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Ligaments of the lumbar spine : a review

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Summary. A thorough knowledge of the anatomy of the intervertebral ligaments is necessary to provide the basis for good clinical management of back injuries. This paper reviews the literature concerning the lumbar ligaments, including the zygoapophyseal joints. While general principles regarding the anatomy of the ligaments is relatively clear, areas of ommission or discrepancy exist. There is very little substantiated information on: the dimensional characteristics of the ligaments; the fibre lengths of the facet capsule; the attachments of the anterior longitudinal ligament; the orientation of the interspinous ligament, and the extent of the supraspinous ligament.

Les ligaments du rachis lombaire : une revue de la littérature

Résumé. Une connaissance approfondie de l'anatomie des ligaments intervertébraux est la base nécessaire à toute prise en charge clinique des lésions lombaires. Cet article est une revue de la littérature concernant les ligaments du rachis lombaire y compris ceux des articulations zygapophysaires. Alors que les principes généraux concernant l'anatomie de ces ligaments sont à peu près clairement établis, plusieurs points cependant font l'objet d'omissions ou de polémiques. Il y a très peu de données bien fondées sur les dimensions ligamentaires, la longueur des fibres capsulaires, les insertions du ligament longitudinal ventral, l'orientation des ligaments interépineux et l'étendue du ligament supra-épineux.

Key words : Lumbosacral spine — Lumbar ligaments — Anatomy — Zygoapophyseal joints — Spinal biomechanics

Good clinical management of injuries of the spine requires a thorough understanding of its anatomy, biomechanics and pathology; without this background of knowledge, assessment and diagnosis is difficult. This is evident in reports by Potter (1977); Sims-Williams et al (1979) and Cassidy et al (1985) where patient trial groups are classified on grounds other than diagnosis.

Increasing interest has been shown over the past few years in the biomechanics of the lumbar spine (Twomey and Taylor 1982; Adams and Hutton 1983; Panjabi et al 1984; Pearcy et al 1984; Stokes and Greenapple 1985). This paper will review the literature concerning the ligaments of the lumbar spine especially those factors which are considered to influence the mechanics of the lumbar spine. The review would appear to be necessary given that many of the more recent studies have used mathematical models or finite element analysis to explain the structure and function of this region (Soni et al 1982; Tencer and Mayer 1983; Anderson et al 1985). However, the accuracy of the results from these studies are directly dependent on the accuracy of the information used in the construction of the model, particularly its anatomical structure. Oversimplified models have limitations, while complex models with unrealistic anatomical and physiological bases often produce invalid results (Crowninshield and Brand 1981).

The ligamentous tissues to be reviewed in this paper are the capsule of the apophyseal joints (articularions zygapophysiales), the anterior longitudinal ligament

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(ligamentum longitudinale anterius), the posterior longitudinal ligament (ligamentum longitudinale posterius), the ligamentum flavum, the interspinous ligament, the supraspinous ligament and the intertransverse ligament.

The properties of connective tissues

The overall behaviour of any connective tissue is due to the interaction between its constitutive matrix of collagen and elastin fibres, and its ground substance of cells, proteoglycans, water and other non-collagenous proteins. The behaviour of ligamentous tissue under load is complex, and several reviews have described its response characteristics (Viidik 1973; Wu and Yao 1976; Shah et al 1977; Noyes et al 1984). Briefly, some strains can be accomodated by the crimp structure of collagen fibres, with increasing loads behing borne by alteration in the alignement of collagen fibres within the tissue matrix itself. Once a tissue is loaded to a degree that the crimp in the collagen fibres is uncoiled and the fibres are oriented along the axis of the load, they undergo elongation and it is then their stiffness which determines the ultimate failure of the tissue (Elden 1968; Kingsbury et al 1978). However it is apparent that fibre length as well as stiffness is also an important variable; for example, Haut (1986) examined collagenous tissue from rat tail tendon and found different failure strains for different lengths of tendon. It should further be noted that the behaviour of connective tissue is anisotropic and time dependent and will therefore respond differently to various loading rates (Virgin 1951; Hirsch and Nachemson 1954; Viidik 1968; Twomey and Taylor 1982).

