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ISOKINETIC STRENGTH AND ENDURANCE IN PERIPHERAL ARTERIAL INSUFFICIENCY WITH INTERMITTENT CLAUDICATION

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ABSTRACT. Isokinetic plantar flexor peak torques (PT) and contractional work (CW) of the triceps surae muscle have been measured in 24 patients with peripheral arterial insufficiency and intermittent claudication and in 15 controls. Tests were performed both during non-fatiguing (30–180°/s) and fatiguing (200 repeated plantar flexions at 60°/s) conditions. The electromyographic signals (iEMG) from all three heads of the triceps surae were measured. The patients were significantly weaker (PT) and produced significantly less contractional work (CW) than the controls. In contrast, similar iEMGs of the triceps surae heads indicated similar levels of activation. At 40 contractions the majority of the patients had already given up and the remainder showed significantly greater declines in PT (50 %) and CW (55 %) than did the controls (13 % and 18 %, respectively). The decline in muscular excitations was similar in both groups. The ratio CW/iEMG showed a dramatic decline in the patients but was virtually constant in the controls. These results indicate a fatigue of low-frequency type in the patient group. There were close correlations between maximum walking tolerance and total work production.

Key words: Peripheral arterial insufficiency, intermittent claudication, skeletal muscle, strength, endurance, isokinetic, physiology

Intermittent claudication, leg pain at rest and/or peripheral gangrene are characteristics of peripheral arterial insufficiency (PAI).

The grading of PAI for the choice of treatment is generally based on case history, clinical examination and assessment of walking tolerance on level ground or on a treadmill (10). In patients with intermittent claudication a negative correlation between walking tolerance and the oxidative capacity of lower leg muscle (1) has been found, and may be seen as a functionally insufficient phenomenon of muscular adaptation to the PAI. Using force plates, Carlsöö et al. (2) found normal walking patterns in PAI. Many studies concern the arterial situation in the legs of patients with PAI (cf 29), and with determination of local tissue perfusion (5, 9, 26, 33, 40, 41). These methods cannot, however, be used to determine muscular performance per se, but may be useful for the assessment of enzymatic and metabolic processes; for example in relation to physical training (3, 19, 24, 26, 34, 35).

We have previously measured (17) maximum plantar flexion strength and contractional work in middle-aged and elderly clinically healthy subjects using isokinetic dynamometry. Formulae were derived from these measurements. A reliable and valid method for describing isokinetic plantar flexor endurance has also recently been devised (14, 15). The method employs a combination of measurement of torque and electromyographic signals. We suggested that the ratio, contractional work/degree of muscular excitation, adequately reflects output/input balance during isokinetic plantar flexor fatigue.

This investigation was designed to study isokinetic plantar flexor performance in patients with peripheral arterial insufficiency and intermittent claudication and to gauge whether the patients' muscular performance differed from that of clinically healthy subjects.

MATERIALS

Patients

Twenty-four males with PAI, mean age 60±6 years, volunteered to participate. They had had symptoms of intermittent claudication (CI) for more than 6 months. When walking on level ground at about +20°C pain in one leg caused intermittent halts at ≤500 m. None had pain at rest or gangrene. They were thus in Fontaine categories II or III (10). Eight (33 %) had angina pectoris but not preceding CI-symptoms; 7 (29 %) had survived one myocardial infarction. Four (17 %) had arterial hypertension and 23 (96 %) were or had been smokers for many years. According to angiography (*n*: 19) and/or occlusion plethysmography (*n*: 22) stenosis or occlusion of the iliac or femoral arteries occurred for 23 patients above mid-thigh and for one of them below mid-thigh. The mean lower leg/forearm blood pressure (mmHg) ratio lay between 0.42 and 0.24.

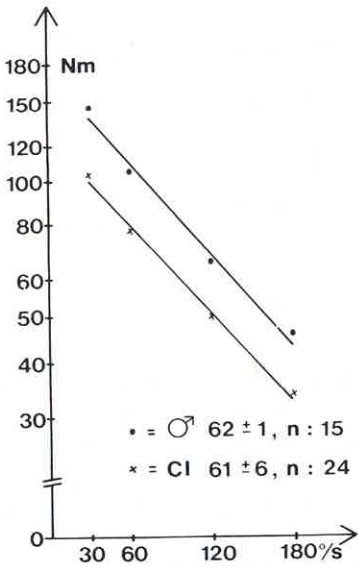

Fig. 1 a. Exponential relationships between peak torque (Nm, *Y*-axis) and velocity of angular motion (°/s, *X*-axis). ●, controls (15 males; 62±1 years); ×, patients (24 males; 61±6 years).

