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Paraspinal muscle fibre type alterations associated with scoliosis: an old problem revisited with new evidence

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Abstract To establish the extent to which the paraspinal muscles are affected in idiopathic scoliosis, samples from patients must be compared with controls of a similar gender and age. To date, insufficient control data has been available for these purposes. The aim of this study was to redress this tissue, in order to identify whether one side of the apex of the scoliotic curve showed greater muscular abnormalities than the other. Bilateral samples of the paraspinal muscles were obtained during surgery from 14 female scoliosis patients, at the apex of the scoliotic curve at T9–T11. Percutaneous muscle biopsy samples were obtained from nine female volunteers, on the left side of the spine at T10. Samples were prepared for routine histochemistry for the identification of muscle fibre types. Fibre size was measured using computerised image analysis. Compared with control muscle, there was a significantly lower proportion of type I (slow-twitch oxidative) fibres in the muscle on the concave side of the scoliotic curve, but no difference on the convex side. The proportion of type IIB (fast-twitch, glycolytic) fibres was higher on both sides of the curve compared with controls, with the effect being significantly more marked on the concave side. The percentage of type IIA (slow-twitch, oxidative-glycolytic) fibres did not differ between the groups, and neither did fibre size (although there was a tendency for the controls to have larger type IIA fibres than the patients). Collectively, the differences in fibre type size and distribution meant that on the concave side the relative area of the muscle occupied by type I fibres was smaller, and on both sides of the curve the relative area occupied by type IIB fibres was greater and by type IIA fibres smaller, in comparison with controls. In scoliosis, the spinal musculature is most affected on the concave side of the curve's apex. The muscle adopts a 'faster', or more 'glycolytic' profile, which would be consistent with a reduced low-level tonic activity of the muscle, perhaps consequent to a local change in activity on this side of the spine following progression of the curve. Less marked changes, in the same direction, are also evident on the convex side; these may be the result of general disuse of the paraspinal muscles associated with the spinal deformity.

Key words Scoliosis · Muscle fibre types · Paraspinal muscles · Multifidus · Erector spinae

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Introduction

The role of the spinal musculature in the pathogenesis of scoliosis has been the subject of much investigation, particularly in terms of identifying the deviations in muscle fibre type distribution associated with the deformity. Differences have been observed between the muscle on the concave and convex sides of the curve's apex [3, 4, 7, 9, 24], although it is still not clear which side reflects the adaptation, or, indeed, whether it is even unilateral in nature. Whether the muscle dysfunction is secondary to the development of the scoliotic curve, or is a primary factor in its aetiology, also remains to be established with certainty; proponents of both the consequential [14, 23, 24] and causal [3, 10, 12, 18] schools of thought exist.

Answers to the above questions are difficult to obtain in the absence of an adequate database describing the normal fibre type characteristics of the musculature at the relevant level of the spine. Sirca and Kostevc [17] report 'normal' data obtained from post-mortem samples of the thoracic paraspinal muscles, but the study group included male subjects only, who were up to 46 years old and with an unspecified back pain history. This data is inappropriate for comparison with muscles obtained from idiopathic scoliosis patients, who are predominantly young, female adolescents. Bylund et al. [3] compared their scoliosis patients with a group of controls, but neither the method of acquisition of the control muscle samples, nor the age and gender of the group, were well described.

This investigation sought to compare directly the fibre type size and distribution of the thoracic spinal musculature of young, healthy females with that of scoliosis patients attending for spinal surgery. The controls were drawn from a large group of healthy subjects [13] in an attempt to provide the best match with the patients [14] in terms of age and gender; these two factors have previously been identified as highly influencial per se in determining the paraspinal muscle fibre type characteristics [13].

Subjects and methods

Subjects

The study was approved by the local Medical Ethics Committee. The control group (CTRL) comprised nine female volunteers, from whom informed consent was obtained. These were drawn from a large group of normal controls in whom the fibre type characteristics of the paraspinal muscles at the level of T10 had been analysed [13], as being the best matched to the young female patient group. The patient group (SCOL) comprised 13 females, scheduled for spinal surgery, in whom the apex of the scoliotic curve arose between T9 and T11 [14]. The mean duration of the idiopathic scoliosis was 5 ± 3 (range 1–10) years, and the mean Cobb angle was 56° ± 10° (range 40°–75°). All but one subject had thoracic convexity to the right. The physical characteristics of the subjects in each group are shown in Table 1.