Because the orientation of collagen determines the ultimate stress and load bearing behaviour of connective tissues, the geometric arrangement of ligamentous fibres should be carefully considered in any study of their mechanism. For example, by comparing 3 different theoretical structural arrangements for a ligament (for example the interspinous ligament in lumbar flexion), the relationship between geometric alignment and ligament strain can be assessed (Fig. 1).

The first fibre arrangement "A", takes a simple vertical course, the second, "B", a dorsocephalad alignment, while the third, "C", a dorsocephalad course but with the fibres having a more curved arrangement in the resting position. By comparing the change in fibre length from the neutral position to the flexed position (i.e. length of A to length A') the strain of the different alignments can be assessed (where strain is: change in length/original length). The strain for the different types of alignment can then be compared (Table 1).

These strain values for different fibre alignments during a given movement indicate that fibre orientation is a critical factor determining the strain placed on a ligament during movement, and emphasises the need for its careful consideration when analysing ligament function.

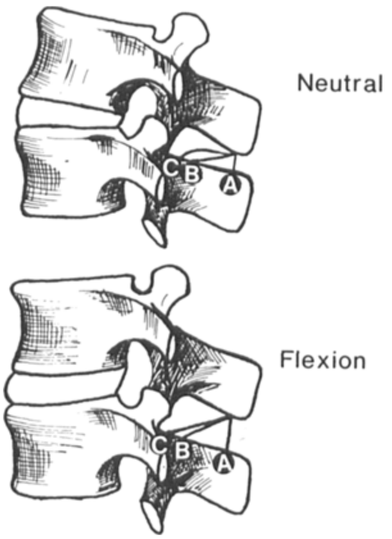

Fig. 1
Relationship between geometric alignment and ligament strain
Schémas illustrant les relations entre l'orientation spatiale des fibres et leur indice d'allongement

Table 1. Relationship between initial length and predicted strain of theoretical ligament

	Original length (neutral)	Final length (flexion)	Strain (1/1 initial)
Fibre A	5 mm	13 mm	160%
Fibre B	14 mm	19 mm	35%
Fibre C	18 mm	21 mm	17%

Capsule of the apophyseal joint

The apophyseal joints are true synovial joints formed between the superior articular facets of one vertebra with the inferior articular facets of the vertebra above. In the literature these joints are variously titled apophyseal joints, zygoapophyseal joints, posterior vertebral joints or facet joints.

The structure of the apophyseal joints is open to some dispute. The capsule is generally described as attaching between the engaging superior and inferior articulating processes and is stated by Park (1975) as thin and lax and loose cephalically and dorsally. Lewin et al (1962) indicated it is reinforced by muscle Multifidus dorsally and replaced by ligamentum flavum ventrally. This view is also held by Bogduk and

Twomey (1987) and Yong-Hing (1976). The latter felt the role of ligamentum flavum was to give elasticity to the joint. According to Putz (1985), further reinforcement is provided inferiorly by fibres of the interspinous ligament. In contrast, Rouvière (1962) and Farfan (1973) stated that there is little laxity in the capsule.

The strength of an articular capsule is directly related to the direction of its fibres. While the fibres of the facet capsule are generally described as transverse (Poirier and Charpy 1926; Lewin et al 1962), there is a paucity of research on their actual measurement, and no data available regarding orientation or laxity of fibres. Cyron and Hutton (1981) tested the tensile strength of facet capsules and found individual ligaments able to withstand up to 2 times body weight. They noted that rupture occurred in 2 stages: the first fibres to fail were considered to be short ones located on the ventral aspect of the capsule; however at no stage were fibres actually measured.

The presence of joint inclusions in the spinal apophyseal joints has been reported by several authors (Lewin et al 1962; Tondury 1971; Kos and Wolf 1972; Engel and Bogduk 1982; Mac Millan and Lockyer 1982; Giles and Taylor 1984). The joint inclusions appear to be variable and of several types with differing strengths, which may account for the different descriptions and ascribed functions which have appeared in the literature. Nevertheless, these should also be taken into consideration in any discussion of the biomechanics of a joint as they represent extensions of the capsule and certainly will influence its behaviour.

