Anatomy and biomechanics of quadratus lumborum

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Abstract: Various actions on the lumbar spine have been attributed to quadratus lumborum, but they have not been substantiated by quantitative data. The present study was undertaken to determine the magnitude of forces and moments that quadratus lumborum could exert on the lumbar spine. The fascicular anatomy of quadratus lumborum was studied in six embalmed cadavers. For each fascicle, the sites of attachment, orientation, and physiological cross-sectional area were determined. The fascicular anatomy varied considerably, between sides and between specimens, with respect to the number of fascicles, their prevalence, and their sizes. Approximately half of the fascicles act on the twelfth rib, and the rest act on the lumbar spine. The more consistently present fascicles were incorporated, as force-equivalents, into a model of quadratus lumborum in order to determine its possible actions. The magnitudes of the compression forces exerted by quadratus lumborum on the lumbar spine, the extensor moment, and the lateral bending moment, were each no greater than 10 per cent of those exerted by erector spinae and multifidus. These data indicate that quadratus lumborum has no more than a modest action on the lumbar spine, in quantitative terms. Its actual role in spinal biomechanics has still to be determined.

Keywords: lumbar spine, anatomy, muscles, biomechanics, quadratus lumborum

1 INTRODUCTION

The functions of the quadratus lumborum muscle are a mystery. This muscle lies lateral to the lumbar spine and connects the ilium to the twelfth rib and to the lumbar vertebrae. Because of its costal attachment, anatomists have accorded it a role in respiration [**1**, **2**] and, because of its vertebral attachments, they have accorded it a function in moving the lumbar spine [**1**, **2**]. Confidently they stated that quadratus lumborum causes lateral flexion, but uncertainty applies to extension. Anatomy texts state that the quadratus lumborum 'probably helps to extend' [**1**] or 'may extend' [**2**] the lumbar spine. Bioengineers have found the muscle to be active during a variety of lumbar movements, including extension, and have concluded that it is an important stabilizer of the lumbar spine [**3–6**].

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Notwithstanding these beliefs, quadratus lumborum has not been subjected to detailed study of either its morphology or its biomechanics. Other muscles of the lumbar spine, namely erector spinae [**7–10**], multifidus [**8**, **11**, **12**], and psoas major [**13**], have each been carefully studied, and the forces exerted by each of their component fascicles have been fully determined. No comparable data are available for quadratus lumborum. Yet, without such data the function of quadratus lumborum cannot be sensibly and validly determined.

Accordingly, the present study was undertaken in order to complete the anatomical and biomechanical catalogue of muscles of the lumbar spine. It describes the detailed structure of quadratus lumborum and the possible actions and other effects of each of its component fascicles.

2 METHODS

The anatomy of quadratus lumborum was studied by dissection of six embalmed cadavers obtained from the schools of anatomy of the University of Newcastle and the University of Queensland. One cadaver was used to determine the general morphology of the muscle; another was used to obtain photographs of strategic phases of the dissection. In four cadavers on both sides, the detailed structure of its component fascicles was examined by piecemeal dissection. A fascicle was defined as a bundle of muscle fibres with unique and distinct attachments at either or both ends. From one attachment or the other, each fascicle was systematically stripped from the muscle, leaving any remaining fascicles intact. If and when fascicles interweaved, each was carefully mobilized until it could be stripped without compromising the integrity of the other fascicles.

As each fascicle was removed, its sites of attachment were recorded with map pins inserted into the cadaver. Subsequently, these sites were transferred on to an idealized tracing of a standard anteroposterior radiograph of the lumbar spine, which included the ilium and twelfth rib. Sites that were areas, rather than points, were normalized in order to accommodate differences in size between cadavers. Once each area had been defined, it was divided into medial, intermediate, and lateral thirds, and fascicles were assigned to one of these divisions, according to the proportional distance along the area that its actual attachment assumed.

Once each fascicle had been removed, any tendons were trimmed, and the length of the muscle bundle was measured with a ruler to the nearest 5 mm. The volume of each fascicle was measured by placing it into a volumetric cylinder and recording the displaced volume to the nearest 0.5 ml. From the data obtained, the physiological cross-sectional area (PCSA) was calculated as the dividend of the volume and length of each fascicle. A precision greater than 5 mm for length and 0.5 ml for volume was considered unnecessary for the purposes of the present study, for it is evident from previous studies [**7**, **8**, **13**] that the magnitude of biological variation far exceeds and would swamp any errors in measurement of the order of ± 2.5 mm and ± 0.25 ml.

The biomechanics of quadratus lumborum was explored by plotting its component fascicles on six sets of anteroposterior and lateral radiographs of normal subjects in the standing posture. These radiographs were drawn from those used in previous studies of lumbar spine biomechanics [**8**, **9**, **13**, **14**].

