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Back extensor muscle fatigability in chronic low back pain patients and controls: Relationship between electromyogram power spectrum changes and body mass index

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Abstract. Back extensor muscle fatigability and its relationship to body mass index (BMI) was measured in 12 chronic nonspecific low back pain (CNLBP) patients (7 women and 5 men) and 12 healthy age-and gender-matched controls. Subjects performed Sørensen back isometric endurance test until exhaustion while EMG spectral mean power frequency (MPF) over the lumbar erector spinae muscle and endurance time were recorded. The CNLBP patients had significantly shorter endurance time than healthy controls. Spectral MPF significantly declined as time of isometric contraction progressed. Relative decrease of the MPF per minute (MPF slope) for left and right side, and pooled MPF slope was significantly higher in CNLBP patients compared with controls. In CNLBP patients the isometric endurance time correlated significantly negatively with BMI ($r = -0.71$). In controls BMI correlated significantly positively with MPF slopes of left ($r = 0.68$) and right ($r = 0.57$) side, and pooled MPF slope ($r = 0.62$).

Keywords: Low back pain, back extensor muscle fatigability, body mass index

1. Introduction

In physically demanding occupations, back muscle fatigue is easily developed during repetitive lifting, bending and twisting maneuvers, which have been shown to be occupational risk factors for low back pain [11]. A common finding in many chronic low back pain patients is that the back extensor muscles are both excessively fatigable and weak [4,12,14,15,24,28,30]. Therefore, the evaluation of the back extensor muscle fatigability has important applications in ergonomics as well as in assessment of patients with low back pain during rehabilitation.

Sørensen back isometric endurance test, i.e. holding the torso against gravity, which is about 40–50% of maximal voluntary contraction force [18] has been widely used to assess back extensor muscle fatigability [1,4,7,14,15,18,21,22]. During this test the subject is placed prone, the lower body below the superior border of the anterior iliac crest is secured and strapped onto an examination couch, and the upper body is unsupported with the head held in a neutral position. The torque created by upper body during the Sørensen back isometric endurance test can be calculated on the basis of body weight and height [32]. It has been observed that body weight [1,4,18] and body mass index [14] have a significant influence on lumbar back muscle fatigability in Sørensen endurance test. Body mass index (BMI) is the ratio of body weight in kilograms to height in meters squared (BMI $=$ kg/m^2) and gives a quantified answer to the question of whether an individual is underweight, of normal weight, or overweight. Increased BMI is positively associated with chronic low back pain [2,8,27].

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Assessment of fatigability in the Sørensen back isometric endurance test is based on measuring endurance time, but this is hampered by subjective qualities, eg, motivation and tolerance to discomfort or pain. Surface electromyogram (EMG) power spectrum parameters and their shift toward lower frequencies has been employed to objectively assess the back extensor muscle fatigability in sustained isometric contractions [3, 14,18,30,34]. EMG power spectrum shifts to lower frequencies caused by neural and metabolic factors in the muscle. The muscle fatigue-induced changes in EMG spectrum parameters have been related to the action potential conduction velocity propagation, which is believed to be a result of metabolic by-product accumulation (e.g. lactate, H^+ and extracellular K^+) [5, 35]. Mean power frequency (MPF) and median frequency (MF) have been suggested to be the most suitable parameters to measure EMG spectrum shifts toward lower frequencies. EMG spectrum MPF/MF decrease over time (slope) has been accepted as an objective measurement of local muscle fatigue [23], also in lumbar back extensor muscles [9,14,15]. Differences in EMG power spectrum parameters in low back pain patients compared with those in healthy controls have been usually shown a steeper slope [21,29]. However, conversely, a less steep slope for low back pain patients has also been reported [28]. Studies in low back pain patients have shown difference in MPF or MF slope between the right and left side of bilateral recordings of an isometric contraction of back extensor muscles [26, 30], but for healthy subjects difference between both sides [33] and no difference [19,25] have been shown. Despite the wide-spread use of EMG power spectrum parameters to monitor of the back extensor muscle fatigue, its relationship with subjects BMI, has received only little attention [14]. The relationship between the changes in EMG power spectrum during fatiguing sustained isometric contractions of the back extensor muscles and BMI in subjects with chronic low back pain is poorly understood.