In summary, there is disagreement as to whether the facet joint capsule is lax or not. Apart from an observation that some of the fibres of the capsule are transverse no information is available regarding their orientation. Variable estimates of the length of the capsular fibres have been offered but these are not supported by any date.

The anterior longitudinal ligament

General concensus indicates that this ligament extends from the basioccipital bone (os occipitale) down the entire length of the spine to the sacrum (os sacrum). Louis (1983) illustrates the ligament as ending at the level of S3 while Rouvière (1962) noted that it ended at S2. Poirier and Charpy (1926) stated that it ended at S2 but it was not unusual to find fibres extending to the coccyx. There is also disagreement as to the sites and strength of its attachment, and to the lengths of its fibres. The ligament is broadest at its attachment to the intervertebral discs (disci intervertebrales), and narrowest and thickest as it passes over the anterior concavity of the vertebral bodies (corpus vertebrae) (Romanes 1981; Warwick and Williams 1980; White and Panjabi 1978).

Rouvière (1962); Tkaczuk (1968); White and Panjabi (1978) and Bogduk and Twomey (1987) stated it was attached to the vertebral bodies, especially to the rims adjacent to the intervertebral discs, and to the annulus fibrosus (Fig. 2A). White and Panjabi (1978) noted that the ligament was easily separated from its attachment to the disc. Warwick and Williams (1980) and Kazarian (1981) indicated that the ligament was firmly attached to the disc and vertebral rims but failed to describe an attachment to the bodies (Fig. 2B) and Kapandji (1984) believed the attachment was only to the discs and anterior vertebral bodies, but not at all to the rims adjacent to the discs (Fig. 2C). It can be seen from this brief review that the points of attachment of the ligament are not at all clear.

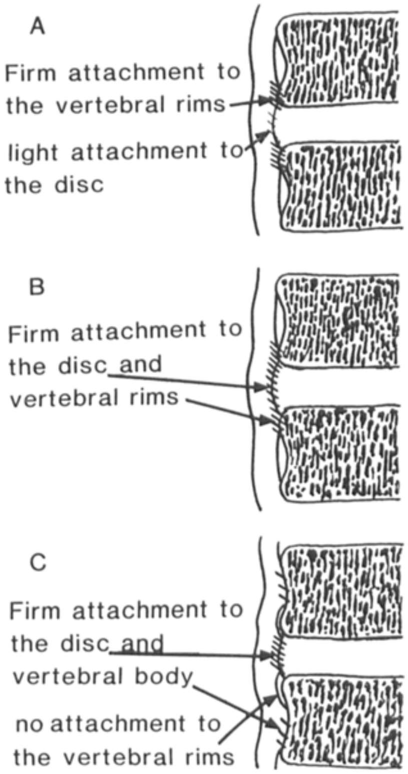

Fig. 2
Anterior longitudinal ligament : sites of attachment

Ligament longitudinal ventral : lieux et types d'insertion **A** Insertion ferme aux bords marginaux des corps vertébraux, insertion lâche au niveau des disques **B** Insertion ferme aux disques et aux bords marginaux **C** insertion ferme aux disques et aux corps vertébraux, pas d'insertion aux bords marginaux

The strength of attachment of the ligament to the disc will obviously affect its ability to reinforce it. If the anterior longitudinal ligament is only weakly attached to the anterior disc, then its capacity to resist anterior disc protrusion would seem to be limited. Kapandji (1984) implies that the absence of attachment to the vertebral rims produces a potential space where osteophytes may form, but this observation is not supported in any other work.

