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# WALKING EFFICIENCY BEFORE AND AFTER LONG-TERM MUSCLE STRETCH IN PATIENTS WITH SPASTIC PARAPARESIS

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**ABSTRACT. Eight patients with stationary, spastic paraparesis were treated with long-term stretch of the hip adductor muscles to improve walking ability. Gait pattern, walking speed and perceived exertion of walking were assessed. Walking efficiency was assessed before and after treatment by measuring oxygen consumption and blood lactate level. After treatment walking pattern was improved. Perceived exertion decreased but walking speed was unchanged. Oxygen cost directly after treatment was lower in six patients, unchanged in one and higher in one. In the patient with unchanged oxygen cost the blood lactate level decreased, probably due to decreased recruitment of fast, type II muscle fibres. Blood lactate was unchanged in the other patients. When assessing walking ability, measurement of energy cost was found to be a valuable supplement to clinical judgement, but in spastic patients both oxygen cost and blood lactate must be considered.**

*Key words:* gait, lactate, muscle stretch, oxygen consumption, paraparesis, spasticity, walking efficiency.

Individual variations in gait characteristics are due, partly to physiological conditions (6). In patients with paraparesis, spasticity of the hip adductor muscles is an important obstacle to walking. Treatment with long-term stretch of the hypertonic muscles gives a reduction of both spasticity and co-contraction and an increased range of motion in the hip joint (11). Assessment of the treatment effects using EMG recordings from agonistic and antagonistic muscles has demonstrated however, that the effects can be variable and unpredictable (11). The influence of long-term muscle stretch on walking ability and efficiency has not previously been studied.

Walking ability and efficiency can be assessed objectively by measuring the energy cost of walking at different speeds (6). Measurements have been performed in patients with various walking impairments (4, 6), but not hitherto in patients with spastic paraparesis. Energy cost has been evaluated mostly by determination of oxygen uptake ($V_{O_2}$) during walking on a treadmill. However, patients with spastic paraparesis cannot manage treadmill walking. In this study we therefore used light-weight equipment developed to allow measurements of $V_{O_2}$ and the energy cost of floor walking, and thus suitable for patients with spastic paraparesis (10).

A previous report on hemiparetic patients showed blood lactate to be increased during one-leg exercise at 10 W on a bicycle ergometer. This increase was ascribed to reduced muscle blood flow and increased activation of fast-twitch muscle fibres (9). These results indicate that even during moderate exercise such as self-selected level walking, blood lactate must be taken into consideration when energy cost is measured in spastic patients.

The aim of the present study was to assess walking ability and efficiency in patients with spastic paraparesis before and after treatment with long-term stretch of spastic hip adductor muscles. Clinical assessment was supplemented with measurements of oxygen cost and determination of blood lactate.

## MATERIALS AND METHODS

*Patients*

All patients with stationary spastic paraparesis, admitted to the Department of Neurology, Karolinska Hospital during one year, were clinically examined. Patients able to walk for at least 10 min at the same speed ($n=10$) were selected for treatment with long-term stretch of the hip adductor muscles according to a method previously described (11). Only patients exhibiting a significant reduction of muscle spasticity and co-contraction after this treatment were included. Eight patients volunteered to participate.

The study thus comprised six men and two women, aged 45–68 (mean 57) years, who fulfilled these criteria (Table I). The diagnoses were myelopathia of unknown origin in five patients, multiple sclerosis in two and chronic cervical compression myelopathia due to cervical spondylosis in one. The spastic paraparesis had been clinically stable and the patients