Each fascicle was plotted as a straight line between its two points of attachment. A maximum force capability was ascribed to each fascicle. This was calculated as the product of its PCSA and a force-equivalent. The force-equivalent used was 46 N/cm^2, which has been shown to apply to lumbar back muscles [**8**] and provides an estimate of the maximum force exerted by the fascicle. By analysing the three-dimensional geometry of each fascicle, this force was resolved into longitudinal, sagittal, and coronal vectors, with respect to the vertebra (rib) to which the fascicle attached, and to any interposed vertebra across which the fascicle would act. Also, the moments generated by each fascicle in the sagittal and coronal planes were calculated.

The analysis involved a complex and protracted algorithm, which has been detailed elsewhere in the context of other back muscles [**8**, **13**, **14**]. In essence, the algorithm involved establishing the longitudinal and transverse planes of each vertebra, the angle that each formed within the lumbar lordosis, and the angle between each plane and the line of action of the fascicle as seen in anteroposterior and lateral projections. From these angles, the force exerted on each vertebra can be resolved trigonometrically into compression, posterior shear, and lateral shear vectors, and forces exerted in the sagittal plane and in the coronal plane. Forces exerted on subjacent vertebrae can be determined by adjusting for the intersegmental angles of those vertebrae.

For moments in the sagittal plane, the moment arm was measured as the perpendicular distance from the line of action of the fascicle as seen in lateral projections to the centre of rotation of each vertebra on which the fascicle might act. Moments were calculated around the mean location of the centre of rotation of each lumbar motion segment as determined in normal volunteers [**15**]. For moments in the coronal plane, the normal location of the centre of rotation has not been determined. As a surrogate, the centres, at each segment, were assumed to lie at the intersection of the midline and the projection in anteroposterior views of the mean centre of sagittal rotation for that segment.

Once the vectors and moments for each fascicle had been calculated for each of the six sets of radiographs, they were tabulated, and a mean value and standard deviation were calculated for each. The results were compared with equivalent data, calculated in the same way, and published for the other muscles that operate on the lumbar spine.

The effect of forces on the twelfth rib was treated in two ways, according to whether the rib was assumed to be a mobile hinge or a fixed rod. Under the former condition, forces were assumed to be dissipated by movement of the rib, and not to be transmitted to the lumbar spine. Under the latter condition, the rib was assumed to act as an enlarged transverse process of the twelfth thoracic vertebra which could transmit forces, received by it, into the lumbar spine.

3 RESULTS

Quadratus lumborum was found to consist of several types of fascicle arranged in three layers. An anterior layer and a posterior layer enclosed a middle layer. Around the medial and lateral edges of the middle layer the anterior and posterior layers were confluent. In these regions, no morphological features clearly distinguished fascicles as belonging to the anterior or to the posterior layer. Consequently, in some instances, fascicles ascribed to the anterior layer might properly belong to the posterior layer, and vice versa.

As defined by their osseous attachments, the principal types of fascicle were iliocostal, iliolumbar, iliothoracic, and lumbocostal. These fascicles arose from the iliac crest passed to the twelfth rib, from the transverse processes of lumbar vertebrae, from the lateral surface of the twelfth thoracic vertebra, or from the lumbar transverse processes and passed to the twelfth rib respectively. On the twelfth rib, fascicles attached to an area on the lower anterior surface that extended to between 4.5 and 7 cm from the head of the rib. On the iliac crest the muscle occupied an area extending from 5 to 7 cm laterally from a point opposite the tip of the L4 transverse process. Occasionally, fascicles arose from the iliolumbar ligament instead of the iliac crest.

The anterior layer formed the anterior surface of the muscle, and presented a smooth quadrangular surface of regularly arranged fibres (Fig. 1). It was a thin layer, consisting of iliocostal and iliothoracic fascicles, which assumed muscular or tendinous attachments at either end. Between specimens, particular fascicles varied considerably in incidence and size (Table 1). The iliocostal fascicles arose from various points along the anterior margin of the attachment site on the iliac crest; only occasionally did fascicles arise from the iliolumbar ligament. They were distributed to various points along the entire attachment site on the twelfth rib (Fig. 2). The iliothoracic fibres arose from various points along the iliac site and converged to the lateral surface of the body of the twelfth thoracic vertebra (Fig. 2). In some specimens they were joined by fascicles from the L4 and L5 transverse processes. In one specimen, a fascicle from the iliolumbar ligament reached the L1 transverse process.

