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Electromyography of the paravertebral muscles in idiopathic scoliosis

Measurements of amplitude and spectral changes under load

The myoelectric activity of the paraspinal muscles was recorded in girls with idiopathic scoliosis and in healthy controls. The muscles of the back were loaded isometrically and the signals recorded at the T8 and L3 levels were analysed as regards amplitude and frequency. A comparatively higher signal amplitude was found on the convex side of the scoliosis curve. This was found to be due to a lower amplitude on the concave side when the scoliosis group was compared to the controls. The amplitude difference was correlated to the degree of scoliosis. A shift in the myoelectric spectrum toward lower frequencies occurred during the loading period. There were no differences in this respect between the sides of the scoliosis, nor were there differences between the scoliosis patients and the controls.

Secondary adaptation to the higher load demand by the muscles on the convex side in scoliosis is the most probable explanation for our observations.

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Electromyography (EMG) has been used previously to study the activity of back muscles in scoliosis. Alexander & Season (1978), Butterworth & James (1969), Henssge (1962), Redford et al. (1969), Riddle & Roaf (1955) studied the myoelectric activity of the unloaded spine, while Güth et al. (1978) and Güth & Abbink (1980) studied the myoelectric activity when walking with and without braces. Brussatis (1962), Hertle & Jentschura (1958), Le Febvre et al. (1961) and Zuk (1962) used loaded positions of various types in their studies. An increased myoelectric amplitude and a spontaneous activity on the convex side of the curve near its apex were the main findings.

Quantitative methods were used only by Güth et al. (1978) and Güth & Abbink (1980). However, differences in myoelectric activity in the concave and convex side of the scoliosis when subjected to load were not quantified in their studies, nor have such differences been related to the degree of the curve.

Analyses of the myoelectric power spectrum can be used to study the influence on the myoelectric signals (Lindström 1974, Lindström & Magnusson 1977, Lindström et al. 1977, Lindström & Petersén 1981). A strong muscle contraction causes a shift in the spectral curve toward lower frequencies. This shift has been found to be related to a decrease in the propagation velocity (Lindström et al. 1977), which in turn is related to the accumulation of acid metabolites in the muscle (Mortimer et al. 1970). The power spectrum thus permits an analysis of the response of the muscles to a functional demand.

The purpose of the present investigation was to study the function of the thoracic and lumbar parts of the erector spinae muscles under load, by means of EMG, in patients with idiopathic scoliosis and healthy controls.

Patients

Forty-one girls with idiopathic scoliosis were investigated along with 19 healthy controls. The patients were carefully selected to provide a uniform study group. The controls consisted of girls picked out at random from two schools in Gothenburg. All scoliosis curves were primary thoracic, convex to the right, and with the apex at the T7 to T9 levels. The scoliosis angles (Cobb 1948) had a mean of 29 (5–70) degrees at the thoracic level, and a mean of 19 (5–47) degrees at the lumbar level. The mean age of the scoliosis patients was 14 (11–18) years. All except one were right-handed.

The mean age of the controls was 13 (10–16) years. They were all right-handed. The presence of any significant scoliosis was excluded by physical examination and by using the moirée topography technique (Willner 1981).

Methods

In a pilot study several aspects of external loading of the spine were evaluated. The most constant results, concerning fatigue in the erector spinae muscles at both the thoracic and lumbar levels, were found by asking the girls to lie prone and to hyperextend their backs. Thus, the trunk itself comprised the isometric load. The position was maintained for 2 min. The myoelectric signals were picked up by means of four bipolar surface electrodes, placed symmetrically on the back at the T8 and L3 levels, about 2.5 cm from the midline. The electrode levels corresponded to the apex vertebrae of the primary and the secondary scoliosis curves. The signals were amplified and fed to the analog-to-digital converter of a computer for storage and analysis. The sampling rate was set to 2048 Hz per channel. The quality of the signal was checked visually on an oscilloscope screen, and an automatic artefact control program was used in the analysis process (Arvidsson et al. 1981); over 99 percent of the signal samples were accepted. For amplitude analysis, the root mean square (rms) value of the signal was determined using the first 8 s of the recording period; this period was chosen to minimize a possible influence of fatigue on the amplitude.

