J. Anat. (1988), 156, pp. 177–183
With 6 figures
Printed in Great Britain

Ligaments associated with lumbar intervertebral foramina. 1. L1 to L4*

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(*Accepted* 1 *May* 1987)

INTRODUCTION

The intervertebral foramina, aptly described by Hadley (1949) as being at the crossroads between the peripheral nervous system and the movable skeletal support, transmit the spinal nerves, spinal arteries and veins, the recurrent meningeal nerves and lymphatics. Reports of studies of the aetiology of low back pain suggest that pressure on the emerging spinal nerve or other contents of the foramen in the lumbar region could be an important source of low back pain and sciatica. Adequacy of space within the foramen with respect to the foraminal contents is therefore of serious import. The intervertebral foramen differs from other osseous foramina in having as part of its boundaries two movable joints, namely the intervertebral joint anteriorly and the joint between the articular processes (zygapophyseal joint) posteriorly. Normal spinal movements therefore, cause changes in the size of the foramen. Evidence brought by Hadley (1949), Payne & Spillane (1957), Sunderland (1980), Rothman & Simeone (1982) and Crelin (1982) suggests that the foramen undergoes narrowing or widening depending on the movement performed. It can be envisaged that if the foraminal contents were merely supported by fat and loose areolar tissue, there could be some relative movement between them. With the exception of some to and fro movements of the spinal nerve (Maurice-Williams, 1981), there appears to be no experimental evidence to suggest that the other contents move in relation to each other during spinal movements. Clearly, in normal individuals it appears that the structures within the intervertebral foramen are securely accommodated and protected from pressure by neighbouring structures. This is evidenced by the fact that movements are not usually accompanied by pain.

In a meticulous morphological study of ten lumbar spines Golub & Silverman (1969) reported that nine of the spines had ligamentous bands running across some intervertebral foramina. These bands were neither seen at all levels nor were they seen on both sides of the same spine. According to them these ligaments were inconstant and probably anomalous. They suggested that the ligaments could be a source of nerve root entrapment as they diminished the space available for the passage of the spinal nerve. The reports of Macnab (1977), Bachop & Stern (1981), Bachop & Hilgendorf (1981), and Bachop & Janse (1983) have supported the observations of Golub & Silverman (1969), but stressed that the ligaments were more commonly seen at the level of the fifth lumbar foramen.

There appear to be some discrepancies in the accounts of the precise nature of these

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ligaments. According to Golub & Silverman (1969), the ligaments in most instances appeared to be condensations in the fascia overlying the foraminal exits although they had features of specific ligamentous structures. They classified obliquely placed bands into superior and inferior corporotransverse ligaments while tranversely running bands were referred to as transforaminal ligaments. Macnab (1977) described the ligament at L5 as corporotransverse, while Bachop and his colleagues (1981, 1983, 1984) found that it extended superopostero-laterally. They did not give precise attachments but stressed that it showed marked variability in morphology. In some subjects it presented as a tough band while in others it was a rigid rod-like structure. It could be positioned more towards the upper half of the foramen or displaced towards the lower half.

In spite of these clarifications, the following still remain unresolved. Are these structures true ligaments or are they fascial condensations of the overlying muscles? Do they occur randomly or is there a pattern of incidence? How are these ligaments related to the structures traversing the intervertebral foramen? The present study was undertaken in an attempt to find answers to these questions.

MATERIALS AND METHODS

Twelve lumbosacral spines, complete with postvertebral and paravertebral muscles *in situ* were removed from embalmed adult cadavers. Case histories were not available but in selecting the specimens care was taken to exclude spines showing evidence of previous trauma or bony disease. Specimens that had structural deformities or osteophytes were also excluded. The psoas major muscle was dissected out piecemeal from its attachment to the lumbar spine taking care to preserve the roots of the lumbar plexus. The ventral rami were followed proximally to their points of exit from the intervertebral foramina. The lumbar part of the sympathetic chain and its rami communicantes to the lumbar ventral rami were then identified and traced to their attachment to the ventral rami. Next, lumbar segmental vessels were dissected and their course and position in relation to the intervertebral foramina noted. It was often necessary to remove large venous plexuses in order to get a clear view of the structures within the exit of the foramina. Loose areolar tissue and large amounts of fat within the foramen were removed using a combination of blunt and sharp dissection. Tough ligamentous bands encountered during this process were preserved and studied. At this stage each vertebral column was bisected sagittally in the median plane to enable each intervertebral foramen to be examined from within the vertebral canal as well as from without. The relative positions of the spinal nerve, the recurrent meningeal nerve and the spinal vessels were carefully studied on the inner and outer aspects of the foramina. These studies were made on segments L1–L4.