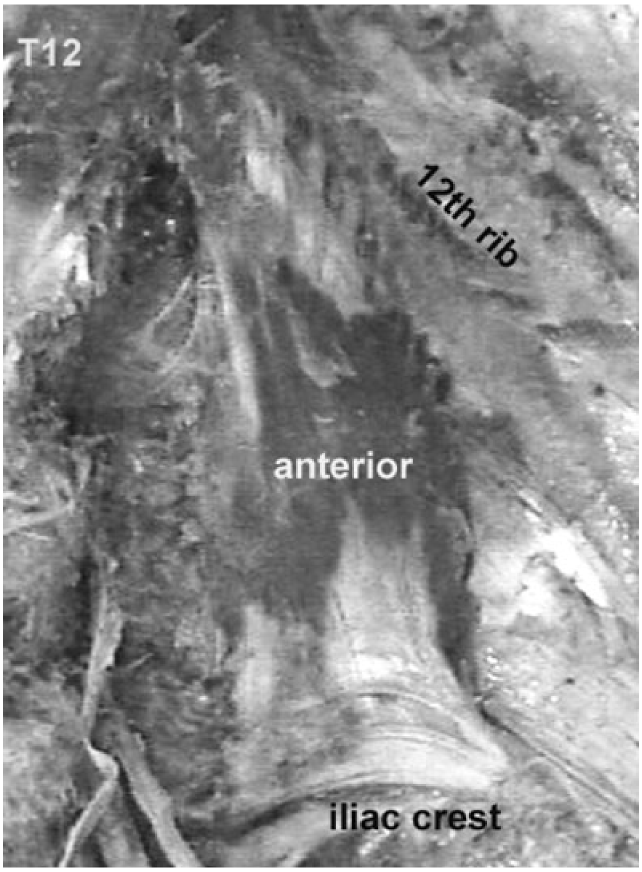

Fig. 1 A photograph of a dissection of the anterior layer of a left quadratus lumborum

The intermediate layer consisted of set of lumbocostal fascicles, irregular in nature, number, and size (Table 1). This layer was distinguished by the radiate arrangement of its fascicles (Fig. 3). Most consistently, fascicles radiated from the tip of the L3 transverse process to various points on the costal attachment site of the muscle, behind the fascicles of the anterior layer (Fig. 4). These fascicles were supplemented by similar fascicles arising most often from the L4 transverse process, and less often from the L2 and L5 transverse processes.

The posterior layer consisted of iliocostal fascicles laterally and iliolumbar fascicles medially (Fig. 5). They varied in incidence and size (Table 1). The iliocostal fascicles arose from the lateral third of the iliac attachment site but passed to all thirds of the costal attachment site, inserting behind or lateral the fascicles of the middle layer (Fig. 6). Rostrally, the more lateral fascicles of the posterior layer typically became tendinous and appeared to insert into the middle layer of thoracolumbar fascia, but their tendons could be traced, through the fascia, into the twelfth rib. The iliolumbar fibres arose from all thirds of the iliac site and passed to the tips of the

Table 1 The incidence and size of various types of fascicle represented in the three layers of quadratus lumborum on each side (R, right; L, left) of four cadavers

	Physiological cross-sectional area (mm^2) for the following specimens and sides							
Layer*	1R	1L	2R	2L	3R	3L	4R	4L
Anterior								
Iliothoracic								
IL–T12	8	25						
I.1–T12	17							
I.2–T12	28	10	17	7				
I.3–T12				28	35	42, 13		
Lumbothoracic								
L4–T12			14	14		13		
L5–T12			21	8				
Iliocostal								
IL–12.1		8					10, 6	
I.2–12.1	10	8						10, 17, 23
I.2–12.2	8	8, 20						
I.3–12.1			8	31				
I.3–12.1								
I.3–12.2			8	15			12	
I.3–12.3	8	10	14,14	8			11, 9	8
Iliolumbar								
L1–IL	12							
Middle								
Lumbocostal								
L2–12.1				20			25, 10, 20	25
L2–12.2				25				
L3–12.1	14, 25	17, 11	25		10, 33	62	9,8	
L5–12.1				10				
L3–12.2	14, 20	11, 13	17	14			11	
L3–12.3		11	10	17			13	
L4–12.1			17				8, 8	14, 31
L4–12.2			11				17, 10	11
L4–12.3	9			20				
L5–12.2			10					
L5–12.3				11				
Posterior								
Iliocostal								
I.3–12.1	10		6				11	19, 29
I.3–12.2	8				24		9, 17, 10	
I.3–12.3		8	10	12, 12		40	10, 19	7, 13
Iliolumbar								
I.1–L3	33	50					25	50
I.1–L4							25	
I.2–L1		17						
I.2–L2		10		10				20, 36
I.2–L3	17, 14	50			33	18, 58	25, 33	50, 13
I.2–L4			80	50	43	38		
I.3–L1		10	21	37	53	28	33, 28	15
I.3–L2	18		8	57	14	50		
I.3–L3		25	58	38, 83	44			