The layered arrangement of the anterior longitudinal ligament has also received some attention in the literature. For example, Rouvière (1962); Warwick and Williams (1980); Kazarian (1981) and Bogduk and Twomey (1987) state that it consists of several layers: the most superficial extending over 3 to 4 vertebral levels while the deeper pass over only 1 to 2. In contrast, Kapandji (1984) indicates that long fibres pass the whole length of the spine (from the basiocciput to the sacrum), with short fibres extending between adjacent vertebrae. Considerations of the arrangement of this structure are important given that the length of fibres comprising the ligament will determine the degree of strain it can tolerate during various movements of the trunk. Furthermore, by passing over the bulging intervertebral discs and attaching to the concave anterior surfaces of the vertebral bodies, the anterior longitudinal ligament will assume a curved shape which may further alter its tolerance to strain.

The posterior longitudinal ligament

In contrast to the previous ligament, the literature is in general agreement as to the structure of the posterior longitudinal ligament. It is said to lie on the ventral aspect of the vertebral canal; that is, over the posterior aspects of the vertebral bodies and the intervertebral discs. It extends from the body of the axis cephalically down to the sacrum, with Rouvière (1962) describing its caudad extent to the coccyx. In the cervical and upper thoracic regions the ligament is almost uniform in width. In the lower thoracic and lumbar regions it is denticulate — becoming narrower as it passes over the vertebral bodies (Rouvière 1962; Tkaczuk 1968; Farfan 1973; Warwick and Williams 1980; Kazarian 1981). The ligament was observed to have a thickened midline band by Poirier and Charpy (1926).

The posterior longitudinal ligament attaches to the posterior aspect of the intervertebral discs and to the adjacent margins of the vertebral bodies, but only weakly or not at all to the mass of the posterior bodies (Rouvière 1962; Tkaczuk 1968; Romanes 1972; Warwick and Williams 1980; Park 1975; Kapandji 1984; Moore 1985) (Fig. 3). Kapandji (1984) indicates that the space provided allows the passage of a paravertebral venous plexus.

Similar to the anterior longitudinal ligament, the posterior ligament consists of several layers — the superficial passing across 3 to 4 vertebral levels with the deeper layers bridging only 1 or 2 (Poirier and Charpy 1926; Park 1975; Warwick and Williams 1980; Bogduk and Twomey 1987). The fibre orientation over the lateral aspects of the intervertebral discs appears to be oblique (Park 1975).

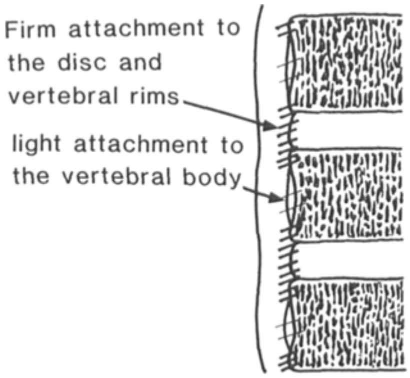

Fig. 3
Posterior longitudinal ligament : sites of attachment

Ligament longitudinal dorsal : lieux d'insertion. Insertion ferme aux disques et aux bords marginaux. Insertion lâche aux corps vertébraux

Bogduk and Twomey (1987) indicate that the course of the fibers is from the superior margin of one vertebra, passing upwards to describe a curve concave laterally, and then attaching to the inferior margin of a vertebra 2 to 5 levels above.

No clear information is given in the literature concerning the actual length, thickness or cross-sectional area of this ligament. Nor is it established whether the oblique fibres which extend out over the intervertebral discs are of short length or if they are the ends of longer fibres extending over several intervertebral levels.

Ligamentum flavum

The ligamentum flavum, also called the interlaminar ligament or the yellow ligament, is found along the length of the whole spine. With the laminae of the vertebrae, this ligament forms the dorsal surface of the spinal canal (Ramsey 1966).