In order to establish the presence of the ligaments during early stages of development a fetus of 24 weeks was also studied.

OBSERVATIONS

The arrangement of structures related to the external opening of the intervertebral foramen are well described in standard anatomical texts. Relevant aspects of topographic details will nevertheless be mentioned here.

Topographical relationships in the approach to the lumbar intervertebral foramen

Psoas major muscle overlies the openings of all the lumbar intervertebral foramina. Fascial condensations bridge the concavities of the lateral surfaces of the vertebral bodies to give attachment to the muscle and also to allow the passage of vessels and nerves from the ventral part of the vertebral bodies towards the region of the foramen. On removing the psoas major muscle and the associated tendinous arches from their vertebral attachment the intervertebral foramina were seen to be obscured by extensive and intricate paravertebral venous plexuses (Fig. 1). At each lumbar level, the plexus received several tributaries from the intervertebral foramen and also from the dorsal musculature. Segmental plexuses freely communicated with each other by longitudinal channels. Lumbar arteries running anteroposteriorly were noted to lie superficial to the venous plexuses and on reaching the foramen, each artery gave several branches (2 or 3) which entered the foramen. Ascending and descending branches of these segmental arteries anastomosed with similar branches from the contiguous segments. The lumbar artery then continued dorsally across the upper part of the foramen and divided into branches that accompanied the medial and lateral divisions of the posterior primary rami. Branches (rami) from the sympathetic chain were often seen to be accompanied by fine branches of the lumbar artery as they passed into the intervertebral foramen to join the ventral ramus. Neural and vascular structures had to be dissected away in order to get a full view of the foramen.

Ligaments associated with the intervertebral foramen

All fetal and adult intervertebral foramina had ligaments crossing their openings (Fig. 2i, ii). The ligaments had smooth, glistening surfaces and were covered by loose areolar tissue which separated them from the overlying vessels and muscle. There was no evidence that any of these ligaments gave attachments to muscle fibres. The ligaments appeared to be better developed in some subjects than in others but generally, in all subjects, they were stronger in the upper lumbar region than at lower levels. In the upper lumbar segments these ligaments presented mainly as rounded cords but at lower levels, they gave way to flattened bands. The morphology of ligaments in the lumbosacral transitional region differed markedly from L1 to L4. This will be the subject of a separate study.

Arrangement and attachment of the ligaments

At each level ligaments were seen in relation to the inner (internal) margin, within the foramen, and overlying the external aspect of the foramen. The different ligaments may therefore be designated as (i) internal (ii) intraforaminal (iii) external foraminal (Figs. 3–5).

Internal ligaments

The oblique inferior transforaminal ligaments were found in the lower part of the intervertebral foramen. They were broad ligamentous bands passing obliquely downwards and backwards from the posterolateral surface of the intervertebral disc to the anterior surface of the superior articular facet. They crossed lateral to the free border of the ligamentum flavum, and bridged over the superior vertebral notch, converting it into a separate compartment in the lower part of the intervertebral foramen. In some cases, an internal ligament was represented by more than one band (Fig. 3). The compartments thus formed were noted to transmit veins.

Intraforaminal ligaments

These ligaments were attached to the margins of the foramen. They were found constantly in three positions.

(*a*) Anteriorly, a small vertically placed crescentic ligament, the deep anterior intraforaminal ligament running from the root of the pedicle to the inferior border of the same vertebral body above the level of the disc. The compartment so formed transmitted the recurrent meningeal nerve and a small branch of the spinal artery (Fig. 3).

(*b*) Antero-superiorly, the oblique superior transforaminal ligament running from the angle between the posterior end of the pedicle and the root of the transverse process to the postero-lateral surface of the body of the same vertebra, above the level of the intervertebral disc (Fig. 4i). This formed an antero-superior compartment that was seen in all subjects to transmit a large branch of the segmental artery.

(*c*) A strong, transversely placed ligament, the horizontal mid-transforaminal ligament, extending from the anterior surface of the upper border of the superior articular facet to the postero-lateral surface of the vertebra above. This ligament formed the bed of the emerging spinal nerve (Fig. 4ii). The lateral surface of this ligament was commonly adherent to the inferior corporotransverse ligament.

External ligaments

The ligaments related to the external aspect of the intervertebral foramen appeared to radiate forwards from the root of the transverse process. Thus at each level, discrete bands of variable thicknesses were seen running superiorly, transversely and inferiorly towards the vertebral bodies (Fig. 5).

From the root of the transverse process, the superiorly directed bands were attached to the postero-lateral surface of the vertebral body above and adjacent intervertebral disc. Transversely running bands were inserted into the lateral surface of the waist of the same vertebra. Inferiorly directed bands were attached to the lateral side of the vertebra below, anterior to the root of the pedicle. In view of their attachments, these bands may be described as superior, middle and inferior corporotransverse ligaments. Slips from the superior corporotransverse ligament crossed the lower part of the foramen above, while those of the inferior ligament crossed the foramen of the corresponding level.