* T, T12 vertebral body; L1–L5, lumbar transverse processes; IL, iliolumbar ligament; I.1, I.2, I.3, medial, intermediate, and lateral thirds respectively of the iliac attachment site; 12.1, 12.2, 12.3, medial, intermediate, and lateral thirds respectively of the attachment site on the twelfth rib.

upper lumbar transverse processes, most consistently to L3 and L1, and less often to L2 and L4. The posterior layer was wedge shaped in longitudinal profile: thick inferiorly and tapering superiorly. This feature arose because, from below upwards, individual fascicles twisted, such that more lateral fibres covered their more medial companions, as the fascicle flattened out towards its costal attachment. As a result, fascicles with a thick, but narrow, origin from the iliac crest assumed a wide, but thin, linear insertion on the twelfth rib.

Given the variability in the number and size of the fascicles encountered in the various specimens, no particular combination of fascicles could be regarded as typical of the structure of quadratus lumborum for the purposes of modelling its actions. Incorporating every type of fascicle would overstate its size and complexity. Assigning every fascicle with

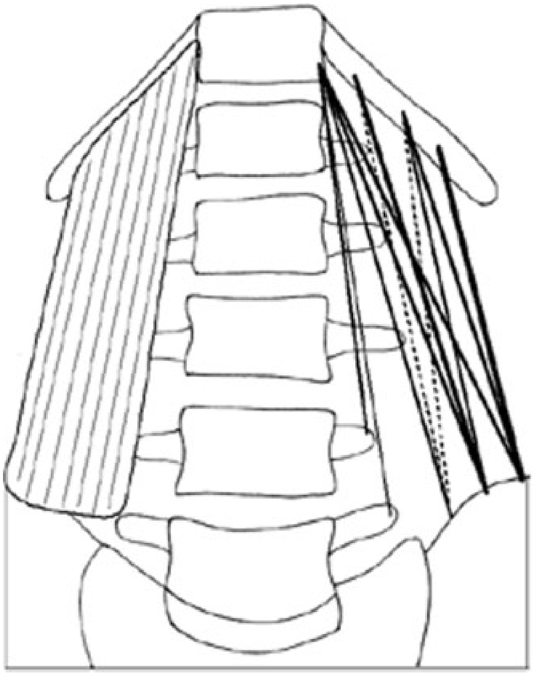

Fig. 2 A sketch of the anterior layer of quadratus lumborum and its component fascicles. The lines depicting each type of fascicle have been drawn with a thickness proportional to the incidence of the fascicle. The dotted lines indicate fascicles that were seen only once in eight muscles

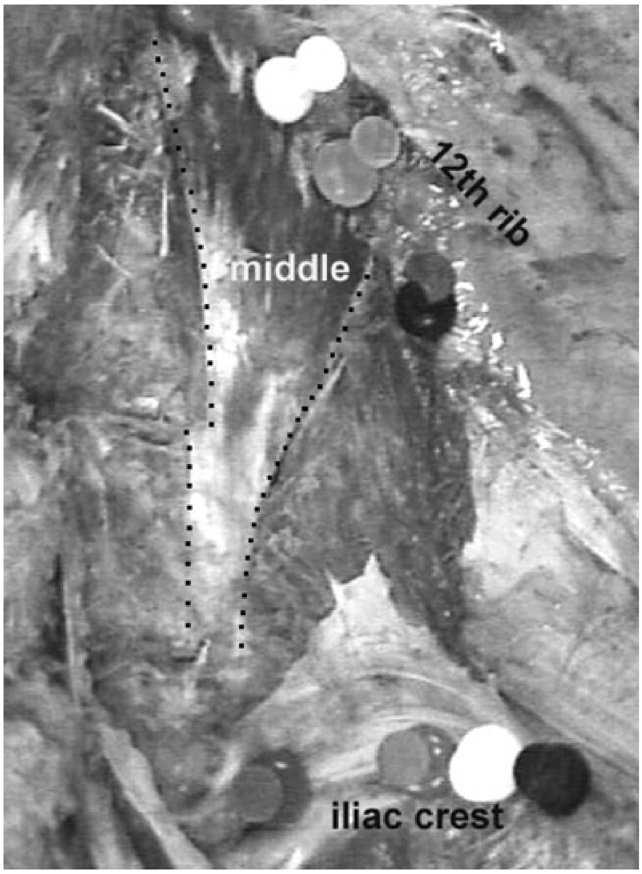

Fig. 3 A photograph of a dissection of the middle layer of a left quadratus lumborum. Its borders have been marked with a dotted line. The other fibres evidently belong to the underlying posterior layer

a weighted mean size would incorporate many trivial force-equivalents. Reciprocally, modelling only the most common fascicles could underestimate its actions. Consequently, as a compromise, the muscle was modelled by incorporating all fascicles that occurred four times or more in the specimens dissected (Fig. 7). The PCSAs of these fascicles and the force-equivalents assigned to them are recorded in Table 2.