Each ligament passes from one lamina (lamina arcus) to the next — attaching from the deeper surface of the superior lamina to the upper edge of the lamina of the vertebra below. It extends from the midline, where the laminae meet to form the spinous process, out to the apophyseal joints laterally. The fibres of the ligamentum flavum are longitudinally aligned in the medial portion while the more lateral fibres are oblique, passing downwards and laterally (Ramsey 1966; Nachemson and Evans 1968; Yong-Hing et al 1976). The lateral oblique fibres of the ligamentum flavum form the ventral part of the apophyseal joint capsule (Poirier and Charpy 1926;

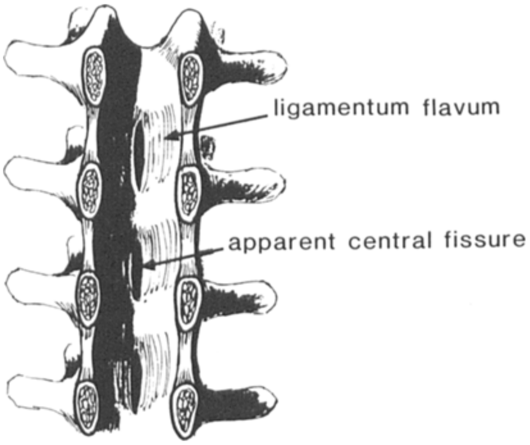

Fig. 4
Ligamentum flavum (anterior view)
Ligament jaune (vue ventrale). Fissure médiane apparente

Lewin at al 1962; Rouvière 1962; Ramsey 1966; Yong-Hing et al 1976) (Fig. 4). There is a fat-filled recess between the 2 sides of the ligament — thought to preserve the rounded contour of the vertebral canal (Parkin and Harrison 1985).

Poirier and Charpy (1926); Rouvière (1962); Ramsey (1966) and Kapandji (1984) indicate that the ligamentum flavum of either side actually join in the midline without any fissure existing. However, Parkin and Harrison (1985) disagree, believing that the ligament is actually divided in half with a fissure existing posteriorly; they noted that in some instances this fissure is obscured by the intervening anterior fibres of the interspinous ligament. This arrangement would affect the manner in which it is loaded during movement.

The ligamentum flavum is distinct from the other ligaments of the spine in that it has a very high elastin/collagen ratio (Ramsey 1966; Nachemson and Evans 1968; Yong-Hing et al 1976). Nachemson and Evans (1968) found the average ligament to contain 70% elastin: 30% collagen, while Yong-Hing et al (1976) reported an average ratio of 80:20. This high elastin content ensures that the ligament does not buckle into the spinal canal on extension movements as well as contributing elasticity to the posterior joints (Ramsey 1966; Yong-Hing et al 1976; Warwick and Williams 1980).

There is some disagreement on the thickness of the ligamentum flavum. While consensus has it that the ligament becomes thicker in the lower spinal regions (i.e. lumbar) (Ramsey 1966; Warwick and Williams 1980; Yong-Hing et al 1976; Kazarian 1981); Ramsey (1966) states that it goes from a thickness of 1.5 mm in the cervical spine to a thickness of 4 to 6 mm in the lumbar spine, while Yong-Hine et al (1976) and Parkin and Harrison (1985) reported an average thickness of around 3 mm, with a range of 2 to 5 mm in the lumbar spine. The thickness of the ligament will affect its strength and how much elasticity it can contribute to the spine.

Interspinous ligament

The interspinous ligament is described in most detail in the studies by Rouvière (1939); Rissanen (1960) and Heylings (1978); and in the text by Bogduk and Twomey (1987). Its fibres are generally found to pass upwards and backwards. The ventral fibres are said to arise from the ligamentum flavum and pass upwards and backwards to attach to the anterior part of the inferior surface of the cephalad spinous process (processus spinosus). The midline fibres (or ventromedial and dorsomedial fibres in the Rissanen 1960 paper), pass upwards and backwards from the superior surface of the spinous process of the caudad vertebra to the inferior surface of the spinous process of the cephalad vertebra. The dorsal fibres pass upwards and backwards from the superior surface (posterior part) of the spinous process

