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The density of muscle spindles in the medial, intermediate and lateral columns of human intrinsic postvertebral muscles*

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INTRODUCTION

Studies of the mechanics of the trunk have reported that during the initial phase of lifting in the stooped position the body uses additional support of intratruncal pressure to limit the work done by the erector spinae muscle (Davis, 1956; Bartelink, 1957). These workers showed that intrathoracic and intra-abdominal pressures varied proportionately with the work done. Kumar & Davis (1973) observed that variations in intra-abdominal pressures closely correlated with electrical activity in the postvertebral as well as the anterior abdominal wall muscles. They suggested that receptors in the erector spinae muscles might be implicated, but they did not specify which components of the muscle were involved.

Work done by Etemadi (1963) and Bogduk (1980) have shown that the component slips of the muscle are multi-articular and therefore their pattern of recruitment during movement would depend critically on afferent inputs into the central nervous system. The quality of sensory innervation, and, particularly, the density of muscle spindles in these muscles is, therefore, of interest. Information on the sensory innervation of the back muscles is incomplete. The segmental distribution of muscle spindles in the intrinsic postvertebral muscles was reported by Gregor (1904) in some parts of the group, and by Amonoo-Kuofi (1982) in all members of the group, but the density of spindles in the individual columns was not given.

In order to determine the relative importance of the different columns of back muscles in postural and dynamic functions, their respective spindle contents must be expressed in relation to the bulk of muscle.

This paper reports on the densities of muscle spindles in postvertebral muscles, based on the areas occupied by individual columns at each segmental level.

MATERIALS AND METHODS

Estimation of areas of the three columns of muscle

Measurements of areas occupied by each of the three columns at segmental levels were made from serial transverse slices of the trunks of eight embalmed cadavers, four females of 60, 67, 70 and 75 years, and four males of 40, 50, 58 and 64 years. Each cadaver had been injected with embalming fluid and frozen in solid carbon dioxide to ensure firmness and thus avoid tearing of tissue during slicing.

Transverse slices of the body were then cut at regular intervals to correspond with

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Table 1. *Cross sectional areas of postvertebral muscles per segment*

	Medial column		Intermediate column (sq mm)		Lateral column (sq mm)		Total (sq mm)	
	L	R	L	R	L	R	L	R
At skull insertion	30	29	11	8	—	—	41	37
C 1	41	46	9	10	—	—	50	56
C 2	49	67	8	14	—	—	57	81
C 3	64	57	15	12	—	—	79	69
C 4	52	56	33	31	—	—	85	87
C 5	73	57	16	12	—	—	86	69
C 6	38	42	20	30	—	—	58	72
C 7	73	75	17	9	14	14	104	98
T 1	40	47	12	13	7	9	59	69
T 2	47	34	22	17	12	10	81	61
T 3	30	29	26	23	9	10	65	62
T 4	26	25	18	18	8	8	52	51
T 5	25	25	22	20	6	7	53	52
T 6	23	20	21	17	10	8	54	45
T 7	18	21	26	24	10	11	54	56
T 8	17	18	18	21	7	9	42	48
T 9	22	20	30	28	7	7	59	55
T 10	20	21	47	37	17	10	84	68
T 11	20	24	38	41	14	12	72	77
T 12	31	30	70	54	29	24	130	108
L 1	32	26	87	92	34	35	153	153
L 2	30	30	84	81	67	67	181	178
L 3	35	31	166	149	—	—	201	180
L 4	54	56	137	137	—	—	191	193
L 5	69	62	98	91	—	—	167	153
S 1	71	66	—	—	—	—	71	66
S 2	37	38	—	—	—	—	37	38
S 3	5	5	—	—	—	—	5	5
S 4								
S 5								

known segmental levels, in a constant and carefully maintained horizontal plane. Stitches were used to prevent loose parts from falling out. The slices were labelled and stored individually in containers filled with embalming fluid to prevent drying and to ensure comparable hydration of all slices. Although it was not possible to obtain a full medical history of all the subjects, it was ascertained as far as possible that they did not have any gross disorders of the muscles. When taking measurements, the specimens were laid flat on a table and tracings of the outlines and subdivisions were made on to a perspex sheet applied directly on to the section. Planimeter readings were then made directly from the outlines traced on the perspex sheets, using an Allbrit Planimeter.