Modelling quadratus lumborum revealed that the maximum possible moments and compression forces exerted on the lumbar motion segments were all quite small (Table 3). The data in Table 3 represent the results when the twelfth rib is treated as a fixed beam, and all forces acting on it are transmitted to the lumbar spine. If the twelfth rib is treated as a hinged beam, the moments and forces generated for the iliocostal and lumbocostal fascicles are dismissed, and the results are those attributed to the iliolumbar fascicles alone.

4 DISCUSSION

Textbooks of anatomy [**1**, **2**, **16**] do not mention any layered structure of quadratus lumborum, yet it was quite evident in the present study when the muscle was systemically resected, fascicle by fascicle. That approach identified that the muscle primarily consisted of iliolumbar and iliocostal fibres in the posterior layer, lumbocostal fibres in the middle layer, and iliocostal fibres again in the anterior layer. It also revealed iliothoracic fibres which, although not regularly encountered, were nonetheless common. Some textbooks mention an attachment to the twelfth thoracic vertebra [**1**, **16**], but others do not [**2**].

What was conspicuous in the present study was the great variability in the muscle, between both sides of any one cadaver, and between specimens. Fascicles varied in number and in size. Most fascicles were small, with PCSAs in the range between 10 and 20 mm^2, but many were smaller than this, and some were considerably larger: up to 40 and 60 mm^2. Also, although fascicles could be classified in general as iliocostal, lumbocostal, or iliolumbar, individual fascicles did not consistently

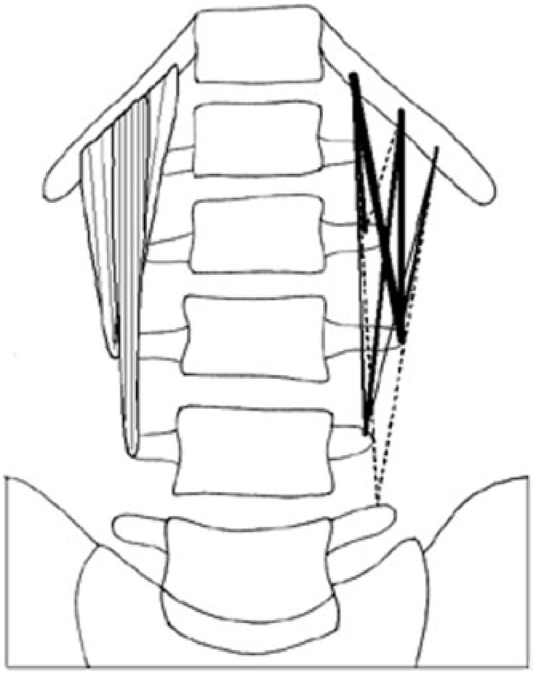

Fig. 4 A sketch of the middle layer of quadratus lumborum and its component fascicles. The lines depicting each type of fascicle have been drawn with a thickness proportional to the incidence of the fascicle. The dotted lines indicate fascicles that were seen only once in eight muscles

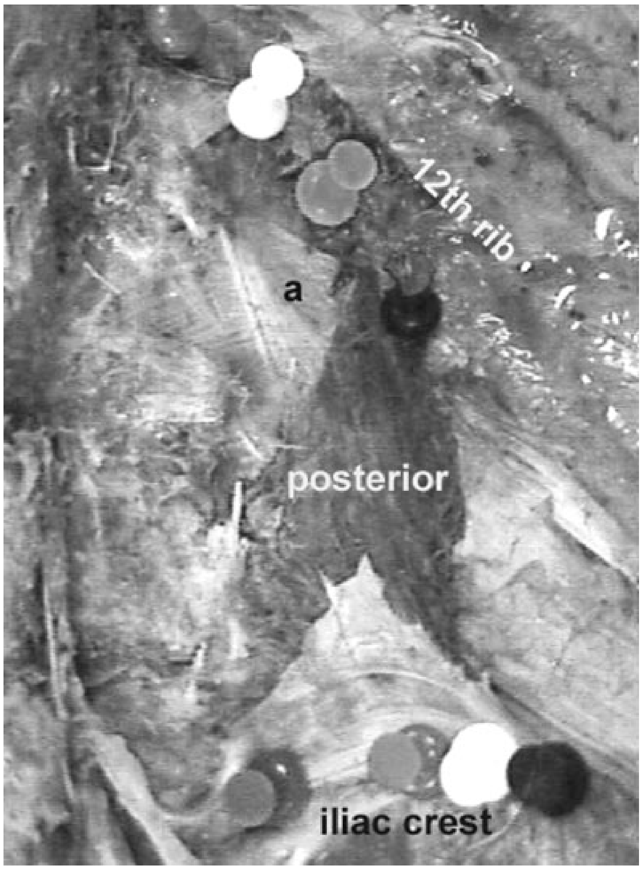

Fig. 5 A photograph of the posterior layer of a left quadratus lumborum. The aponeurosis of the more medial fibres is labelled a