Table I. *Presentation of patient data. Oxygen uptake and blood lactate, at rest, in sitting position*

| Pat. no. | Sex | Age | Height (cm) | Weight (kg) | Walking aids | Oxygen uptake ($ml \cdot kg^{-1} \cdot min^{-1}$) | Blood lactate ($mmol \cdot l^{-1}$) |
|---|---|---|---|---|---|---|---|
| 1 | F | 65 | 168 | 67 | 1 cane | 3.9 | 1.0 |
| 2 | M | 64 | 180 | 75 | – | 4.8 | 1.6 |
| 3 | M | 68 | 176 | 78 | – | 5.5 | – |
| 4 | F | 51 | 159 | 61 | 1 cane | 3.5 | – |
| 5 | M | 45 | 176 | 78 | – | 4.5 | 2.0 |
| 6 | M | 50 | 175 | 72 | – | 4.3 | 2.3 |
| 7 | M | 53 | 185 | 91 | 1 cane | 4.1 | 1.6 |
| 8 | M | 60 | 177 | 81 | 1 cane | 3.2 | 1.9 |

had used the same anti-spastic drugs during the previous two years. Three patients used Baclofen (Lioresal) 50–75 mg daily. All eight had spasticity in the hip adductor muscles with influence on walking ability. All were able to walk for at least 10 min but at a reduced speed.

*Treatment*

With the patient supine, individually-adjusted adductor muscle stretch was performed during 30 min using a mechanical leg-abductor device. The passive moments were obtained with an individually adjusted constant pulling force. In all patients, co-activation of the antagonists was lower after the stretch session, reflected in improved voluntary hip abduction, also a significant reduction in muscular hypertonus was achieved, evaluated according to the method previously described (11).

*Walking test*

The walking tests were performed in a large hall with a quiet atmosphere. To ensure physiological steady-state conditions the patients walked for 4 min. Walking speed was determined with a speedometer mounted on a small cart pushed by the test leader alongside the patient, according to a method previously described (10). During the walking test, speed was monitored and, when so required, controlled by the test leader.

Before treatment, walking tests were performed at three different speeds. One speed was selected by the patient as his or her most comfortable one (in a previous study (10) comfortable, self-selected walking speed was found to be reproducible with a coefficient of variation of less than 2%). The other two speeds were determined by the test leader as 20 $m \cdot min^{-1}$ higher and lower respectively than the self-selected speed.

Directly after treatment the patient was asked to walk at his most comfortable walking speed. The patient was also guided by the test leader to walk at the speed that had been selected as the most comfortable before treatment. Heart rate was recorded before and after treatment. Gait pattern was assessed visually using a three-grade scale (improved, unchanged, impaired) before and after treatment. Stride length was measured from a videotape. Perceived exertion was graded by the patient using a ten-grade scale according to Borg (1).

*Energy cost*

During the walking test the patients carried a 3.5-kg backpack containing a 10-litre mixing box. The patients wore a noseclip and exhaled through a breathing valve connected to the box with a flexible low-resistance hose. Argon gas was fed into the box with a constant well-defined flow for determination of ventilation. A sample of the gas mixture was aspired with a glass syringe at the end of each walking test and analysed with a respiratory mass spectrometer using a method previously described (10). Oxygen uptake ($V_{O_2}$) was expressed as ml of $O_2$ at standard temperature and pressure (STPD), consumed per kg body-weight and time (min) or distance (m).

Blood lactate level was assessed from a capillary blood sample taken before and 30 sec after each walking test. In previous studies these methods have given reproducible results with a coefficient of variation of less than 2% for determination of $V_{O_2}$ and less than 5% for determination of blood lactate (8, 10).

*Statistical methods*

Values are presented as means ±1 standard deviation (SD) and range. Student's matched pairs *t*-test and Wilcoxon's matched pairs signed ranks tests were used to test individual differences.

## RESULTS

### *Range of hip motion*

After treatment with muscle stretch the mean passive and active range of movement for hip-abduction increased from 23±6° to 28±7° ($p<0.05$) and from 23±7 to 31±9° ($p<0.01$), respectively.