The aim of this study was to examine the back extensor muscle fatigability in the submaximal isometric contraction and its relationship to BMI in chronic nonspecific low back pain (CNLBP) patients and healthy controls. Muscle fatigue during Sørensen back isometric endurance test was assessed using MPF slopes of the EMG power spectrum and endurance time. We hypothesized that subjects with high BMI will fatigue faster during Sørensen test than subjects with low BMI.

2. Material and methods

2.1. Subjects

Twelve CNLBP patients (7 women and 5 men) and 12 age- and gender-matched controls participated in this study after signing an informed consent. Patients were recruited through the Tartu University Hospital, where they had frequently sought medical attention for low back pain. In the initial clinical examination at the hospital, the cause of the back pain was confirmed to be nonspecific, and patients with nerve root compression or disc prolapse, severe scoliosis, spondyloarthrosis, previous back surgery, and other serious and specific causes of back pain were excluded. The chronic back pain diagnosis included the criteria that patients had low back pain for longer than 3 months (on the average for 6.8 $\pm$ 2.1 yrs) and that they did not have radicular symptoms. All patients completed questionnaires concerning their back pain history, current back pain and functional disability. None of the voluntary controls had a history of pain in lower back or had experienced lower-back pain during the previous year. The study carried the approval of the University Ethics Committee. The physical characteristics of the subjects are presented in Table 1.

2.2. Sørensen back endurance test

The subject lay in a prone position on a treatment couch with the lower half of the body below the level of the anterior superior iliac spines strapped to the couch at three positions: at the ankles as close to the malleoli as possible, at the knee creases, and at the level of the greater trochanter of the femur. The seat belts were tightened as firmly as possible while considering the subject's level of comfort. The subject's hands were placed at the sides of the trunk, and the chest was supported at a 45° angle downward from the horizontal position. The subject was instructed at the beginning of the test to lift the upper trunk clear of the chair and maintain the horizontal position as long as possible. The horizontal position during the test was controlled by a small sack (hanging from the ceiling), which was placed between the scapulae. The subjects were verbally encouraged to maintain the horizontal position of upper trunk. The test was ended if the subject could no longer hold the test position or stopped because of maximal fatigue. The endurance time was recorded using a stopwatch. The subjects were verbally encouraged to continue throughout the endurance test.

Table 1
The physical characteristics and endurance time of the subjects

Subject	Gender	Age (years)	Height (cm)	Body mass (kg)	Body mass index (kg/m^2)	t_{endur} (s)
CNLBP patients						
1	F	53	165	65	23.9	120
2	F	51	161	63	24.3	222
3	F	59	158	69	27.6	218
4	F	63	172	82	27.8	180
5	F	60	167	97	34.6	133
6	F	38	164	66	24.4	249
7	F	58	160	54	21.2	470
8	M	25	183	62	18.5	420
9	M	65	180	84	25.9	165
10	M	18	174	76	25.1	214
11	M	47	189	102	28.3	240
12	M	35	165	79	29.0	186
Mean		47.4	169.8	74.9	25.9	235.0*
± SE		± 4.4	± 2.9	± 4.2	± 1.2	± 30.7
Controls						
1	F	44	163	67	24.8	273
2	F	48	170	60	20.7	362
3	F	46	165	66	24.4	285
4	F	45	164	75	27.4	300
5	F	43	159	68	18.9	425
6	F	43	163	65	24.5	664
7	F	41	163	84	31.8	229
8	M	46	180	65	20.1	305
9	M	58	184	78	22.9	250
10	M	44	175	104	34.0	351
11	M	48	178	78	24.4	600
12	M	54	163	81	30.1	180
Mean		46.7	168.8	74.3	25.3	352.0
± SE		± 1.4	± 2.4	± 3.5	± 1.4	± 42.2

t_{endur} – endurance time; Body mass index = body mass/height^2.
$^*P < 0.05$ compared to controls.