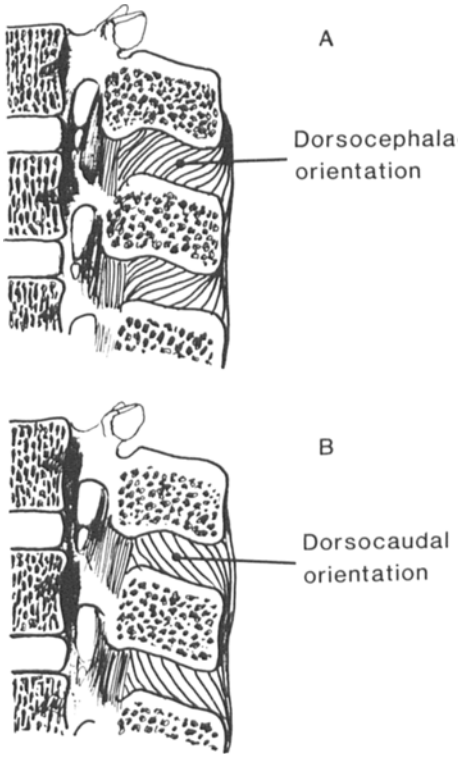

Fig. 5
Variations in interspinous ligament orientation
Variétés d'orientation des fibres du ligament interépineux **A** Orientation dorso-crâniale **B** orientation dorso-caudale

of the caudad vertebra and attach to the supraspinous ligament (Fig. 5A). Rouvière (1939) also noted that some midline fibres of the interspinous ligament had a virtually horizontal alignment. The ligament is described as bilateral anteriorly — joining posteriorly (Heylings 1978).

The upwards and backwards direction of the fibres of the interspinous ligament, as described above, is quite different to the illustrations of the ligament appearing in texts such as "Grays'Anatomy" (Warwick and Williams 1980). Here the fibres appear to run at right angles to the direction described in the studies by Rissanen (1960) and Heylings (1978) (Fig. 5B). Illustrations in "Cunninghams Textbook of Anatomy" (Romanes 1981) have the fibres of the ligament running dorsocaudally and ventrocaudally, while Louis (1983) illustrates the ligament fibres as being vertically aligned.

Putz (1985) noted that some of the fibres from the interspinous ligament reinforced the apophyseal joint capsule, while Kazarian (1981) described the ligament as thin fibrous bands which were joined posteriorly with the supraspinous ligament and anteriorly with the ligamentum flavum.

Histological observation indicates that the interspinous ligament consists of collagen bundles attached to bone. Ruptures were observed in 21% of subjects over the age of 20 years examined by Rissanen (1960) — always occuring in the middle portion of the interspinous ligament. The middle fibres appear to be more prone to injury due to the fact that they attach directly to bone at either end. The ventral and dorsal fibres attach to bone at only one end and to soft tissue at the other (the ventral fibres attach to the ligamentum flavum, the dorsal fibres attach to the supraspinous ligament).

The attachment of this ligament to the facet capsule, ligamentum flavum and supraspinous ligament would support the view that clinically those structures act as an intergrated unit with a complex behaviour: simple models probably being unable to explain their true mechanism. Determination of the correct orientation of the ligament is necessary given that a dorso-cephalad orientation whould undergo much less strain than a dorso-caudad orientation, especially when the coupling of spinal flexion with posteroanterior translation of the superior vertebra is considered (Schultz et al 1979; Berkson et al 1979).

Supraspinous ligament

This ligament is described by Warwick and Williams (1980) and illustrated by Louis (1983) as a strong fibrous cord, extending from the spinous process of the seventh cervical vertebra to the sacrum. Rouvière (1962) and Kapandji (1984) considered the ligament to pass from one spinous process to the next; and in the lumbar spine to be almost indistinct as it merged with the raphe formed by the criss-crossing insertion of the lumbodorsal muscles. Others have it organized into layers, with the deeper fibres extending over one vertebral joint while the more superficial fibres pass over 3 or 4 vertebrae (Warwick and Williams 1980; Kazarian 1981). The ligament blends with the neighbouring fascia. Heylings (1978) and Rissanen (1960) in contrast both stated that the ligament never reached the sacrum, ending in the vicinity of L4 or L5. The absence of the ligament in lower lumbar levels could partly explain the greater range of flexion reported at these levels (Allbrook 1957).

