 and type 2 fibre differentiation (3). According to the electromyographic recordings there were no signs of reduced central drive in the patients or the controls.

The examination design included one minute of rest between isokinetic test movements. Muscle fatigue of longer duration (1, 6, 13) cannot be fully excluded. There were, however, no signs of larger fatigue during the testing procedure in the patients than in the controls.

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