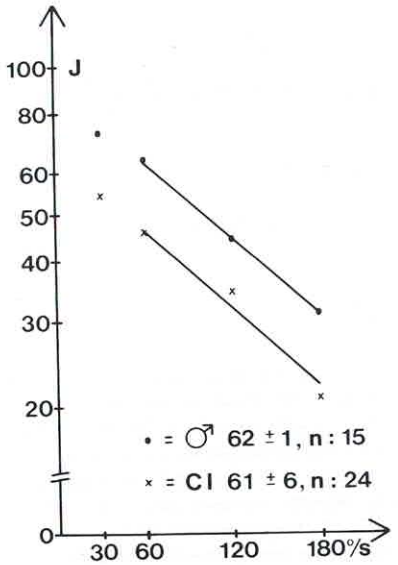

Fig. 1 b. Exponential relationship between contractional work (J, *Y*-axis) and velocity of angular motion (°/s, *X*-axis). ●, controls (15 males; 62±1 years); ×, patients (24 males; 61±6 years).

Controls

The controls were 15 clinically healthy, but otherwise randomly chosen males aged 60–64 years (62±1). They have been described in detail elsewhere (17). Three were smokers. The anthropometric characteristics of controls and patients (Table I) did not differ significantly.

METHODS

For measurements of performance/velocity relationships at 30, 60, 120 and 180°/s, the subjects were placed on a bench in the supine position, knees were fully extended and each foot was strapped to the foot plate(s) of a Cybex II® dynamometer (Lumex Inc, New York). For the patients, plantar flexion was studied for that leg which usually restricted walking tolerance. For the controls, either the right or the left leg was tested. Care was taken to align the flexion–extension axis of the talocrural joint with the rotation axis of the foot plate.

Following appropriate rests, the subjects were placed in the prone position and were instructed to perform as many plantar flexions (60°/s) as possible. The experiment was interrupted if the subjects felt they could not continue due to leg pain, muscular fatigue or of general exhaustion. Those without such symptoms performed 200 plantar flexions at their own pace. To ascertain that the subjects cooperated optimally each manoeuvre was monitored by

Table I. *Mean values ±1SD of certain anthropometric measurements for controls (clinically healthy) and patients (intermittent claudication due to peripheral arterial insufficiency)*

n denotes number of patients or controls

	Patients	Controls
n	24	15
Weight (kg)	75±11	75±10
Length (cm)	175±5	176±5
Crural circumference (cm)	36±3	36±3
Age (years)	60±6	61.7±1.3

Table II. *Integrated electromyograms of the m. triceps surae/manoeuvre time (iEMG/t) for controls and patients during the isokinetic endurance test at the pre-set velocity of 60°/s*

Values are expressed as mean value ±1 SD for five manoeuvres. *n* denotes number of patients or controls

Number of contractions	1–5	21–25	56–60
Controls	4.1±1.0	4.0±1.0	3.7±1.0
n	15	15	15
	NS	NS	NS
Patients	4.0±1.1	3.7±1.1	3.2±1.3
n	24	22	9

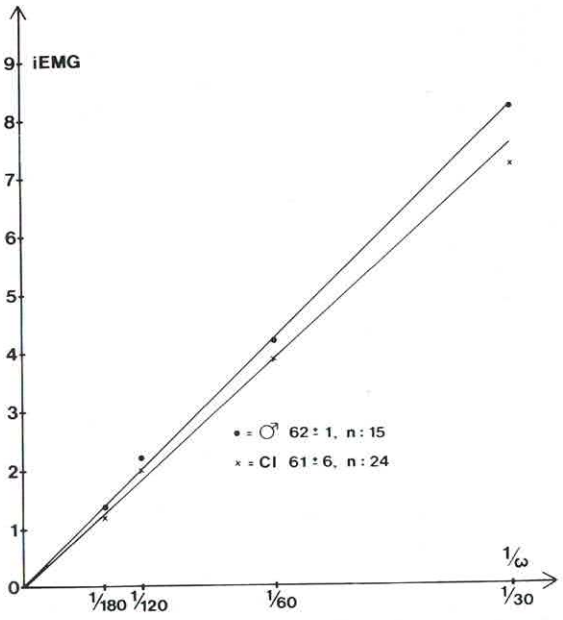

Fig. 2. Relationships between integrated electromyograms (iEMG, arbitrary units, *Y*-axis) and velocity of angular motion (1/velocity, °/s, *X*-axis) for the three heads of the triceps surae at isokinetic plantar flexions. ●, controls (15 males, 62±1 years); ×, patients (24 males, 61±6 years).