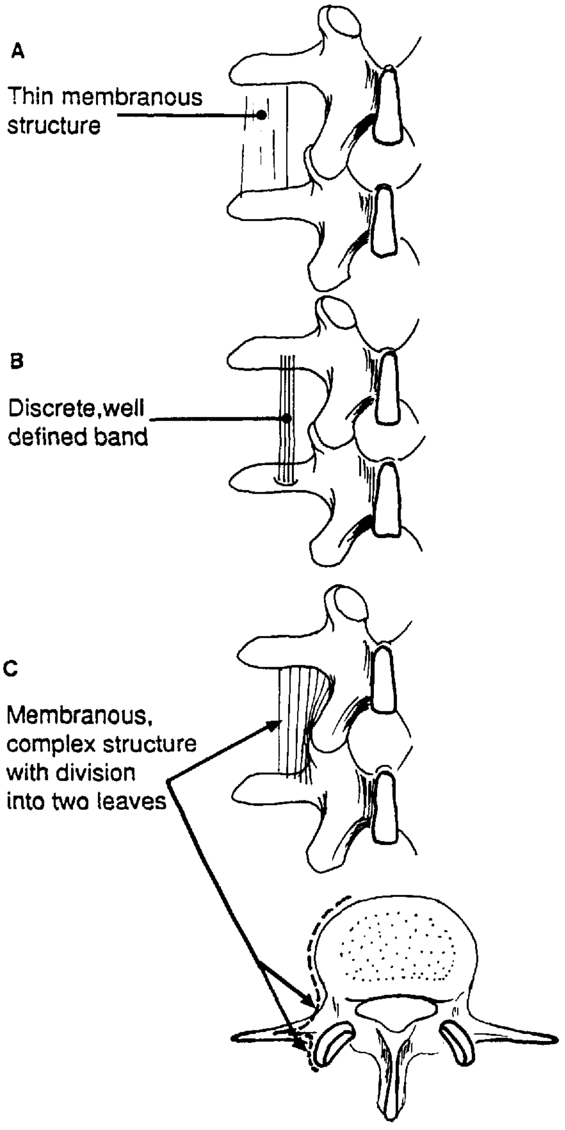

Fig. 6
Intertransverse ligament

Ligament intertransversaire A Mince tractus fibreux B ligament étroit mais bien individualisé C structure fibreuse complexe divisée en 2 feuillets

On histological examination Rissanen (1960) found the supraspinous ligament to be tendinous or fibrocartilaginous in structure, and in some cases ossified.

As with other ligaments, clarification of the length and structure of the ligament is required before we can biomechanically explain its function.

Intertransverse ligament

The intertransverse ligament in the lumbar spine is described by Warwick and Williams (1980), Romanes (1981) and Bogduk and Twomey (1987) as thin and membranous — passing from one transverse process (processus transversus) to another (Fig. 6A). In contrast Rouvière (1962) and Kapandji (1984) described it as a well developed band passing from one accessory process (processus accessorius) to the next (Fig. 6B).

Lewin et al (1962) reported that the ligament arises from the medial portion of one transverse process passing to the adjacent vertebra, lying medial to the intertransverse muscles (Mm intertransversarii lumborum). As the ligament extends medially to the outer margin of the ligamentum flavum, it divides into ventral and dorsal leaves. The ventral leaf passes lateral