Based on the rms values, an amplitude ratio Q was calculated for each spinal level and each subject:

$$Q = 2\,(Vr-Vl)/(Vr+Vl) \qquad (1)$$

where V denotes the rms value of the signal amplitude and r and l denote right and left sides, respectively.

The myoelectric signals were analyzed for frequency changes during the 2 min recording period by repeated calculations of power spectra based on consecutive half second signal segments. Shifts of the myoelectric signal power spectrum along the frequency axis were characterized by means of the Center Frequency (CF). The center frequency of a power spectrum (also denoted centroid frequency and Mean Power Frequency, MPF) is defined as the frequency mean, calculated by weighing the frequencies according to the spectral power density.

For the calculations, special computer programs were developed including routines for fast Fourier transformation. The analysis was performed in two steps. The primary analysis comprised calculations of series of CF values and also rms values of the signal amplitude. In the secondary analysis, fatigue curves were obtained by plotting the CF values versus time. Since it has been found that the CF decreases exponentially with time in isometric, fatiguing contractions (biceps brachii), fatigue curves were also plotted with the frequency values scaled logarithmically. The average slope of the curve in this case was estimated by means of linear regression analysis. This slope, with the opposite sign, has been referred to as the fatigue index (Lindström et al. 1977). Thirty second averages of the rms values were also plotted versus time in the secondary analysis to indicate any effects of fatigue on the amplitude of the myoelectric signal.

Results

The standard deviations of the individual signal amplitudes were approximately 10 per cent, indicating good stability in the contraction level. The interindividual variation of the amplitude values was large; the coefficient of variance ranged from 31 to 60 per cent for the different electrode positions.

The scoliosis group showed a higher myoelectric activity on the convex than on the concave side, for both the primary thoracic and the secondary lumbar curves (Table 1). The amplitude of the myoelectric signal increased at the T8 level on the convex side and decreased on the concave side during the period studied. A decrease was found on both sides at the L3 level.

No significant side differences were found in the controls. There was, however, a slightly higher numerical rms value on the left side at the T8 level and on the right side at the L3 level, i.e. the opposite pattern to the scoliosis group (Table 1). There was an increase in the amplitude on both sides at the T8 level and a decrease at the L3 level during the loading period in the control group.

Table 1. The myoelectric amplitude (rms) value in μV during the 2 min study period.
*Mean (SEM) 40 scoliosis patients and 19 controls: ns = not significant, *convex side (one patient only recorded 15 s).*

Electrode level	Subject group	Side Left	 Right	*t*-test
T8	Control	121 (6.9)	112 (7.3)	ns
	Scoliosis	88 (7.0)	102 (7.6)*	p<0.001
t-test		p<0.01	ns	
L3	Control	97 (6.7)	98 (6.0)	ns
	Scoliosis	94 (5.2)*	83 (4.7)	p<0.01
t-test		ns	ns	

The myoelectric amplitude on the concave side of the scoliosis curve was lower than the amplitude at the corresponding level in the controls. The amplitude on the convex side in the scoliosis group, on the other hand, was the same as that of the corresponding level in the controls. Thus, the amplitude difference between the two sides of the scoliosis curves appeared to be due to a lower than normal activity on the concave side.

In the scoliosis group the rms ratio was positive at the T8 level and negative at the L3 level. The ratio differed from the null hypothesis for the thoracic curves over 10 degrees and for all lumbar curves (Table 2). For the control group this ratio did not differ from the null hypothesis on either level (Table 2). The rms ratio was correlated to the degree of the scoliosis both for the primary thoracic and for the secondary lumbar curves (Figures 1 and 2).

No correlations were found between the amplitude ratios and age, standing and sitting

Table 2. The myoelectric amplitude, expressed as rms-ratio μV, over the first 8 s at T8 and L3 levels in 41 scoliosis subjects and 19 controls.

Electrode level	Subject groups	N	RMS-ratio Mean (SEM)	*t*-test
T8	Control	19	−0.04 (0.06)	
	Scoliosis	41	0.08 (0.05)	ns
	Scoliosis† 11–70°	38	0.12 (0.04)	p<0.05
L3	Control	19	0.05 (0.04)	
	Scoliosis	41	−0.13 (0.04)	p<0.02
	Scoliosis† 11–50°	31	−0.16 (0.05)	p<0.01

† Subgroups according to scoliosis angle.