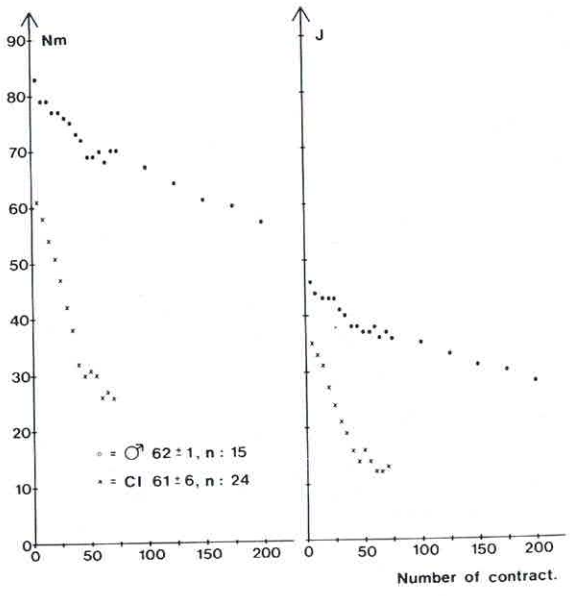

Fig. 3. Relationships between peak torque (Nm, *Y*-axis), contractional work (J, *Y*-axis) and number of isokinetic plantar flexions (*X*-axis), at the pre-set velocity 60°/s. ●, controls (15 males; 62±1 years); ×, patients (24 males; 61±6 years). Symbols represent mean values of five isokinetic plantar flexions.

simultaneous displays of torque and angular motion on an oscilloscope. During the experiment the subjects were frequently encouraged to perform evenly, i.e. to maintain the initially chosen frequency of plantar flexions.

For each contraction peak torque (PT), contractional work (CW) and range-of-motion (RoM) were registered. Integrated electromyograms (iEMGs) were recorded from the soleus muscle and the gastrocnemius muscles using surface electrodes (Medico-Tests, Ølstykke, Denmark), the centres of each pair of electrodes being 38–44 mm apart. Detailed methodological and procedural descriptions have been published elsewhere (12, 17).

Each patient estimated the distance he could usually walk until it was impossible to walk further (maximum walking tolerance, MWT). In most patients walking tolerance was also tested on a horizontally positioned treadmill (4 km/h) and the distances walked were noted when: (*a*) initial pain occurred (initial walking tolerance, IWT), (*b*) the patient wished to stop because of pain (relative walking tolerance, RWT) and (*c*) pain prohibited further walking (maximum walking tolerance, MWT). In a subsample (*n*: 15) a physiotherapist measured walking tolerance (IWT, RWT and MWT) indoors.

Statistics

The results are given as mean values (± one standard deviation). To evaluate co-variations between pairs of variables Pearson's coefficients were calculated. Differences between the controls and the patients were estimated using Student's *t*-test (31). The level of significance chosen was $p \leq 0.05$, two-tailed.

RESULTS

Both for patients and for controls the mean peak torques (PT) and contractional work (CW) decreased exponentially, and in parallel, with increasing velocity of angular motion (Fig. 1 *a*, *b*). The patients were significantly weaker in terms of PT than the controls (about 70–75%) at all velocities of angular motion and performed significantly less (about 70%) contractional work. RoM and iEMG/manoeuvre time for each velocity did not differ significantly between controls and patients. The mean total of iEMGs for all three heads of the triceps surae was similar for both groups and inversely proportional to the velocity of angular motion (Fig. 2).

Endurance

All the controls could perform more than 100 plantar flexions and 14 out of 15 performed all 200 of

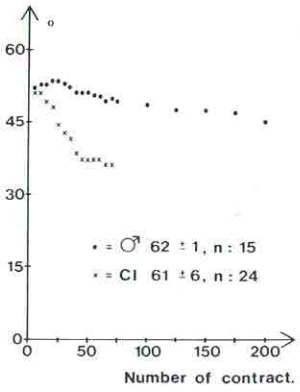

Fig 4. Relationships between range-of-motion (i.e. manoeuvre time) (°, *Y*-axis) and number of isokinetic plantar flexions (*X*-axis), at the pre-set velocity 60°/s. ●, controls (15 males; 62±1 years); ×, patients (24 males; 61±6 years). Symbols represent mean values of five isokinetic plantar flexions.

