SEGMENTAL NEUROPHYSIOLOGICAL MECHANISMS IN SCOLIOSIS

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Segmental spinal reflexes (stretch reflexes) were studied in patients with scoliosis. The proprioceptive responses to the phasic stretch of the paraspinal muscles were asymmetric in all patients, and were increased on the convex side. The asymmetry was more pronounced when the patients were standing. The observed asymmetry of the reflex responses was taken to indicate asymmetry in the tone and postural activity of the superficial layer of the paraspinal muscles.

A reciprocal relationship was found in the segmental reflex organisation between the superficial and deep layers of the paraspinal muscles.

The increase in reflex response of the superficial muscles on the convex side can be due to diminished reciprocal inhibition from weak, deep muscles. Thus a segmental neurogenic disorder involving predominantly the deep paraspinal muscles of the convexity of the curve may be the primary lesion responsible for the development of scoliosis.

Muscle imbalance may be a factor in the pathogenesis of idiopathic scoliosis (Allbrook 1955; Riddle and Roaf 1955). Scoliosis is encountered in disorders involving muscles and their innervation, such as muscular dystrophy, spinal muscular atrophy, poliomyelitis or spinal root damage (Enneking and Harrington 1969; Hensinger and MacEwen 1976), and has been produced in animals by motor and sensory denervation of the paravertebral muscles (MacEwen 1968). We have examined 170 patients with degenerative neuromuscular disorders (limb-girdle or Duchenne muscular dystrophy, Kugelberg-Welander spinal muscular atrophy or peroneal muscular atrophy) and found scoliosis in 56 per cent. Of the seventy-six patients who were in the early phase of their respective disorders (Stages 1 to 6 of Gardner-Medwin and Walton 1974), 72 per cent showed a scoliosis. The incidence of scoliosis was not related to the duration or degree of clinical weakness. Morphologically, scoliosis in these disorders was not found to differ from idiopathic scoliosis.

Differences in electromyographic activity between the convex and the concave side of the spinal curvature have been described (Riddle and Roaf 1955; Žuk 1962; Redford, Butterworth and Clements 1969), and usually increased postural muscle activity has been seen on the convex side. Riddle and Roaf (1955) attributed this difference to asymmetrical muscle strength, while others suggested a secondary stretch reflex (Henssge 1964), a compensatory mechanism of some kind (Redford et al. 1969), and a fatigue reaction (Žuk 1962). Such explanations try to account for the increased muscle activity on the convex side as a consequence, rather than the cause, of scoliotic deformity.

In this study we have tried to determine whether this phenomenon is primary rather than secondary, and therefore part of the pathogenic mechanism.

MATERIAL AND METHODS

Forty patients were investigated. There were five normal adolescents. One boy, aged seven, had 3.5 centimetres of shortening of his left leg and a consequent lumbar curve. Twenty patients, aged between six and twenty-eight, had degenerative neuromuscular disorders, resulting in a scoliosis or deviation of between 3 degrees and 30 degrees, with a mean of 9 degrees. Fourteen patients, aged between eight and seventeen, had idiopathic scoliosis, with primary curves ranging from 10 degrees to 34 degrees, and a mean of 19 degrees.

The stretch reflexes of the paravertebral muscles were elicited by means of an electrodynamic hammer (Trontelj, Dimitrijević and Prevec 1968), which delivered taps, directed 45 degrees cranially, in the midline between the adjoining spinous processes so as to stretch the paravertebral muscles simultaneously on both sides. Electromyographic activity was recorded through surface electrodes placed over paired paraspinal muscles. In order to differentiate between the activity in the superficial and deep muscle layers needle electrodes were positioned at these two levels. Recordings were made at the upper lumbar segments with the patients standing free or lying prone. In the fourteen patients with idiopathic scoliosis electrodes were also placed at the apex of the thoracic curve.