assume the same segmental attachments within and between specimens. In its detailed structure, quadratus lumborum did not conform to any archetypical or modal pattern. Variability was the persistent feature and not consistency.

This variability renders the muscle difficult to model. With no guidelines as to what should be the typical, or representative, structure of the muscle, a pragmatic decision was taken to model only those fascicles with an incidence of 50 per cent or greater. Doing this accords the more common fascicles with a greater prevalence than possibly deserved but, given the results of the modelling, the overestimate is not fatal to the conclusions drawn.

A simplistic method was used to estimate the forces exerted by quadratus lumborum, which involved multiplying the PCSA of each fascicle by a force-equivalent of 46 N/cm^2. This method may be contentious, but there is no better validated means by which to estimate force from morphology. Although the same method has been used for other back muscles, it may be equally invalid for them. For that reason, however, the results of the present study have been expressed in two ways. First, absolute values derived from the force-equivalent are reported. Second, the magnitude of the derived forces and moments for quadratus lumborum are compared with those of the other lumbar spinal muscles. Accordingly, since the same method was used, even if the absolute magnitudes of the forces calculated are in error, their relative magnitudes should be valid.

The moments calculated for the sagittal plane have combined magnitudes that amount to less than 10 N m per segment. These are less than 10 per cent of the magnitude of the extensor moments generated by the erector spinae and multifidus, which amount to between 100 N m and 150 N m per segment [**8**]. Consequently, quadratus lumborum cannot be regarded as a significant or substantial contributor to extension.

Despite its lateral location, quadratus lumborum generates moments in the coronal plane that are less than 10 N m per segment. Modelling studies, with which to compare this value have not been published, but a study of trunk strength in normal volunteers established that the lowest values for lateral flexion, averaged between males and females

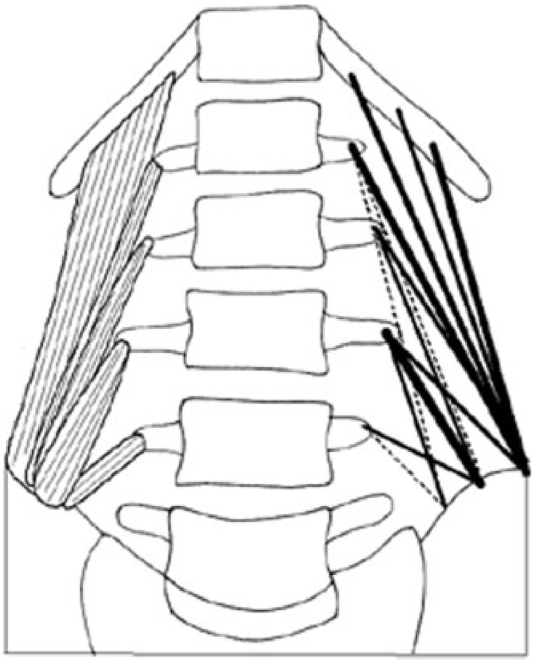

Fig. 6 A sketch of the posterior layer of quadratus lumborum and its component fascicles. The lines depicting each type of fascicle have been drawn with a thickness proportional to the incidence of the fascicle. The dotted lines indicate fascicles that were seen only once in eight muscles

Fig. 7 A tracing of a radiograph of the lumbar spine, on to which have been plotted the 18 fascicles incorporated into a model of quadratus lumborum. On the specimen's left side, the iliolumbar, iliothoracic, and iliocostal fascicles have been depicted. On the right, the lumbocostal fibres have been depicted

was 103 N m [**17**]. Thus, at best, quadratus lumborum contributes less than 10 per cent of the strength of lateral flexion.

Axial rotation moments were not calculated for quadratus lumborum for two reasons. First, its fascicles lie essentially parallel to axes of axial rotation and consequently express trivial force vectors around the axes. Second, it has been shown that erector spinae, which has a greater mechanical advantage for axial rotation than does quadratus lumborum, exerts only trivial axial moments [**10**].