2.3. EMG recording and analysis

While the Sørensen test was performed, surface EMG was recorded bilaterally from the erector spinae muscles at L3 level. It has been indicated that lumbar L3 region of erector spinae is sensitive area for monitoring the EMG power spectrum changes during fatiguing isometric contraction [18]. After the skin was rubbed with alcohol, pairs of bipolar EMG electrodes (Beckman miniature skin electrodes) were attached over the thickest part of the erector spinae muscle (approximately 3 cm laterally to the spinous process) of the right and left side. The electrodes were applied with inter-electrode (centre-to-centre) distance of 20 mm, in the direction of the muscle fibres. As a reference electrode a large carbon rubber plate (Nemectron, Germany, 7 × 12.5 cm) was placed on the iliac crest. The EMG signals were amplified and displayed with Medicor MG-440 preamplifiers with the frequency band ranging 1 Hz–1 kHz. The output signals from EMG preamplifiers were digitized on-line (sampling frequency 1 kHz) by analogue-to-digital converter installed in personal computer. The digitized signals were stored on a hard disk for further analysis. Spectral mean power frequency (MPF) was determined by using fast Fourier transform algorithms [16], in which a 1024-data-point window (1 s) slides over the whole recorded signal area with a 512-point shift (50% overlap). The MPF was defined as the weighted mean value of the data points forming the single spectrum. During Sørensen back endurance test the MPF was determined and averaged over each period of 5 s. The following characteristics were calculated: initial MPF (first 5 s), end MPF (last 5 s), MPF slopes (% change/min) for right and left side, and pooled MPF (mean of the right and left side data).

2.4. Statistics

Standard statistical methods were used for the calculation of means and standard errors of the means (±

SE). A three-way repeated-measures ANOVA with two within factors (time and side) and one between factor (group) was used. Post hoc analysis was performed using Tukey's test. Pearson product-moment correlation was determined between BMI, endurance time and EMG spectral parameters. Statistical significance was accepted at $P < 0.05$.

3. Results

CNLBP patients had significantly shorter ($P < 0.05$) endurance time of the Sørensen test as compared to healthy controls (Table 1). No significant differences ($P < 0.05$) in initial MPF of right or left side during first 5 s of the Sørensen back isometric endurance test between the measured groups were observed (Fig. 1). The MPF significantly declined as time of isometric contraction progressed. No significant differences ($P > 0.05$) in end MPF of right or left side during last 5 s of the Sørensen back isometric endurance test between the measured groups were observed. CNLBP patients had significantly higher ($P < 0.05$) MPF slope for left and right side (Fig. 2(A)), and pooled MPF slope (Fig. 2(B); $P < 0.05$) than healthy controls.

In CNLBP patients the endurance time of the Sørensen test correlated significantly negatively with BMI ($r = -0.71;\ P < 0.01$), and MPF slope of right side ($r = -0.85;\ P < 0.001$), MPF slope of left side ($r = -0.65;\ P < 0.05$), and pooled MPF slope ($r = -0.76;\ P < 0.01$) (Table 2). In controls BMI correlated significantly positively with initial MPF of right side ($r = 0.58;\ P < 0.05$) and left side ($r = 0.72;\ P < 0.01$), MPF slopes of right side ($r = 0.57;\ P < 0.05$) and left side ($r = 0.68;\ P < 0.05$), and pooled MPF slope ($r = 0.62;\ P < 0.05$). A significant negative correlation between endurance time, MPF slopes of right side ($r = -0.80;\ P < 0.01$) and left side ($r = -0.73;\ P < 0.01$), and pooled MPF slope ($r = 0.77;\ P < 0.01$) was also observed.