In six patients with idiopathic scoliosis the stretch reflex was elicited in the external intercostal muscles of both sides in the segment corresponding to the apex of the curve. The taps were delivered either perpendicular to the sternum or to the rib below the intercostal space from which recordings were made, directed downwards so as to stretch the external intercostal muscle on either side. Needle electrodes were used in three patients and surface electrodes in three others. The external intercostal muscles are analogous in structure and function to...
the corresponding deep paraspinal muscles and also monosegmentally innervated.

Normal subjects were first tested while standing, in order to evaluate the normal variation in the symmetry of the stretch reflex elicited. They then stood with one foot on a support, raised 1, 2 or 3 centimetres and with both knees extended, so as to produce varying degrees of tilt of the spine. The recording electrodes were placed at the apex of the curve. The same procedure was performed in the boy with congenital shortening of the left leg, first without and then with foot supports of different heights.

The stretch reflex of the paraspinal muscles is elicited simultaneously on both sides by means of an electrodynamic hammer directed to the interspinous space obliquely upwards, in the plane of the spinous processes. Recordings are made from two pairs of surface electrodes, one on each side of the curve.

The electromyographic activity was fed to a computer system to be summated and averaged. A series of thirty consecutive responses were analysed simultaneously on both sides. The summated responses were also rectified and integrated to make possible quantitative comparison between the stretch reflexes of the two sides (Fig. 1). Typically, the recorded responses had a latency of about 9 to 12 milliseconds. Sometimes there was an additional polysynaptic response with a latency of about 40 to 50 milliseconds.

RESULTS

In normal subjects the summated stretch reflex showed negligible degrees of asymmetry between the left and the right sides. However, when standing with one foot on the elevated support, the response in the apex of the thoracic curve was decreased on the elevated, convex side. The degree of asymmetry correlated well with the height of the unilateral foot support and thus with the degree of tilt of the spine. Similar recordings were obtained in the boy with unilateral shortening of the leg except when a support was used which equalised limb length exactly. Overcorrection resulted in an inverted pattern of asymmetry.

Of the thirteen patients with neuromuscular disease and scoliosis of the lumbar spine, twelve showed unequivocally increased surface-recorded stretch reflexes on the convex side of the curve (Fig. 2). When there was a late response, this also tended to be increased on the convex side (Fig. 2). On-going motor unit activity was sometimes seen without stimulation, and was also more marked on the convex side. This asymmetrical response was considerably more pronounced with the patient standing than when lying prone. The remaining patient showed an opposite asymmetry, the response being larger on the concave

![Figure 1](image)

**Fig. 1**

The stretch reflex of the paraspinal muscles is elicited simultaneously on both sides by means of an electrodynamic hammer directed to the interspinous space obliquely upwards, in the plane of the spinous processes. Recordings are made from two pairs of surface electrodes, one on each side of the curve.

![Figure 2](image)

**Fig. 2**

Surface-recorded, averaged stretch reflex activity of the paraspinal muscles at the lumbar level on the two sides of a scoliotic curve of a patient with spinal muscular atrophy. The tracings represent an average of thirty consecutive responses. The monosynaptic response is between the two vertical lines and there is a later polysynaptic response. Note that both responses are larger on the convex side of the curve.

![Figure 3](image)

**Fig. 3**

Surface-recorded, averaged paraspinal stretch reflex activity of a patient with spinal muscular atrophy and a spinal curvature. Responses are larger on the concave side.

side. He had Duchenne type muscular dystrophy with a pronounced lumbar lordosis and a relatively small scoliosis of 8 degrees, as measured by the Cobb method.

There were seven patients with neuromuscular disease with non-scoliotic curvature of the lumbar spine, and six had an increased stretch reflex on the concave side (Fig. 3). One boy with Duchenne dystrophy had a small deviation of 5 degrees, and he showed increased reflexes on the convex side.
The fourteen patients with juvenile idiopathic scoliosis all had asymmetric reflex responses with the increase seen on the convex side of the curve, both at the apex (T6–8) and as low as the upper lumbar region. The side which demonstrated increased stretch reflexes usually showed greater on-going motor unit activity (Fig. 4).