The compression forces exerted by quadratus lumborum amount to approximately 200 N per segment, which is dwarfed by the compression forces of erector spinae and multifidus, which range between 1800 N and 2800 N [**8**]. For that reason, it is difficult to attribute a significant role for quadratus lumborum as a stabilizer of the lumbar spinae by virtue of its compression of lumbar motion segments.

In all instances, the reason for the small moments and forces lies in the small size of fascicles, and their limited number. In comparison, the fascicles of the multifidus and erector spinae are some four to ten times larger, and greater in number than those of quadratus lumborum.

Table 2 The identity of the fascicles of quadratus lumborum that were modelled, together with their physiological cross-sectional area, and the force-equivalent assigned to them

Fascicle*	PCSA (mm^2)	Standard deviation	Maximum force (N)
T12–I.2	15.4	9.2	7.1
T12–I.3	29.2	12.5	13.4
12.1–I.2	10.1	4.0	4.7
12.1–I.3	19.4	8.3	8.9
12.2–I.3	12.8	5.5	5.9
12.3–I.3	14.7	8.8	6.8
L2–12.1	20.0	6.1	9.2
L3–12.1	23.8	16.0	11.0
L3–12.2	14.3	3.2	6.6
L3–12.3	12.6	2.9	5.8
L4–12.3	11.8	2.8	5.4
I.3–L1	28.0	13.3	12.9
I.2–L2	19.1	12.5	8.8
I.3–L2	29.5	22.5	13.6
I.1–L3	39.6	12.5	18.2
I.2–L3	30.5	16.8	14.1
I.3–L3	50.4	21.1	23.2
I.2–L4	52.6	19.0	24.2

* T, T12 vertebral body; 12.1, 12.2, 12.3, medial, intermediate, and lateral thirds respectively of the attachment site on the twelfth rib; I.1, I.2, I.3, medial, intermediate, and lateral thirds respectively of the iliac attachment site; L1–L5, lumbar transverse processes.

Table 3 Biomechanical variables of the fascicles of quadratus lumborum, exerted on the lumbar motion segments, assuming maximum contraction of all fascicles. For sagittal plane moments, the values represent the effect of bilateral contraction of the fascicles. For coronal moments, the values pertain to unilateral contraction The values are the mean values determined from plotting the fascicles on six radiographs. Standard deviations appear in parentheses

Variable	Value for the following segments				
	L1–2	L2–3	L3–4	L4–5	L5–S1
Sagittal moment (N m)					
Iliolumbar fascicles	1.1 (0.15)	2.6 (0.19)	5.4 (0.16)	3.1 (2.50)	
Iliocostal fascicles	1.4 (0.35)	1.5 (0.21)	1.5 (0.18)	1.3 (0.16)	
Lumbocostal fascicles	2.0 (0.37)	1.5 (0.11)	0.3 (0.04)		
Combined	4.5 (0.81)	5.5 (0.43)	7.2 (0.22)	3.8 (3.27)	
Coronal moment (N m)					
Iliolumbar fascicles	0.6 (0.04)	1.5 (0.34)	3.4 (0.19)	6.2 (0.85)	7.0 (1.10)
Iliocostal fascicles	0.5 (0.02)	1.3 (0.06)	1.6 (0.09)	1.9 (0.09)	2.1 (0.07)
Lumbocostal fascicles	1.3 (0.07)	0.8 (0.04)	0.2 (0.00)		
Combined	2.4 (0.12)	3.6 (0.38)	5.1 (0.28)	8.1 (0.86)	9.1 (1.06)
Compression force (N)					
Iliolumbar fascicles	57.1 (1.4)	94.7 (2.4)	182.3 (7.6)	197.9 (15.1)	181.2 (17.1)
Iliocostal fascicles	48.0 (1.0)	47.6 (1.1)	45.7 (0.5)	41.3 (1.3)	33.4 (3.4)
Lumbocostal fascicles	72.9 (1.2)	55.1 (0.8)	10.5 (0.2)		
Combined	178.0 (2.1)	197.4 (3.4)	238.5 (7.9)	239.2 (15.2)	214.5 (19.6)

Moreover, the aforementioned properties of quadratus lumborum are based on modelling the twelfth rib as a fixed beam. Yet it is evident that the twelfth rib is not a rigid extension of the twelfth thoracic vertebra; it can move. How a mobile attachment should properly be modelled was beyond the scope of the present study. For present purposes it is enough to recognize that, because the rib is mobile, it will not transmit to the vertebral column all the forces exerted on it. Consequently, the aforementioned properties of quadratus lumborum must be an overestimate. Nor would incorporating a greater number of fascicles increase the magnitude of the forces and moments generated. Modelling all fascicles seen at least twice in the dissections increases the sagittal and coronal moments by less than 2 N m, and the total compression forces by only 80 N [**14**].