4. Discussion and conclusions

The lumbar erector spinae muscle MPF decreases observed in the present study during Sørensen back isometric endurance test are in agreement with the results of previous studies of back extensor muscle isometric contractions [14,18,29,32,34]. This EMG spectrum shift has been attributed to changed muscle metabolism during fatiguing contractions: intracellular pH decrease due to lactate accumulation and H^+ concentration [5] or extracellular K^+ accumulation [17, 31]. In moderate contractions investigated, lactate production was expected to have been minimal, especially in view of the high percentage of type I (slow twitch) muscle fibres shown to be present in erector spinae muscle [13]. Extracellular K^+ accumulation might, therefore, be the important factor limiting erector spinae muscle endurance at moderate contraction levels. The exact physiological mechanisms behind the EMG spectral changes are believed to be multifactorial, where a number of factors has been suggested to influence the rate of EMG spectral shifts toward lower frequencies during fatiguing contractions. These factors include: (1) slowing of action potential velocity, (2) synchronization of motor units, (3) slowing of firing frequency, (4) recruitment of new motor units during the fatiguing contraction [9].

The present study indicated that CNLBP patients performed a shorter sustained isometric contraction of the back extensor muscles till exhaustion (endurance time of Sørensen test) and showed greater lumbar erector spinae muscle MPF slopes for right and left side, and pooled MPF slope, than did age-and gender-matched healthy controls. This suggests that CNLBP patients fatigued faster than controls in Sørensen back endurance test. This finding is in agreement with several earlier studies [4,12,21,24,29]. In this study, endurance time of the Sørensen test correlated negatively with MPF slopes of the erector spinae muscle in CLBP patients and healthy controls. High correlations have been reported between MPF or MF slopes during fatiguing contractions of the back extensor muscles and endurance time by several authors [18,34].

The initial MPF of the erectus spinae muscle during the first 5 s of the Sørensen back endurance test did not differed significantly between the groups of CNLBP pain and healthy controls, which indicates the similar back extensor muscle loading in both subject groups in pre-fatigue condition. This confirms the group differences in fatiguability to be real and not caused by group differences in muscle loading. No right-left side differences were found for initial MPF and MPF slope in CNLBP patients and controls. Thus, the muscle loading and rate of decrease of muscle activation during fatiguing contraction was similar for both sides.

The differences between CNLBP patients and controls in back extensor muscle fatigability during the Sørensen test can be explained by several factors. Subjects with low back pain often avoid using their back in everyday situations, because of fear of pain and its con-

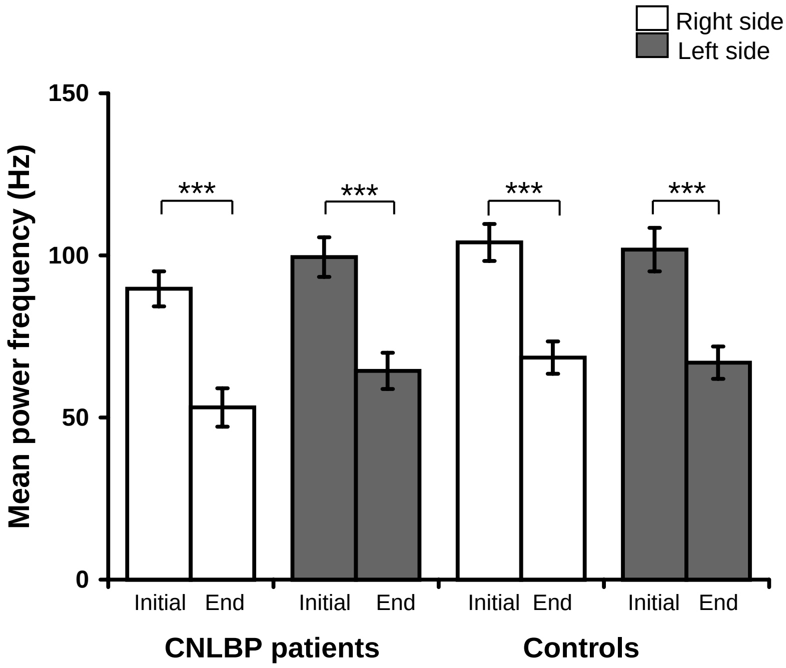

Fig. 1. Initial and end mean power frequency during Sørensen back endurance test in CNLBP patients and controls (mean ± SE).$^{***}P < 0.001$.