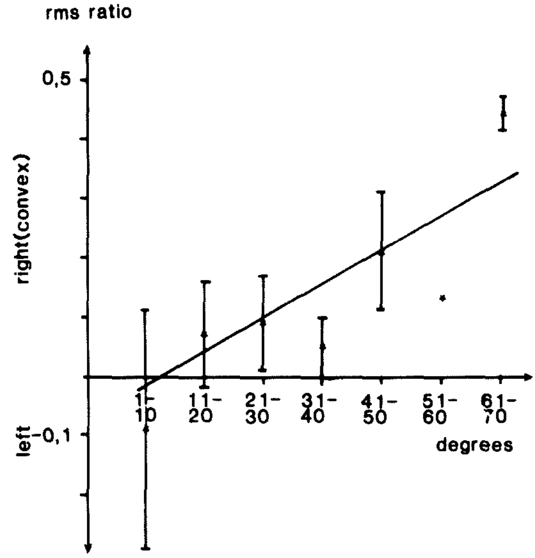

Figure 1. The myoelectric amplitude ratio, mean ± SEM, in thoracic scoliosis (n = 41).
The slope of the regression line was significant (p < 0.05).
All curves were convex to the right.

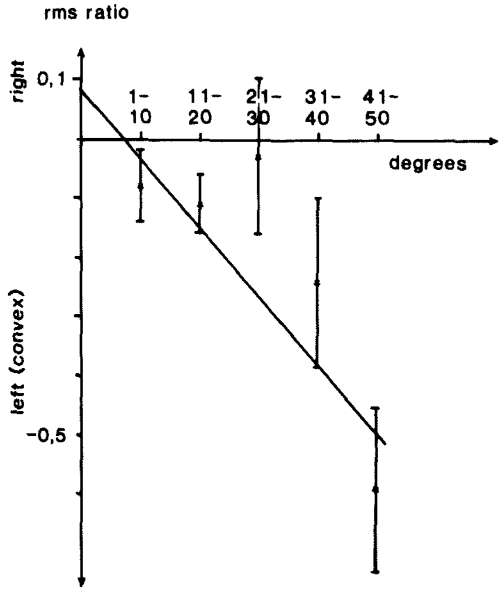

Figure 2. The myoelectric amplitude ratio, mean ± SEM, in the secondary lumbar curves.
The slope of the regression line was significant (p < 0.001).
All curves were convex to the left.

Table 3. The centre frequencies in Hz of the power spectra during the 2 min study period in 40 scoliosis patients and 19 controls.
Mean (SEM). The centre frequency values were higher at the lumbar level compared to the thoracic (p<0.001).

Electrode level	Subject group	Side		*t*-test
		Left	Right	
T8	Scoliosis	92 (2.8)	98 (3.2)†	p<0.01
	Control	96 (3.8)	98 (3.8)	ns
t-test		ns	ns.	
L3	Scoliosis	122 (1.9)†	123 (2.4)	ns
	Control	123 (2.3)	122 (2.3)	ns
t-test		ns	ns	

† Convex side.

heights, weight, height to weight ratio, skeletal maturation according to Greulich & Pyle (1959) and to the iliac apophysis sign (Risser 1958).

The results of the spectral analyses were similar for the scoliosis and control groups. There was a decrease in the CF during the 2 min periods: it decreased fairly linearly with time, but the curves had a slightly downward convexity, indicating a shift toward lower frequencies. A higher CF was constantly seen at the L3 level compared to the T8 level, in both the scoliosis and control groups (Table 3). CF was lower on the left or concave side in the scoliosis group than on the right.

There were no differences in the fatigue index values between either side of the back or between the two investigated groups (Table 4). The slope of the regression line of the logarithmically scaled CF curves was significant in over 95 per cent of the patients and electrode positions, indicating a high degree of fatigue development in the muscles. Slightly, but insignificantly, higher fatigue index values were found at the thoracic as compared to lumbar levels in both groups (Table 4).

Table 4. The fatigue index values in dB (SEM) for 40 scoliotic subjects and 19 controls.
No statistically significant differences were found.