Calculation of density of spindles

In order to find the number of muscle spindles per unit area of muscle (density of spindles), the values of absolute number of spindles at each segmental level reported by Amonoo-Kuofi (1982) were divided by the areas of the corresponding segments of back muscle (Tables 2–5).

Table 2. *Number and density of spindles in the medial column*

Vertebral level	Left: No of spindle capsules*	Left: Mean area of muscle sq mm)	Left: No of spindles /sq mm	Right: No of spindle capsules*	Right: Mean area of muscle (sq mm)	Right: No of spindles /sq mm)
C 1	27	41	0·66	23	46	0·50
C 2	25	49	0·51	23	67	0·34
C 3	26	64	0·41	31	57	0·54
C 4	46	52	0·89	44	56	0·79
C 5	36	73	0·49	34	57	0·60
C 6	35	38	0·92	27	42	0·64
C 7	29	73	0·40	28	75	0·37
T 1	18	40	0·45	18	47	0·38
T 2	20	47	0·43	18	34	0·53
T 3	23	30	0·77	21	29	0·72
T 4	13	26	0·50	17	25	0·68
T 5	21	25	0·84	21	25	0·84
T 6	21	23	0·91	21	20	1·05
T 7	17	18	0·91	19	21	0·91
T 8	20	17	1·18	20	18	1·11
T 9	15	22	0·68	18	20	0·90
T 10	14	20	0·70	21	21	1·00
T 11	20	20	1·00	20	24	0·83
T 12	25	31	0·81	18	30	0·60
L 1	19	32	0·59	23	26	0·89
L 2	29	30	0·97	21	30	0·70
L 3	23	35	0·66	25	31	0·81
L 4	34	54	0·63	33	56	0·59
L 5	15	69	0·22	25	62	0·40
S 1	23	71	0·32	23	66	0·35
S 2	16	57	0·43	14	38	0·37

* From Amonoo-Kuofi (1982).

RESULTS

The relative sizes of the compartments of the postvertebral muscles

In all the specimens studied, the intermuscular septa were clearly identifiable in the cervical, thoracic and upper lumbar regions. The different muscle compartments were therefore easy to identify and measure, although the semispinalis and spinalis columns were often difficult to differentiate from each other. In the lower lumbar region (below L2), the septum did not extend into the whole depth of the common muscular mass. Thus, although the multifidus muscle was distinctly demarcated, no further subdivision of the common muscle mass of the erector spinae muscle could be seen. This part was therefore regarded as one mass.

Spinalis, semispinalis, multifidus and intertransverse muscles were grouped together and measured as the medial column, because of the smallness of their individual cross sectional areas. The longissimus muscle is referred to as the intermediate column and iliocostocervicalis muscle as the lateral column. Below the level of L2, multifidus muscle continues as the medial column whilst the conjoint mass of the longissimus and iliocostocervicalis muscles is seen posterolateral to it.

Table 3. *Number and density of spindles in the intermediate column*

Vertebral level	Left: No of spindle capsules*	Left: Mean area of muscle (sq mm)	Left: No of spindles /sq mm	Right: No of spindle capsules*	Right: Mean area of muscle (sq mm)	Right: No of spindles /sq mm)
C 1	5	9	0·56	4	10	0·40
C 2	14	8	1·75	10	14	0·71
C 3	15	15	1·00	11	12	0·92
C 4	21	33	0·64	20	31	0·65
C 5	19	16	1·19	24	12	2·00
C 6	23	20	1·15	24	30	0·80
C 7	16	17	0·94	12	9	1·33
T 1	30	12	2·50	28	13	2·15
T 2	42	22	1·91	43	17	2·53
T 3	32	26	1·23	36	23	1·57
T 4	27	18	1·50	33	18	1·83
T 5	39	22	1·77	37	20	1·85
T 6	37	21	1·76	33	17	1·94
T 7	30	26	1·15	32	24	1·33
T 8	30	18	1·67	32	21	1·52
T 9	25	30	0·83	27	28	0·96
T 10	32	47	0·68	34	37	0·92
T 11	32	38	0·84	33	41	0·81
T 12	49	70	0·70	49	54	0·91
L 1	53	87	0·61	58	92	0·63
L 2	51	84	0·61	56	81	0·69
L 3	38	166	0·23	33	149	0·22
L 4	39	137	0·29	44	137	0·32
L 5	36	98	0·37	29	91	0·32