Table 2
Pearson correlation coefficients between BMI, endurance time and EMG spectral parameters during the Sørensen test in CNLBP patients ($n = 12$) and controls ($n = 12$)

Parameters	BMI	t_{endur}	Initial MPF (right)	Initial MPF (left)	MPF slope (right)	MPF slope (left)	MPF slope (pooled)
CNLBP patients							
BMI	X	−0.71*	0.17	0.45	0.47	0.20	0.34
t_{end}		X	0.26	−0.22	−0.85*	−0.65*	−0.76*
Initial MPF (right)			X	0.78*	−0.42	−0.32	−0.38
Initial MPF (left)				X	0.01	−0.06	−0.03
MPF slope (right)					X	0.90*	0.97*
MPF slope (left)						X	0.98*
MPF slope (pooled)							X
Controls							
BMI	X	−0.28	0.58*	0.72*	0.57*	0.68*	0.62*
t_{end}		X	−0.12	−0.23	−0.80*	−0.73*	−0.77*
Initial MPF (right)			X	0.77*	0.32	0.32	0.32
Initial MPF (left)				X	0.48	0.49	0.48
MPF slope (right)					X	0.95*	0.99*
MPF slope (left)						X	0.99*
MPF slope (pooled)							X

Abbreviations: t_{endur}, endurance time; Initial MPF, EMG mean power frequency during first 5 s of the Sørensen test; MPF slope, EMG mean power frequency decrease over time during the Sørensen test.
$^{*}P < 0.05$.

sequences [36]. A decrease in physical activity can result in reduced lumbar mobility and loss of the back extensor muscle strength and endurance because of muscle atrophy [6,20]. It has been shown that lumbar back muscle fatigue leads to abnormal spinal movements due to loss of precise muscle co-ordination which increase mechanical loading of passive elements, such as ligaments and intervertebral discs, and may cause back injury and pain [37]. Poor back muscle endurance may predict future occurrence of low back pain [4,19].