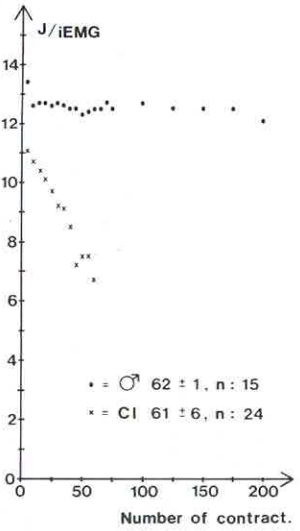

Fig. 5. Relationships between contractional work/integrated electromyograms of plantar flexors (CW/iEMG; *Y*-axis) and number of isokinetic plantar flexions (*X*-axis), at the pre-set velocity 60°/s. ●, controls (15 males, 62±1 years); ×, patients (24 males, 61±6 years). Symbols represent mean values of five isokinetic plantar flexions.

them. Thirteen out of 24 of the patients performed less than 40 and only 1 out of 24 could perform more than 100 (115) plantar flexions. The output declined rapidly as compared with the controls (Fig. 3) whether measured as maximum torque or as contractional work. Thus the 13 patients who could perform at least 40 contractions had a nearly 50% mean decline in PT and 55% decline in CW after that number of contractions. Significantly smaller declines in PT (13%) and contractional work (18%) occurred for the controls. Mean cumulative work performed by the 24 patients was therefore much smaller (1205 J, range 375–2645) than in the controls (6814 J, range 4585–10705). The decrease in maximum performable contractional work was, at least to some extent, caused by a dramatic decrease in RoM (Fig. 4). For the patients, decreases in PT, CW and RoM were significantly more pronounced already after 10 contractions than were the corresponding decreases in the controls. In contrast, patients and controls had similar declines in the ratio: iEMG/manoeuvre time (Table II). This ratio may be seen as an expression of muscular excitation (cf. 14, 15, 17) normalized for range-of-motion.

Throughout the experiment the CW/iEMG ratio, an expression of output/input balance, also decreased markedly in the patients (Fig. 5) while in the controls this ratio remained virtually constant.

Correlation coefficients were calculated (Table III) in order to assess the compatibility of isokinetic contractional work with different measures of walking tolerance. All measures of MWT were found to be closely associated with total work and IWT did not correlate at all with total contractional work.

DISCUSSION

Conventionally, leg muscle functional capacity in patients with peripheral arterial insufficiency and intermittent claudication is measured in terms of walking tolerance on a treadmill or on level ground. Dahllöf et al. (4) recently considered that MWT and IWT registered using a treadmill was preferable to patients' own estimation of walking distance, which they considered to be unreliable. The close association between the patients' estimations of walking tolerance and total contractional work observed in the present investigation appears to validate the patients' reported experiences of walking distance. In fact, IWT lacks prognostic significance. From the clinical point of view a major finding in the present investigation was that differentiated isokinetic measurements of muscular output during repeated manoeuvres are well correlated with maximum functional walking capacities. It is also desirable to measure muscular performance as selectively as possible in these patients. This is because

Table III. *Correlations (linear regression; r and r^2 are given) between free walking distance and treadmill distance, and subjectively estimated distance and total isokinetic work (TPW) respectively*

Distances walked when initial pain occurred (initial walking tolerance, IWT), when the patient usually would have stopped due to pain (relative walking tolerance, RWT) and when pain was so intense that further walking was absolutely impossible (maximum walking tolerance, MWT) were registered. *n* denotes number of patients

			TPW	
		n	*r*	r^2
Free walking	IWT	13	−0.03	0.001
	RWT	12	0.67	0.45
	MWT	15	0.89	0.79
Treadmill	IWT	19	−0.04	0.002
	RWT	19	0.50	0.25
	MWT	22	0.61	0.37
Estimated	MWT	24	0.66	0.44

generalized arteriosclerosis with cardiac insufficiency may commonly disturb tests which involve at least some general physical stress such as measurements of walking distance.