* From Amonoo-Kuofi (1982).

The mean cross sectional areas of the medial, intermediate and lateral columns of the postvertebral muscles at the various spinal levels are given in Table 1, and illustrated graphically in Figures 1 and 2.

The cross sectional area of the combined mass of intrinsic postvertebral muscles is not uniform throughout the length of the vertebral column (Fig. 1). It is largest in the lumbosacral region with a peak in the mid-lumbar area, whilst the smallest cross sectional area is in the mid-thoracic region. The contributions of the individual columns of muscle to the total area vary considerably in the cervical, thoracic and lumbosacral regions (Fig. 2). In the cervical region, the bulk of the postvertebral muscle compartment is occupied by spinalis, semispinalis and multifidus muscles. Longissimus capitis and cervicis muscles are small slips and contribute only a small fraction to the area occupied by the complex. Iliocostalis cervicis muscle arises from the lower part of the cervical region and makes only a small contribution to the area of the cervical part of the postvertebral muscles.

In the thoracic region, the areas of the medial and intermediate compartments are similar, whilst the lateral compartment remains smaller than these two. In the upper two thirds of the thoracic region, the medial compartment is slightly larger than the intermediate compartment, but, in the lower third, the intermediate compartment becomes progressively larger than the medial and reaches a peak in the mid-lumbar region. The diminution in size of the medial compartment is due to the steady de-

Table 4. *Number and density of spindles in the lateral column*

Vertebral level	Left: No of spindle capsules*	Left: Mean area of muscle (sq. mm)	Left: No of spindles /sq mm)	Right: No of spindle capsules*	Right: Mean area of muscle (sq. mm)	Right: No of spindles /sq. mm
C 1	—	—	—	—	—	—
C 2	—	—	—	—	—	—
C 3	—	—	—	—	—	—
C 4	—	—	—	—	—	—
C 5	—	—	—	—	—	—
C 6	—	—	—	—	—	—
C 7	2	14	0·14	5	14	0·36
T 1	22	7	3·14	21	9	2·33
T 2	27	12	2·25	25	10	2·50
T 3	19	9	2·11	14	10	1·40
T 4	19	8	2·38	19	8	2·28
T 5	19	6	3·17	20	7	2·86
T 6	22	10	2·20	22	8	2·75
T 7	13	10	1·30	14	11	1·27
T 8	19	7	2·71	16	9	1·78
T 9	15	7	2·14	12	7	1·71
T 10	15	17	0·88	17	10	1·70
T 11	14	14	1·00	13	12	1·08
T 12	26	29	0·90	23	24	0·96
L 1	27	34	0·79	19	35	0·54
L 2	27	67	0·40	27	67	0·40
L 3	19	98	0·19	19	91	0·21
L 4						
L 5						

NB. At L_4 and L_5 subdivisions between intermediate and lateral columns are incomplete. The combined mass is represented in Table 3.
* From Amonoo-Kuofi (1982).

crease in size of spinalis and semispinalis muscles which do not extend below the level of T 12. Iliocostalis muscle gains in size in the lower thoracic and lumbar region but soon fuses with the longissimus muscles to form the common extensor mass.