Table 2

	Fibre length	Ligament width	Thickness	Cross sectional area	Failure stress	Failure stress	Modulus of elasticity
Facet capsule	1.2 cm (Forton 1973) >1.2 cm (Cyron and Hutton 1981)				153-1266 N (Cyron and Hutton 1981) >100-2000 N (Adams et al 1980)		
Anterior longitudinal ligament				25-66 mm^2 (Chazal et al 1985)	10.6 N/mm^2 (Chazal et al 1985) 1.9 kg/mm^2 (Tkaczuk 1968)	43-59% (Chazal et al 1985)	
Posterior longitudinal ligament				20-34 mm^2 (Chazal et al 1985)	20.8 N/mm^2 (Chazal et al 1985) 1.83 kg/mm^2 (Tkaczuk 1968)	26-43% (Chazal et al 1985)	
Ligamentum flavum	1-2 cm (Ramsey 1966) 19 mm (Chazal et al 1985) 1.1-2.7 cm (Adams et al 1980)	1.3-2.0 cm (Ramsey 1966)	2-3 mm (Yong-Hing et al 1976) 4-6 mm (Ramsey 1966) 2-5 mm (Parkin and Harrison 1985)	39 mm^2 (Chazal et al 1985) 0.77-2.1 cm^2 (Adams et al 1980)	15.2 N/mm^2 (Chazal et al 1985) >100-600 N/cm^2 (Adams et al 1980) 20-100 kg/cm^2 (Nachemson and Evans 1980)	17-25% (Chazal et al 1985) >20-64% (Adams et al 1980) 30-70% (Nachemson and Evans 1980)	19.6-98 N/mm^2 (Nachemson and Evans 1980)
Interspinous ligament	7.4-39 mm (Adams et al 1980)			1.03-3.5 cm^2 (Adams et al 1980)	8.71 N/mm^2 (Chazal et al 1985) >228 N/cm^{-2} (Adams et al 1980)	28% (Waters and Morris 1973) 26-65% (Chazal et al 1985) >50% (Adams et al 1980)	120 N/mm^2 (Waters and Morris 1973)
Intertransverse ligament					50 N/mm^2 (Chazal et al 1985)	16% (Chazal et al 1985)	

to the intervertebral foramen (where it is pierced by the ventral ramus of the spinal nerve and the nerve to the psoas muscles) and then ventrally to lie over the vertebral body to ultimately blend with the anterior longitudinal ligament. The dorsal leaf passes medially and dorsally to attach into the arch of the vertebra, blending with the capsule of the facet joint. The dorsal leaf is pierced by the dorsal ramus of the spinal nerve and blood vessels to the deep dorsal muscles (Lewin et al 1962) (Fig. 6C).

There is disagreement in the literature as to whether this ligament is thin and membranous or a well developed band, and on the extent of bony attachment. These points need to be clarified before we can determine how significant a role the ligament plays in resisting movement and in which movements it is loaded.

Discussion

From the review of the literature concerning the ligaments of the lumbar spine it is apparent that while the basic concepts are established, the detail of their structure has not been thoroughly delineated. Factors such as ligament fibre length, width, thickness and orientation are quite sketchy and in addition, such biomechanically relevant information as failure strain, failure stress or modulus of elasticity is sparse. The available information on anatomical dimensions and biochemical behaviour of the ligaments is shown in Table 2. It should be noted that where information does exist it is often found to differ from source to source. Perusal of this table illustrates the need for further study and quantification of all these parameters.

One reason for some of the discrepancies in the literature could be the tendency of ligamentous tissues to blend with other layers of fascia, for example, in the case of a membranous ligament (intertransverse), the determination of where the ligament begins and ends is not clear; and in some instances its description seems totally arbitrary. The caudad extent of the supraspinous ligament may, in a similar manner be confounded by the blending of that ligament with the thick fascia of the dorsal muscles over the lumbar spine.

In the absence of accurate anatomical information on the structure of the lumbar ligaments, it is difficult to predict when ligaments are loaded during a particular movement, making impossible an accurate diagnosis of which tissues are involved in an injury. Without a precise diagnosis, treatment may then be applied haphazardly and evaluation of the effectiveness of such treatment methods will be limited.

It appears from this review that insufficient data exists at present such that any mathematical modelling or finite element analysis offers a limited degree of accuracy. Further study needs to be carried out into the exact organization of the ligaments of the lumbar spine. Only once this is done can a more precise understanding of the biomechanics of the spine be achieved, leading to more accurate diagnosis of spinal injuries, and the provision of effective treatment. This information may also provide a better background on which to base steps to avoid injuries of the spine.

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