Table 1 Physical characteristics of the subjects in the patient and control groups (mean ± SD with range in parentheses)

Parameter	(n = 9) Controls	(n = 13) Scoliosis patients
Age (years)	23.4 ± 5.8 (19–34)	13.9 ± 1.5 (12–17)
Height (m)	1.64 ± 0.05 (1.57–1.71)	1.63 ± 0.09 (1.46–1.74)
Body mass (kg)	62.3 ± 8.7 (54–74)	49.8 ± 9.1 (34–61)
Body mass index (kg.m^{-2})	23.0 ± 2.0 (20.2–25.7}	18.6 ± 2.0 (21.5–15.7)

Muscle biopsy collection

CTRL group

With the subject lying prone, percutaneous muscle biopsy samples were taken under local anaesthesia from the belly of the lateral tract (iliocostalis/longissimus) of the left erector spinae, at the level of the tenth thoracic vertebra, using the technique described by Dietrichson et al. [5].

SCOL group

Muscle biopsies were taken bilaterally during surgery from the superficial multifidus muscle at the apex of the curve between the 9th and 11th thoracic vertebral levels.

Muscle histochemistry and analysis

The specimens were reacted for myofibrillar adenosine triphosphatase (mATPase) following acid (pH 4.3 and 4.6) and alkali (pH 10.5) preincubations and for cytochrome *c* oxidase (for details, see Meier et al. [14]). Muscle fibres (typically 1000–1500 per section) were assessed for staining intensity and identified as either type I, IIA, IIB or IIC [2], corresponding to the slow-twitch oxidative (type I), fast-twitch oxidative glycolytic (IIA), fast-twitch glycolytic (IIB) and intermediate (IIC) fibres. The type I fibre is the most fatigue-resistant and the type IIB the most fatigable, with the IIA lying somewhere in between. The fatigue characteristics of the IIC fibre are not clear.

Between 150 and 300 fibres per muscle sample were measured for narrow diameter (ND) using computerised image analysis. To estimate fibre cross-sectional area from ND, the fibres were assumed to be circular in cross-section.

Statistics

Results are presented as means ± standard deviation (SD). Differences between the muscle fibre type characteristics of the controls and (on each side of the spine) the patients were analysed using analysis of variance. Statistical significance was accepted at the 5% level.

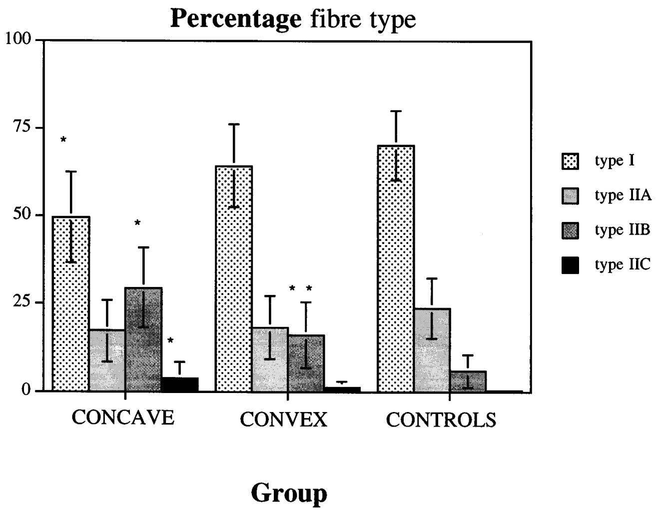

Fig. 1 Relative distribution of the throcic paraspinal muscle fibre types in scoliosis patients, on both concave and convex side of the apex of the curve, and in normal controls (* $P < 0.05$ concave vs other two groups; ** $P < 0.05$ convex vs controls)