The density of spindles in the postvertebral muscles

In order to determine the relative richness of spindles in the individual columns of muscle, the number of spindles obtained from the counts reported by Amonoo-Kuofi (1982) were compared with the respective areas at each segmental level. The values of spindle densities obtained for medial, intermediate and lateral columns are given in Tables 2, 3 and 4 and illustrated in Figure 3.

In the medial column, spindle densities were slightly higher in the upper cervical than in the lower cervical region. The highest spindle densities were found in the mid-thoracic region, with low values in the upper thoracic, lower thoracic, lumbar and sacral regions.

In the intermediate column, spindle densities were generally higher than in the medial column. There was a mid-cervical peak distribution of spindle densities which was more marked on the right side. In the thoracic region spindle densities were higher than cervical and lumbar values, and became progressively reduced caudally. The lowest spindle densities were found in the sacral region. The highest spindle

Table 5. *Number and density of spindles in the entire postvertebral group of muscles*

Vertebral level	Left: No of spindle capsules*	Left: Mean area of muscle (sq mm)	Left: No of spindles /sq mm	Right: No of spindle capsules*	Right: Mean area of muscle (sq mm)	Right: No of spindles /sq mm
C 1	32	50	0·64	27	56	0·48
C 2	39	57	0·68	33	81	0·41
C 3	41	79	0·52	42	69	0·61
C 4	67	85	0·79	64	87	0·74
C 5	55	89	0·62	58	69	0·84
C 6	58	58	1·00	51	72	0·71
C 7	47	104	0·45	45	98	0·46
T 1	70	59	1·19	67	69	0·97
T 2	89	81	1·10	86	61	1·41
T 3	74	65	1·14	71	62	1·15
T 4	59	52	1·14	69	51	1·35
T 5	79	53	1·49	78	52	1·50
T 6	80	54	1·48	76	45	1·69
T 7	60	54	1·11	65	56	1·16
T 8	69	42	1·64	68	48	1·42
T 9	55	59	0·93	57	55	1·04
T 10	61	84	0·73	72	68	1·06
T 11	66	72	0·92	66	77	0·86
T 12	100	130	0·77	90	108	0·83
L 1	99	153	0·65	100	153	0·65
L 2	107	181	0·59	104	173	0·60
L 3	80	201	0·40	77	180	0·43
L 4	73	191	0·38	77	193	0·40
L 5	51	167	0·31	54	153	0·35
S 1	23	71	0·32	23	66	0·35
S 2	16	37	0·43	14	38	0·37

* From Amonoo-Kuofi (1982).

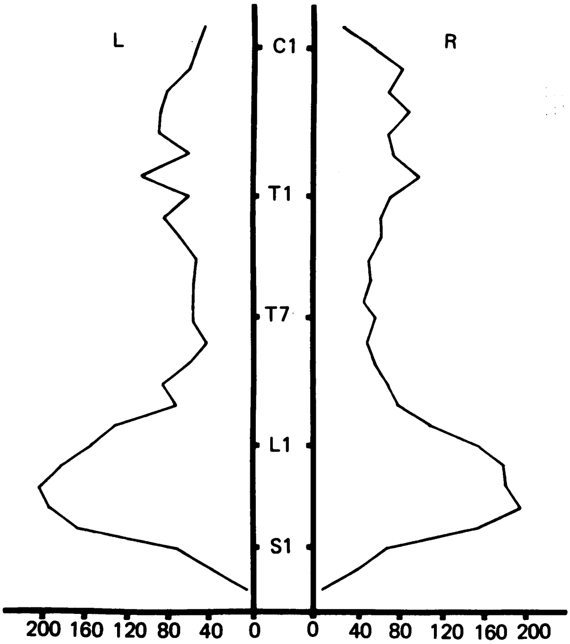
densities among the three columns were found in the lateral column. This was consistent with the histological appearance of the iliocostalis muscle in which the largest number of spindles per microscope field was found.

Spindle densities were higher in the upper and middle thoracic regions and low in the lower thoracic and lumbar regions.