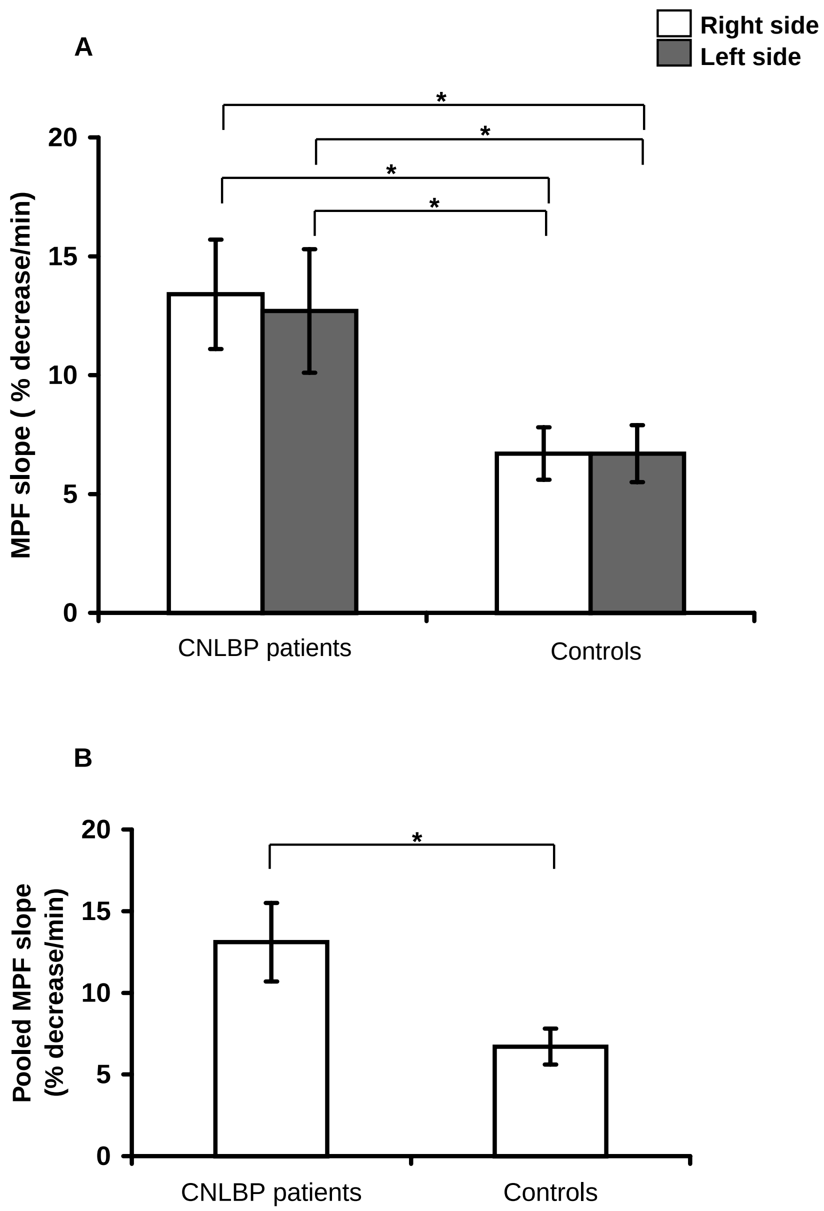

Fig. 2. Mean power frequency decrease over time (MPF slope) of the right and left side (A), and pooled MPF slope (B) during Sørensen back endurance test in CNLBP patients and controls (mean $\pm$ SE).$^* P < 0.05$.

The present data suggest that BMI has a significant influence on back extensor muscle fatigability in the Sørensen isometric endurance test. The correlation analysis indicated that in CNLBP patients with high BMI the endurance time was shorter than in patients with low BMI (Table 2). Healthy control subjects with high BMI had greater lumbar erector spinae muscle initial MPF as well as MPF slope for right and left side, and pooled MPF slope (Table 2). This suggest that subjects with high BMI had greater back extensor muscle loading and fatigued faster during Sørensen test than subjects with low BMI. In literature, there are some suggestions, that subject body mass (weight) may influence the Sørensen isometric endurance test result [1, 4,18]. Kankaanpää et al. [14] investigated the influence of BMI on paraspinal muscle fatigability (endurance time, EMG spectral indices) by using Sørensen test and found a strong influence of this factor. BMI showed a strong negative correlation, and endurance time a strong positive correlation with paraspinal muscle fatigability

(MF slope). Multiple regression analysis indicated that MF slope (fatigue) during the test was dependent on BMI in both sexes, but the effect of BMI was more prounounced in women than men. Several previous studies showed rising of low back pain prevalence with increasing BMI [2,8]. This association may suggest a role of body weight and height in the pathogenesis of low back pain. These findings support the previously reported need for education regarding weight reduction as useful implement in low back pain prevention [27].

In conclusion, the results of the current study have shown that during the Sørensen back isometric endurance test the CNLBP patients fatigued faster than healthy controls. Back extensor muscle fatigability in CNLBP patients and age- and gender-matched controls is influenced by BMI. The greater progressive decrease in MPF (slope) of the EMG power spectrum of the erector spinae muscle during endurance test in CNLBP patients than control subjects is not caused by group differences in pre-fatigue muscle loading.

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