### *Heart rate*

Before and after each treatment session, heart rate (HR) at rest did not differ and averaged 83 beats per minute (bpm), range 72–104. Before treatment during walking at the comfortable speed, HR averaged 92

Table II. *Presentation of variables before (pre) and after (post) treatment and change in per cent*

| Pat. no. | Self-selected walking speed ($m \cdot min^{-1}$) | | | Heart rate (bpm) | | Perceived exertion units | | Oxygen cost ($ml \cdot kg^{-1} \cdot m^{-1}$) | | | Blood lactate ($mmol \cdot l^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Change % | Pre | Post | Pre | Post | Pre | Post | Change % | Pre | Post | Change % |
| 1 | 56.5 | 56.8 | +0.5 | 84 | 84 | 1.5 | 1.0 | 0.29 | 0.27 | −7 | 1.6 | 1.6 | +0 |
| 2 | 38.4 | 46.9 | +22.1 | 80 | 76 | 3.0 | 1.0 | 0.31 | 0.31 | +0 | 2.3 | 1.8 | −22 |
| 3 | 52.7 | 48.0 | −8.9 | 82 | 80 | 2.0 | 1.5 | 0.40 | 0.50 | +2 | – | – | – |
| 4 | 29.1 | 29.6 | +1.7 | 100 | 88 | 4.5 | 3.5 | 0.40 | 0.37 | −7 | – | – | – |
| 5 | 50.2 | 52.3 | +4.2 | 94 | 88 | 0.5 | 0.0 | 0.23 | 0.21 | −9 | 2.2 | 2.2 | +0 |
| 6 | 50.2 | 55.5 | +10.6 | 84 | 84 | 3.5 | 0.0 | 0.25 | 0.22 | −11 | 2.6 | 2.6 | +0 |
| 7 | 31.5 | 36.6 | +16.2 | 92 | 88 | 3.5 | 3.0 | 0.58 | 0.56 | −4 | 1.9 | 1.9 | +0 |
| 8 | 53.9 | 57.1 | +5.9 | 120 | 116 | 3.5 | 2.0 | 0.35 | 0.34 | −3 | 2.6 | 2.6 | +0 |

bpm and after treatment 88 bpm at the same walking speed ($p<0.05$) (Table II).

### *Gait pattern*

After treatment all patients walked more freely and smoothly as subjectively evaluated by the investigator. Four patients used walking aids (one cane) before and after treatment. The average stride length increased from 102±20 cm to 114±22 cm ($p<0.01$).

### *Walking speed*

The self-selected speed was 45.3 $m \cdot min^{-1}$ before treatment and 47.9 $m \cdot min^{-1}$ after treatment. In one patient, walking speed decreased by 4.7 $m \cdot min^{-1}$ (Table II). Before treatment, four patients were able both to increase and to decrease their walking speed by 20 $m \cdot min^{-1}$ in relation to their self-selected speed. The other four patients could only increase and decrease their speed by 10 $m \cdot min^{-1}$ (Table III).

### *Oxygen cost*

In sitting position before treatment, mean oxygen uptake ($V_{O_2}$) was 4.2 $ml \cdot kg^{-1} \cdot min^{-1}$ (Table I). While walking at the same speed before and after treatment, $V_{O_2}$ averaged 15.9 and 15.5 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively, or 0.362 and 0.348 $ml \cdot kg^{-1} \cdot min^{-1}$, $p<0.05$ (Table II).

In six patients $V_{O_2}$ decreased by an average of 0.02 $ml \cdot kg^{-1} \cdot m^{-1}$ (6% decrease). In one patient $V_{O_2}$ was unchanged and in another it increased by 2% (Table II).

Table III. *Presentation of oxygen cost and blood lactate at walking speeds higher and lower than the self-selected speed; before treatment*

| Pat. no. | Walking speed ($m \cdot min^{-1}$) | Oxygen cost ($ml \cdot kg^{-1} \cdot m^{-1}$) | Blood lactate ($mmol \cdot l^{-1}$) | Walking speed ($m \cdot min^{-1}$) | Oxygen cost ($ml \cdot kg^{-1} \cdot m^{-1}$) | Blood lactate ($mmol \cdot l^{-1}$) |
|---|---|---|---|---|---|---|
| 1 | 41.4[a] | 0.30 | 1.4 | 67.0[b] | 0.29 | 2.5 |
| 2 | 21.8 | 0.39 | 3.6 | 60.4 | 0.32 | 1.6 |
| 3 | 38.0 | 0.52 | – | 73.7 | 0.52 | – |
| 4 | 21.8[a] | 0.56 | – | 40.1[b] | 0.33 | – |
| 5 | 29.0 | 0.31 | 2.0 | 77.2 | 0.22 | 3.1 |
| 6 | 28.6 | 0.33 | 2.7 | 71.2 | 0.23 | 2.3 |
| 7 | 25.3[a] | 0.59 | 1.6 | 42.3[b] | 0.53 | 2.8 |
| 8 | 37.5[a] | 0.39 | 2.3 | 59.2[b] | 0.34 | 3.0 |

[a] Problem with balance at lower speed.
[b] Problem with coordination at higher speed.