The density of spindles in the junctional regions

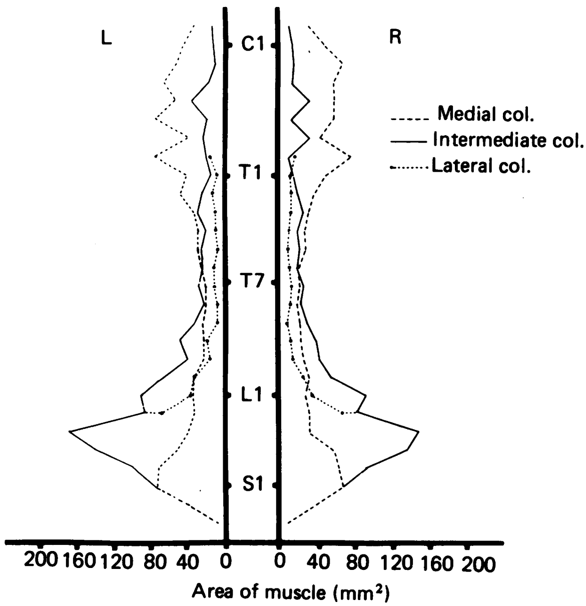
Figure 3 shows a small rise in spindle density which was observed at the cervicothoracic junction whilst the thoracolumbar and lumbosacral junctions showed no change. Of the three columns of muscle, the medial column showed no change in spindle density at the cervicothoracic and thoracolumbar junctions. The intermediate column showed a moderate increase in spindle density at the cervicothoracic junction whilst the lateral column had the highest spindle density at this junction. The intermediate and lateral columns did not show any significant changes in spindle densities at the thoracolumbar junction.

All three columns had high spindle densities in the mid-thoracic region, the lateral column showing the highest concentrations with progressively lower values in intermediate and medial columns.



Area of muscle (mm²)

Fig. 1. Graph showing the mean area of intrinsic postvertebral muscle at each segmental level on both the left (L) and right (R) sides of the body. The size of the muscle compartment is biggest in the lumbar region and smallest in the sacral region. The muscle is fairly bulky in the mid-cervical region.



Area of muscle (mm²)

Fig. 2. Graph showing the mean areas of the medial, intermediate and lateral columns of the intrinsic postvertebral muscles, at each segmental level on the left (L) and right (R) sides of the body. Compare with Fig. 1. The bulk of the postvertebral muscle in the cervical region is formed by the medial column, whilst in the lumbar region, the increase in size is due mainly to the intermediate column. The lateral column forms the smallest compartment in the thoracic region.