In CI patients PT and CW/velocity relationships and degree of muscular excitation during non-fatiguing contractions at different velocities of angular motion were found to be normal compared with the controls, while torque production was impaired. Hence the electrical efficiency (CW/iEMG) of patients was decreased. In clinically healthy subjects, motor units were found to be recruited stereotypically and independently of isokinetic velocity (12, 17).

Excitatory normality in CI patients taken together with similar crural circumferences in patients with CI and in controls indicates that the non-fatigued triceps surae in claudicants has normal, or nearly normal, neuromotor control and unimpaired excitation–contraction coupling. This contradicts the findings of Mäkitie (25) that considerable neurogenic muscular changes occur in the gastrocnemius muscle of claudicants. Our investigations (1, 32) have, however, demonstrated only minor signs of denervation and degeneration accompanied by regeneration of anterior tibial muscle specimens. Hence the low torque production in CI cannot be explained by neural impairment. On the other hand, the oxidative capacity of both FT- and ST-fibres is significantly increased in the leg muscles of patients with CI (19, 20, 21, 30) and it has been found that changes of metabolic properties within these fibres may lead to changes in maximum performance (28). Since, in man, it has been proposed that FT- but not ST-fibres determine peak isokinetic strength (18, 37, 38) it is feasible that the increase in oxidative capacity is accompanied by decreases in torque production. It might be speculated that patients in Fontaine classes II and III walk slower in order to be able to walk longer distances (cf. 24). Furthermore, it cannot be ruled out that the patients with CI, who are often arteriosclerotic, may have reduced their demands upon daily-life physical activities, particularly in relation to the high level of outdoor physical activities normally present in middle-aged and elderly northern Swedes (cf. 17).

If one defines fatigue as failure to maintain required or expected force or power output (8), the pronounced plantar flexor fatigue was evident in subjects with CI already after very few repeated plantar flexions at 60°/s. RoM declined virtually parallel with decreases in output while excitation was normal compared with the controls. Thus, it appears that the considerable decrease in electrical efficiency is due to peripheral fatigue of low frequency type (excitation-contraction coupling impairment; cf. 7). Edwards (6) found that such fatigue occurred in human skeletal muscles during repeated contractions under anaerobic conditions. Increased intramuscular pressure can also lead to

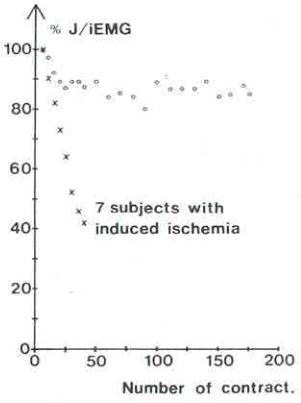

Fig. 6. Relationships between relative electrical efficacy (CW/iEMG, *Y*-axis) and number of isokinetic plantar flexions (*X*-axis) at the pre-set velocity of 60°/s for 7 healthy females (20–34 years) under normal conditions (●) and with impaired blood flow (×) to the leg (i.e. insufflated cuff placed at mid-thigh level).

fatigue (23) which may constitute at least part of the explanation for the approximate 15–20% reduction in iEMG normalized for the RoM previously described (14). For patients with CI, Qvarfordt et al. (27) recently reported that after up to 7 minutes of repeated static plantar flexions the intramuscular pressure of the superficial posterior compartment of the calf increased nearly three-fold in patients but only slightly, and insignificantly, in healthy controls. These authors suggested that increased pressure of the compartment might serve to impair blood perfusion and to aggravate ischemic pain.

After initial falls in torque production to levels of about 75% and 70% for PT and CW respectively, clinically healthy subjects (see Fig. 5; in 14) can normally continue the repetitive contractions. The fact that most patients can only perform a relatively small number of plantar flexions may be explained by the lack of available substrate for fibres, in particular oxidative fibres, to function while the anaerobic metabolism has run out of fuel. This suggestion is consistent with the findings (Fig. 6) that when arterial blood flow to the lower leg in clinically healthy young subjects is impaired (by insufflation of a cuff placed at the mid-thigh level), striking similarities to the group of patients during fatigue are observed (13). We recently suggested that the parallel decrease in output and excitation is due to FT motor unit fatigue (14, 15) in agreement with other authors, while the almost steady-state level may be determined by the relative ST-fibre content and/or area (16, 22). The increased oxidative capacity found may be seen as an adaptive phenomenon which is adequate for short but not for prolonged periods of work.

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