*Blood lactate*

Blood lactate was measured in six patients walking at the same speeds before and after treatment (Table II). In two patients the blood lactate could not be determined for technical reasons, and retests could not be performed because of a fracture injury in one patient and an injury with back pain in the other. Before treatment blood lactate averaged 2.2 $mmol \cdot l^{-1}$ and after treatment 2.1 $mmol \cdot l^{-1}$. In one patient blood lactate was decreased by 0.5 $mmol \cdot l^{-1}$, and in the other five it was unchanged (Tables II and III).

*Perceived exertion*

Perceived exertion averaged $2.8 \pm 1.3$ at self-selected speed before treatment. After treatment the corresponding value was reduced to $1.5 \pm 1.3$ ($p < 0.05$) (Table II).

## DISCUSSION

For all patients the prerequisites for inclusion in this study were a clinically significant treatment effect of long-term muscle stretch, decrease in hypertonus and in coactivation of hip adductor muscles and increase in hip abduction motion range. The main purpose of the study was to quantify in physiological and psychophysical terms this clinically obvious treatment effect on walking efficiency. To reduce the problems of variation in muscle tonus in patients with spastic paraparesis, only patients with a disease in a stationary phase were selected.

Walking ability was improved in all patients after treatment as assessed by subjective perception of less exertion and a more comfortable gait. The self-selected walking speed was mainly unchanged after treatment and still much lower than that of healthy subjects (48 $m \cdot min^{-1}$ compared to 80 $m \cdot min^{-1}$) (6).

Oxygen cost was lower after treatment in all patients except two (patients 2 and 3). One of these (no. 3) was the only one who after treatment did not increase his self-selected walking speed (Table II), which is probably why he did not decrease the oxygen cost. The other patient had an unchanged oxygen cost after treatment but blood lactate was decreased and indicated a treatment effect (Table II).

These variations of metabolism found in our spastic patients may have a physiological explanation. In healthy subjects there is an orderly recruitment pattern of motor units and a subsequent change in metabolism with increased exercise (7). Single motor unit studies have also shown that during locomotion in normal subjects low-threshold, fatigue-resistant, slow-twitch motor units are recruited first (5). In patients with muscle spasticity, fast-twitch fibres can be recruited earlier than in normal subjects, with subsequent increase in blood lactate related to a more intensive contraction of the spastic muscles (9). In normal subjects the self-selected walking speed tends to be the most optimal speed, at which the relative oxygen cost per meter is lowest (6).

In our patients, however, walking speed was limited for neurological reasons and the speed chosen as the most comfortable was not the speed with the lowest oxygen cost (Tables II and III). Fear of falling due to difficulties of coordination at faster speeds and balance problems at slower speeds were the reasons for selection of a walking speed with a higher oxygen cost. These disabilities were clearly illustrated in the patients who could not alter their walking speed by 20 $m \cdot min^{-1}$ compared to their self-selected speed. The choice of a walking speed at higher oxygen cost in our spastic patients tallies with findings from previous studies of walking capacity in hemiparetic patients (2, 3).

After treatment, the patients were tested only at the self-selected walking speed. This was to avoid stressing them and thus running the risk of increased spasticity. While the patients were tested directly before and after treatment, no objective measurements of treatment effect over time were taken. Subjectively, the patients reported improvement lasting for up to 24 hours.

In conclusion, this study has demonstrated that treatment with long-term muscle stretch can improve walking ability and efficiency in patients with spastic paraparesis. In assessment of walking ability, especially in multiple handicapped patients, measurement of energy cost can be a valuable supplement to clinical judgment, but in spastic patients both aerobic and anaerobic metabolism have to be considered.

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