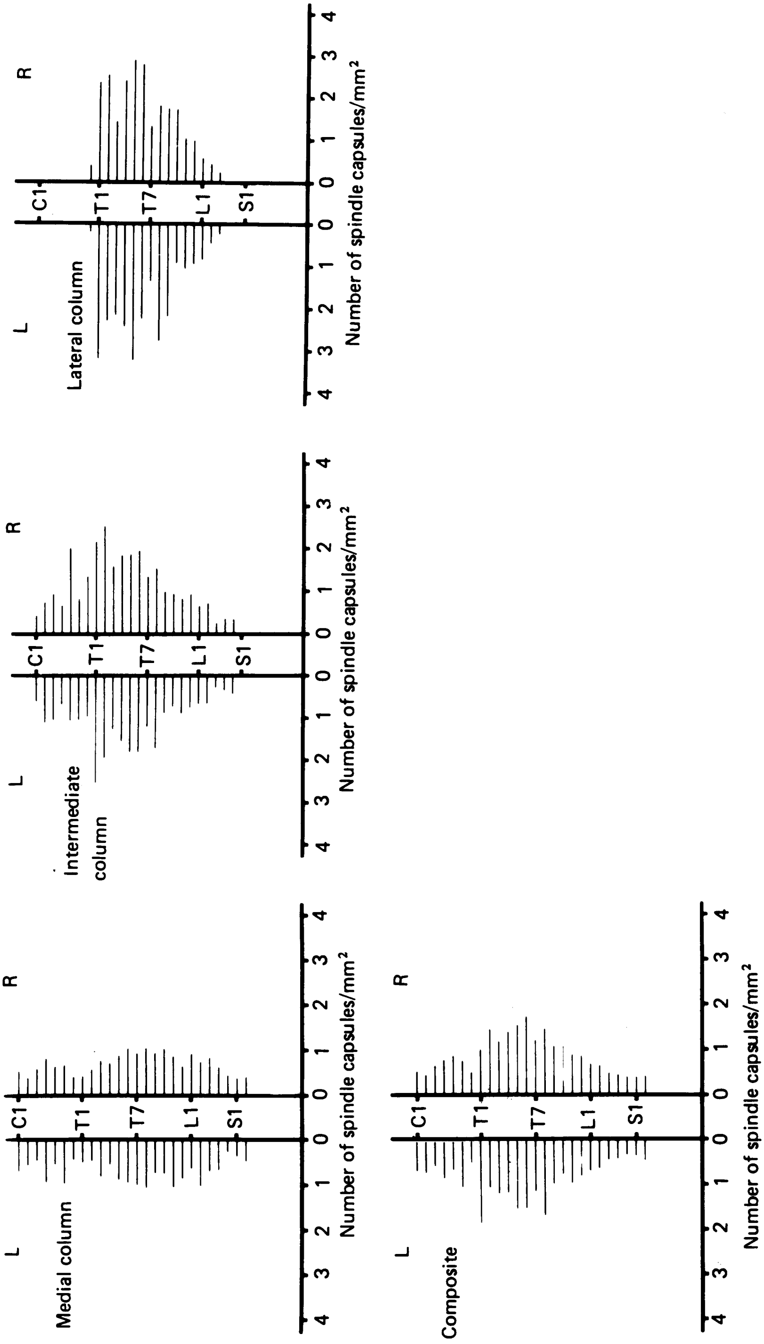


Fig. 3. Bar graphs showing the densities of muscle spindles in the medial, intermediate and lateral columns. Spindle densities are generally high in the thoracic region in all three columns, with the lateral column showing the highest figures. The composite picture illustrates the density of spindles in the entire mass (when the three columns are put together). This emphasises the increase in spindle density in the mid-thoracic region.

DISCUSSION

The absolute number of spindles in a muscle depends to some extent on the size of the muscle; for example, Voss (1937, 1956) showed that the absolute number of spindles in the first lumbrical and latissimus dorsi muscles of man were 51 and 368, respectively. In relation to their weights (lumbrical, 3·1 gm, latissimus dorsi, 246 gm), the first lumbrical had a spindle density of 16·5 spindles per gram of muscle, whilst latissimus dorsi had 1·5 spindles per gram. It appears, therefore, that in order to compare the relative richness of muscles in spindle content, the mass of muscle must be taken into account. In the present study, it has been shown that the area occupied by the deep back muscles per segment is greater in the lumbar region than it is in the cervical and thoracic regions. These findings agree with those of Etemadi (1963, 1974), and reflect the greater load borne by the muscles of this region. The least mobile part of the vertebral column, i.e. the thoracic region, has the smallest areas of muscle per segment.

Comparison of segmental distribution of spindles in relation to the areas of muscle shows that the lateral column has a relatively higher spindle density than the intermediate column at all levels, whilst the medial column has the lowest spindle densities. As Barker (1974) points out, high spindle densities characterise muscles initiating fine movement or maintaining posture, whilst low densities of spindles are found in muscles initiating gross movement. The intrinsic postvertebral muscles subserve both postural and dynamic functions, (Floyd & Silver, 1955; Joseph, 1960; Joseph & McColl, 1961; Jonsson, 1970; Basmajian, 1974, 1976). On the basis of their relative spindle contents, it might be reasonable to suggest that the lateral column would mainly monitor postural activity, whilst the medial column could be considered as mainly dynamic in function; the intermediate column is midway between the two. The interpretation of the spindle density of the medial column is complicated by the fact that it is made up of four separate groups of muscles, viz spinalis, semispinalis, multifidus and rotatores. The value of the spindle density reported for the medial column does not, therefore, reflect the actual spindle densities in the individual muscles.