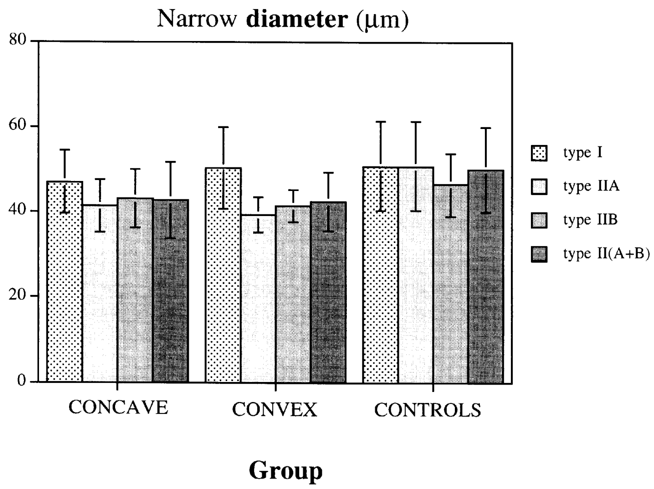

Fig. 2 Paraspinal muscle fibre type size (narrow diameter) in scoliosis patients, on both concave and convex sides of the apex of the curve, and in normal controls

Results

Fibre type distribution

In the muscle from the concave side of the apex (SCOL), the proportion of type I fibres was significantly reduced when compared with the normal muscle; this reduction in the percentage of type I fibres was accompanied by a significant increase in both the percentage of type IIB and the percentage of type IIC fibres (Fig. 1).

The proportion of type I fibres in the muscle from the convex side did not differ significantly from that of the controls; there was an increase in the percentage of type IIB fibres, however, which was mostly at the expense of a reduction (non-significant) in the percentage of type IIA fibres.

Fibre type size

There was a tendency for the type IIA fibres to be larger (by approximately 26%) in the muscle of the controls than in that of the scoliosis patients (Fig. 2); no other significant differences in absolute fibre size were observed between the groups. However, the ratio describing the size of the type I fibre relative to that of the type II (A+B) was greater in the scoliotic than the control muscle, with the difference reaching significance for the convex side ($P < 0.05$).

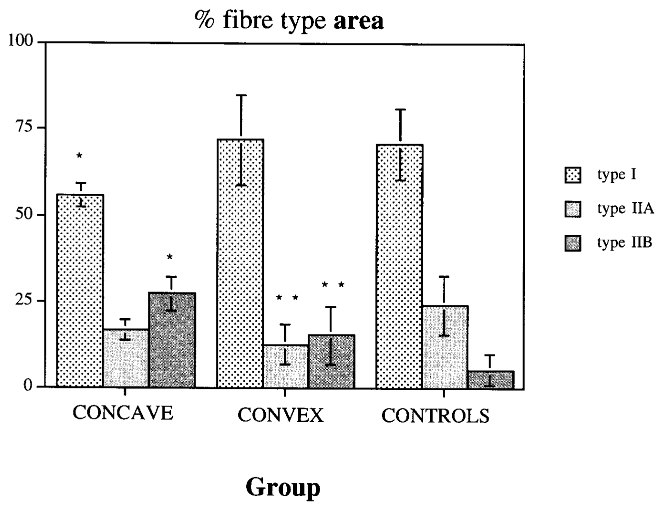

Fig. 3 Relative area of the thoracic paraspinal muscles occupied by each of the main fibre types in scoliosis patients, on both concave and convex side of the apex of the curve, and in normal controls (* $P < 0.05$ concave vs other two groups; ** $P < 0.05$ convex vs controls)

Fibre type area distribution

The relative area of the muscle occupied by type IIB fibres was significantly higher on the concave side of the apex than it was in the control muscle and this change was accompanied by a significant decrease in the relative area of the muscle occupied by type I fibres (Fig. 3).

Compared with the control muscle, the muscle on the convex side showed no difference in relation to the relative area accupied by type I fibres, but *did* display a significantly lower percentage of type IIA fibre area and higher percentage of type IIB fibre area (Fig. 3). In other words, on the convex side, the proportional area accupied by type II fibres was the same as in controls, but the relative area occupied by the sub-types differed (convex: IIB greater than IIA; controls: IIA greater than IIB).