In the normal subjects with needle electrodes placed in the superficial and deep muscles, responses were recorded with the subjects standing erect, and bending towards left and right. A characteristic pattern of reciprocal activity was found in which a manoeuvre enhancing the responses of the superficial layer obliterated the responses of the deep layer, and vice versa (Fig. 5), thus demonstrating the presence of reciprocal segmental innervation between the two layers of the paraspinal muscles.

A similar experiment was performed in two patients with idiopathic scoliosis. Again the increase of superficial response on the convex side corresponded to a decreased response in the deep muscle layers on the same side, suggesting that the deep muscles on the convex side may be the site of the primary abnormality. In a further six patients with idiopathic scoliosis, the external intercostal muscles at the apex of the curve were tested as an analogue of the deep monosegmentally innervated paraspinal muscles, in order to avoid recording difficulties due to movement of the electrodes. In all patients the stretch reflex was unequivocally lower on the convex side (Fig. 6).

DISCUSSION

Evaluation of the stretch reflexes of the paraspinal muscles allows detection of minor asymmetry of muscle tone. Our finding of increased stretch reflexes on the convex side of the curve in scoliosis present in patients with neuromuscular disease, and in juvenile idiopathic scoliosis, is in accordance with the reports of other authors (Bayer 1953; Riddle and Roaf 1955; Žuk 1962, 1968; Redford et al. 1969), who observed increased postural activity in the paravertebral muscles on the convex side of the curve when evaluated by electromyography, which probably indicated increased motor neuron excitability. A reverse asymmetry was found in the patients with non-scoliotic spinal curvature and in the normal subjects standing on an uneven support. An exception to this rule was found only in one patient with scoliosis and in another with lesser spinal curvature. Both these patients had Duchenne muscular dystrophy and were atypical in that they had a very pronounced lumbar lordosis.

It therefore seems that the motor neurons of the paraspinal muscles on the convex side of the scoliotic curve are in a state of increased excitability, being more readily available to participate both in the tonic postural activity and in the segmental phasic stretch reflex. However, the muscles contributing to the surface-recorded responses are almost exclusively those of the superficial layer and do not indicate the state of the
deep, rotator muscles. An inverse relationship between the muscles of the two layers was seen in the investigations with two needle electrodes, one placed in each layer, when the postures increasing the stretch reflex in one layer resulted in reciprocal inhibition of the stretch reflex in the other layer. This suggests that the observed increase in the stretch reflex of the superficial muscles on the convex side of the scoliotic curve may actually be associated with a decreased reflex response in the deep muscles, and this was seen in the two patients with idiopathic scoliosis who were investigated with needle electrodes. Similarly, a decreased stretch reflex was found in the external intercostal muscles on the convex side, in the six patients with idiopathic scoliosis in whom this investigation was performed.

Hoogmartens and Basmajian (1976) carried out a similar study on patients with idiopathic juvenile scoliosis using vibration to induce reflex activity in the paravertebral muscles. The tonic vibration reflex employs some of the same segmental reflex arcs as the phasic stretch reflex (Stålberg and Trontelj 1979). Hoogmartens and Basmajian compared vibration-induced activity in the deep muscles on the two sides of the scoliotic curve and found larger responses on the concave side, which they interpreted to be due to spindle hypersensitivity on the concave side. However, we feel that this asymmetry might be due to a segmental neurogenic lesion, predominantly involving the deep muscles on the convex side. The presence of such a lesion would explain the increase in stretch reflexes of the superficial muscles on the basis of their weakened reciprocal inhibition. Such an imbalance of forces during the growth period might lead to the development of a scoliosis, with rotation of the vertebral bodies to the convex side due to tonic predominance of the rotator muscles of the opposite side. The deep muscles are principally innervated from single spinal segments and might therefore be more liable to interference from local segmental neural injury than the superficial muscles, which have a multi-segmental nerve supply.

Our investigations have shown that asymmetrical reflex and postural activity occurs in the paraspinous muscles in patients with early and established scoliosis due to a variety of causes. We suggest that a neurogenic lesion involving one or a few segments leading to asymmetric muscle weakness, predominantly affecting the deep muscles, might be the primary pathogenic mechanism in idiopathic scoliosis.

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