Pauly & Steele (1966), Donisch & Basmajian (1972) and Basmajian (1974, 1976) noted that iliocostocervicalis muscle was less active than spinalis and longissimus muscles in normal subjects during flexion and extension movements. The relative spindle densities of the three columns reported in the present study are not inconsistent with these dynamic functions, but there is no matching information on their postural functions; most of the studies of postural functions do not differentiate between the individual groups at all levels. Reports of studies of postural functions of iliocostalis, longissimus, spinalis, multifidus and rotatores muscles at thoracic and lumbar levels (Morris, Benner & Lucas, 1962; Donisch & Basmajian, 1972) show that there are no significant differences in postural activity in the erect, sitting and prone positions, but Jonsson (1970) and Waters & Morris (1972) noted that a marked activity of the contralateral iliocostalis muscle was evoked when a weight (of about 10 kg) was held in one hand. No definite conclusions were drawn, but, with the present corroborative information on the density of muscle spindles in the lateral column, it seems reasonable to suggest that iliocostalis is an important postural muscle.

Coughing, straining and other physical functions associated with raised intratruncal pressures have been shown to be accompanied by increased mechanical and electrical activities in the postvertebral muscles (Floyd & Silver, 1955; Kumar, 1971;

Kumar & Davis, 1973). Kumar & Davis (1973) further demonstrated that electrical activity in the erector spinae muscle during lifting was directly proportional to the rise in intratruncal pressures. Topographically, the slips of iliocostalis thoracis muscle, and, to a lesser extent, those of longissimus thoracis muscle are attached to the posterior parts of the outer surfaces of the ribs. Contraction in these slips could therefore influence movement in the costotransverse and costovertebral joints. Conversely, movement at the costotransverse joints (e.g. during breathing, straining, etc.) will stimulate stretch receptors in iliocostalis and longissimus muscles. These muscles, the intercostal muscles and the ventral abdominal muscles are all innervated by thoracic nerves. The posterior primary rami, which innervate the intrinsic postvertebral muscles, also supply articular branches to the costotransverse joints (Wyke, 1975). The finding of high densities of spindles in the thoracic parts of the postvertebral muscles is therefore highly significant. It may be postulated that stretch receptors in the postvertebral muscles, through their influence on the costovertebral and costotransverse joints, could monitor and probably regulate activity in the intercostal muscles, the diaphragm and anterior abdominal muscles, thereby influencing intratruncal pressures.

SUMMARY

The area occupied by the intrinsic postvertebral muscles varies in the different regions of the back. This is associated with variations in the densities of muscle spindles in successive segments of the three columns of muscle. In the thoracic region, the lateral column has the highest density of spindles, whilst the intermediate and medial columns have steadily less.

The attachment of iliocostalis and longissimus thoracis muscles to the ribs is such that contraction of these muscles can produce changes in the costotransverse joints. Conversely, movement in these joints might stimulate stretch receptors in the postvertebral muscles. There is collateral innervation of the costotransverse joints and the postvertebral muscles of the thoracic region by the posterior ramus. The finding of high densities of spindles in the thoracic region would therefore seem to support the hypothesis that these muscles probably monitor postural activity of the back as well as the rib cage.

This work and the previous two studies (Amonoo-Kuofi, *Journal of Anatomy*, 135, 225–233; 585–599) were carried out in the Department of Anatomy at the Royal Free Hospital School of Medicine, London in partial fulfilment of the requirements for the degree of Ph.D. of the University of London. The author extends his thanks to Professor Ruth E. M. Bowden, previously of the Royal Free Hospital School of Medicine, for her helpful criticism and advice. The assistance of Messrs Barry Pike, E. Dawson and P. Dronsfield, all of the Royal Free Hospital, and Mr Abubakar Bello of the Faculty of Health Sciences, University of Ilorin, in preparing the illustrations in this paper is gratefully acknowledged.

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