Discussion

Before interpreting and discussing the results of this comparative study, it is important to address certain methodological aspects that could potentially influence the data. Firstly, in the patients, it was quite clear where the muscle sample was being taken from during surgery, and all samples were harvested from the multifidus between the levels of T9 to T11. The paraspinal muscle biopsies from the control subjects were taken percutaneously at the same vertebral level, but – due to the inherent limitations of this technique – without the ability to specify the precise muscle (longissimus or iliocostalis) that was targeted or the exact depth of sampling. It is difficult to predict the extent of the variation this might introduce, as no study has ever examined the effect of sampling site on the fibre size/type distribution of the back muscles in the thoracic region. However, such studies *have* been conducted for the lumbar region, and, whilst those carried out on post-mortem samples have produced inconsistent findings [11, 15], the studies that examined muscles obtained from volunteers showed that there were no significant differences between multifidus and longissimus/iliocostalis muscles in either fibre size or type distribution [11, 20]. Assuming the same applies for the thoracic muscles, our comparison remains valid. In the present investigation, the sectioning and histochemical analyses of the muscles were all performed in the same laboratory, using the same recipes, and this therefore eliminates one other potential source of error.

The results of this study have shown that, in idiopathic scoliosis, the greatest alterations in muscle fibre type distribution occur on the concave side of the scoliotic curve. If viewed as secondary to development of the deformity, the muscular adaptation could conceivably be considered the result of localised disuse. It has been shown that cessation of normal stretch and repetitive low-level activity patterns – of the type that the back muscles are normally renowned for in stabilising the spine, but which could be rendered counterproductive in the region subtended by the laterally flexed scoliotic spine – results in a transformation of the muscle towards a faster, more fatigable type [8]. This has even been observed in muscles that do not ordinarily express the fast type IIB myosin heavy chain gene, if denied the opportunity to stretch and produce force [8]. Interestingly, in the present study, an increase in the number of type IIC fibres was also observed on the concave side of the curve compared with the control muscles. The IIC fibre is an 'intermediate' type, containing both fast and slow myosins in various proportions [1], and an increase in the proportion of these fibres has been shown to reflect ongoing fibre type transformation [16]. This would tend to support the hypothesis that the muscles on the concave side of the scoliotic curve undergo a gradual change in type, in the direction of slow (type I) to fast (type IIB).

The changes on the convex side of the scoliotic curve were not so extreme as those on the concave side and were mostly concerned with an alteration in the relative distribution of the type II fibre sub-types. These changes may *also* reflect disuse, but of a more general nature, perhaps related to an overall reduction in the performance of vigorous activities involving the back muscles, consequent to the spinal deformity. This is supported by the finding of a higher type I : II fibre size ratio in the muscle of the patients compared with the controls, suggesting a certain degree of type II fibre-specific atrophy. In this sense, the changes seen on the convex side could represent the results of mild disuse, in a continuum proceeding from the normal 'control' state, through to the marked changes seen in the muscle on the concave side.

In discussing abnormalities of the paraspinal musculature associated with scoliosis, an alternative hyothesis that is sometimes advanced is that the altered fibre type characteristics are actually causative in producing the deformity [6, 19]. This hypothesis could certainly be accommodated by the results of the present study, but the supporting evidence is less compelling. It has been shown, using an animal model, that a three-dimensional spinal deformity with the characteristics of idiopathic scoliosis occurs coincidentally with unilateral electrostimulation of various trunk muscles, including the erector spinae [22]. Stimulation on the right side of the spine produced a concavity to the right, suggesting that the bilateral asymmetry in force exerted on the spine may have been instrumental in creating the deformity. This model would thus assign to the concave side the 'active' role, and would presuppose that the muscles here were responsible for initiating the scoliotic curve. As it has now been clearly demonstrated that there is a markedly reduced proportion of type I fibres on the concave side of the curve – and, hence, a reduced ability to sustain tonic contractions for prolonged periods of time – this hypothesis seems unlikely.

Conclusion

The results of this study have shown that, in idiopathic scoliosis, the spinal musculature on the concave side of the apex of the curved spine shows the greatest alterations in fibre type distribution, and that these are consistent with a reduced repetitive low-level use (increased percentage of type II fibres) at a local level. The muscles on the convex side show changes of a similar nature and direction, but not so extreme, and may be the result of inactivity of the back muscles in general. These conclusions have been reached from comparisons drawn with a suitably matched control group, of the appropriate gender and as close in age to the patient group as ethically allowable, and from whom fresh, not post-mortem, muscle samples were obtained. Although unable to settle the argument of 'cause or effect', these results certainly support previous contentions, derived from both muscle histochemical [3, 23] and electromyographic [21, 24] analyses, that the concave side of the curve is the one that is *most* affected in scoliosis.

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