These results go only part of the way to resolving the mystery of quadratus lumborum. Slightly more than half of the number of fascicles, but just less than half of the force capacity of the muscle, lies in its costal fibres. Therefore, quadratus lumborum does seem to be designed as a respiratory muscle: to brace or anchor the twelfth rib and to afford a stable base for the diaphragm. It is the role of the iliolumbar fibres that remains undetermined. Although they constitute less than half the number of fascicles, they nevertheless account for more than half the force capacity of the muscle. Yet they are very weak, as extensors, lateral flexors, and even in generating compression. Therefore, the functions of quadratus lumborum cannot lie in these domains. Whatever function it does serve for the lumbar spine has not yet been perceived, let alone verified. In the light of these conclusions, it is not surprising that a recent modelling study found little effect attributable to quadratus lumborum on the development of stress fractures in cricket fast bowlers, despite marked hypertrophy of the contralateral quadratus lumborum in these sportsmen [**18**].

REFERENCES

1 **Standring, S.** (Ed.) *Gray's anatomy*, 39th edition, 2005, pp. 1115–1116 (Elsevier, Churchill Livingstone, Edinburgh).

2 **Hollinshead, W. H.** *Anatomy for surgeons, vol. 3. The back and limbs,* 3rd edition, 1982, pp. 164–165 (Harper & Row, New York).

3 **McGill, S. M.** Low back exercises: evidence for improving exercise regimens. *Phys. Therapy*, 1998, **78**, 754–765.

4 **McGill, S., Juker, D.,** and **Kropf, P.** Quantitative intramuscular myoelectric activity of quadratus lumborum during a wide variety of tasks. *Clin. Biomechanics*, 1996, **11**, 170–172.

5 **McGill, S., Juker, D.,** and **Kropf, P.** Appropriately placed surface EMG electrodes reflect deep muscle activity (psoas, quadratus lumborum, abdominal wall) in the lumbar spine. *J. Biomechanics*, 1996, **29**, 1503–1507.

6 **McGill, S. M., Childs, A.,** and **Liebenson, C.** Endurance times for low back stabilisation exercises: clinical targets for testing and training from a normal database. *Arch. Phys. Medicine Rehabil.*, 1999, **80**, 941–943.

7 **Macintosh, J. E.** and **Bogduk, N.** The morphology of the lumbar erector spinae. *Spine*, 1986, **12**, 658–668.

8 **Bogduk, N., Macintosh, J. E.,** and **Pearcy, M. J.** A universal model of the lumbar back muscles in the upright position. *Spine*, 1992, **17**, 897–913.
9 **Macintosh, J. E., Bogduk, N.,** and **Pearcy, M. J.** The effects of flexion on the geometry and actions of the lumbar erector spinae. *Spine*, 1993, **18**, 884–893.
10 **Macintosh, J. E., Pearcy, M. J.,** and **Bogduk, N.** The axial torque of the lumbar back muscles: torsion strength of the back muscles. *Aust. N. Z. J. Surg.*, 1993, **63**, 205–212.
11 **Macintosh, J. E., Valencia, F., Bogduk, N.,** and **Munro, R. R.** The morphology of the lumbar multifidus muscles. *Clin. Biomechanics*, 1986, **1**, 196–204.
12 **Macintosh, J. E.** and **Bogduk, N.** The biomechanics of the lumbar multifidus. *Clin. Biomechanics*, 1986, **1**, 205–213.
13 **Bogduk, N., Pearcy, M.,** and **Hadfield, G.** Anatomy and biomechanics of psoas major. *Clin. Biomechanics*, 1992, **7**, 109–119.
14 **Phillips, S. D.** *Anatomy and biomechanics of the quadratus lumborum*. MMedSC Thesis, University of Newcastle, New South Isales, Australia, 2003.
15 **Pearcy, M. J.** and **Bogduk, N.** Instantaneous axes of rotation of the lumbar intervertebral joints. *Spine*, 1988, **13**, 1033–1041.
16 **Poirier, P.** Myologie. In *Traité d'anatomie humaine* (Eds P. Poirier and A. Charpy), 3rd edition, vol. 2, Fasc. 1, 1912, pp. 139–140 (Masson, Paris).
17 **McNeill, T., Warwick, D., Anderson, G.,** and **Schultz, A.** Trunk strengths in attempted flexion, extension, and lateral bending in healthy subjects and patients with low-back disorders. *Spine*, 1980, **13**, 1033–1041.
18 **de Visser, H., Adam, C. J., Crozier, S.,** and **Pearcy, M. J.** The role of quadratus lumborum asymmetry in the occurrence of lesion in the lumbar vertebrae of cricket fast bowlers. *Med. Engng Physics*, 2007, **29**, 877–885.