Electrode position	Subject group	Side	
		Left	Right
T8	Scoliosis	4.9 (0.6)	5.0 (0.7)†
	Controls	6.5 (0.7)	6.9 (0.9)
L3	Scoliosis	3.6 (0.4)†	3.2 (0.3)
	Controls	3.5 (0.5)	3.4 (0.6)

† Convex side.

Discussion

The numerical myoelectric amplitude values differed markedly between individuals, due to possible differences in muscle tension, body configuration and muscle to electrode geometry (Lindström 1974).

The comparatively higher myoelectric signal amplitude in the paravertebral muscles on the convex side of a scoliosis curve, recorded under load is consistent with previous observations (Brussatis 1962, Le Febvre et al. 1961, Zuk 1962). The side difference has been interpreted differently. In early reports a fatigue mechanism was suggested (Riddle & Roaf 1955, Zuk 1962). Butterworth & James (1969), on the other hand, suggested that the difference was due to an effect of stretching of the erector spinae muscles on the convex side. This view is supported by the finding of a stretch reflex (H-reflex) more sensitive to vibration and hammer tapping on the spinous processes on the convex side in larger curves (Hoogmartens & Basmajian 1976, Trontelj et al. 1979).

The trunk, devoid of muscles, buckles at axial loads as small as 20 N (Lucas & Bresler 1961), i.e. far less than the weight of the body segments above a given level in the lumbar or midthoracic region (Nachemson 1981, Yettram & Jackman 1980). The stability of the spine is provided by the muscles. In the scoliotic spine there is a bending moment acting on the spine in the frontal plane, proportional to the degree of scoliosis. This means that to maintain an upright posture the paraspinal muscles on the convex side have to perform greater work than those on the concave side. Our results indicate an increasing myoelectric amplitude difference with increasing scoliosis angle. The myoelectric signal amplitude increases with increasing force exerted (Lippold 1952). This implies that the side differences are probably secondary to the curvature of the spine.

Our study indicates that the difference in myoelectric amplitude was not due to an increase in the activity of the muscles on the convex side, but was instead due to a decrease in activity of the muscles on the concave side. The study does not permit conclusions as to why this is the case.

The myoelectric signal amplitude changed during the recording period. The change was not consistent at all electrode locations, however. While a decrease occurred over time at lumbar levels in both groups, an increase occurred at thoracic levels, i.e. with one exception, the concave side in the scoliosis group. The results at the lumbar levels agreed with those of Chapman & Troup (1970) in their study of normal individuals who were loaded in the upright posture. Several other investigators, however, have found an increase in the signal amplitude during sustained muscle contractions of arm and hand muscles (Bigland & Lippold 1954, Cobb & Forbes 1923, Edwards & Lippold 1956).

The decrease in amplitude at the lumbar level and the increase at the thoracic level may be due to a higher rate of fatigue at the thoracic level. A higher fatigue rate could also be expected in the muscles on the convex side in the scoliosis group due to a higher load as compared to that on the concave side.

The CF curves plotted versus time showed a consistent decrease over the loading period in both subject groups and at all electrode locations, and the fatigue index values were also the same throughout (Table 4), indicating a similar rate of fatigue. Thus, there was no indication of a different response of the paraspinal muscles in the patients with scoliosis as compared to the healthy controls. It is interesting to note that the decrease in CF values was associated with a decrease in amplitude at the lumbar level.

At low levels of muscle contraction, the CF increases with contraction intensity (Hagberg 1981). However, the level of contraction in the present study was high. The higher CF values found at the L3 level compared to the T8 level, could be an effect of higher load at the lower level. The side difference of the CF at the T8 level in the scoliosis group could also be due to a higher load on the convex side. However, there may be other explanations for these differences, such as variations in the muscle fiber length, the area of the muscle, and the distance from the active motor units to electrodes (Lindström 1974, De Luca 1979). The last explanation seems to us to be the most probable.

Our results indicate that the loads on the paraspinal muscles on the convex and concave sides were proportional to the capacity of these muscles. The muscles on the convex side seemed to have adapted to the higher load demand. This is consistent with the findings of the side differences in the morphology of the paravertebral muscles (Zetterberg et al. 1983).

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