At the level of the intervertebral foramen, the inferior ligament crossed superficial to the superior ligament (Fig. 5).

The arrangement of the corporotransverse ligaments and their relationship to intraforaminal and internal ligaments cause the intervertebral foramen to be partitioned into smaller compartments (Fig. 6i, ii). A large centrally placed compartment transmitted the ventral root of the spinal nerve. This was surrounded by smaller openings as follows: antero-superiorly, the opening for the spinal artery; anteriorly and in a slightly deeper plane, the compartment for the recurrent meningeal nerve and a small branch of the segmental artery. Inferior to the nerve, and bordered by the toughest ligaments of the foramen, there were two or more compartments transmitting veins emerging from the foramen. Posteriorly, two neurovascular tunnels, one superior and the other inferior were seen in the intertransverse interval communicating with the exit of the intervertebral foramen. These lay deep to the attachments of the inferior and superior corporotransverse ligaments respectively to the transverse processes. The superior opening lying subjacent to the transverse process above transmitted the medial division of the posterior primary ramus and branches of the lumbar artery and vein. The inferior tunnel situated in the angle between the lateral surface of the superior articular facet and the root of the transverse process (in the lower part of the intertransverse space) transmitted the lateral division of the posterior ramus and branches of the segmental artery and veins. This latter tunnel has been described previously by Sunderland (1980), Bogduk, Wilson & Tynan (1982) and Ro & Bachop (1984).

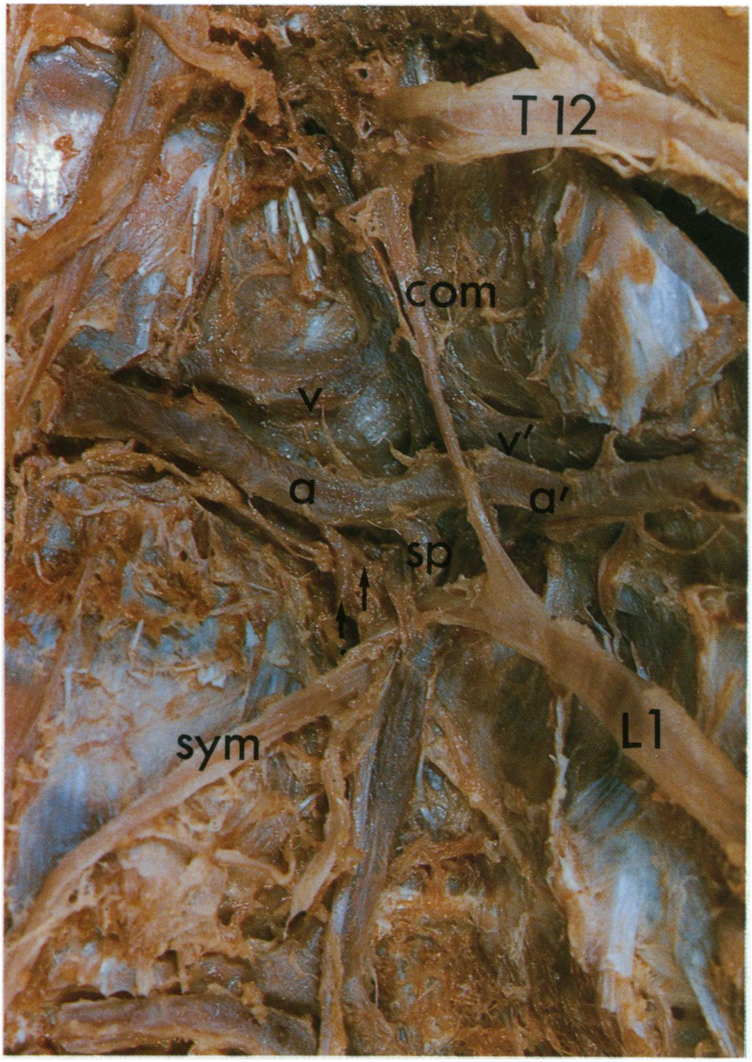

Fig. 1 (i). Photograph showing the superficial relations of the left L1 intervertebral foramen. The segmental artery (a) is seen coursing dorsally, accompanied by its vein (v). The spinal branch (sp) of the artery, and other branches are also seen entering the foramen. á and v́, dorsal continuations of the segmental artery and vein respectively; T12, the subcostal nerve; L1, ventral ramus of the 1st lumbar spinal nerve; Com, communication between T12 and L1; Sym, ramus communicans from L1 to the sympathetic trunk.

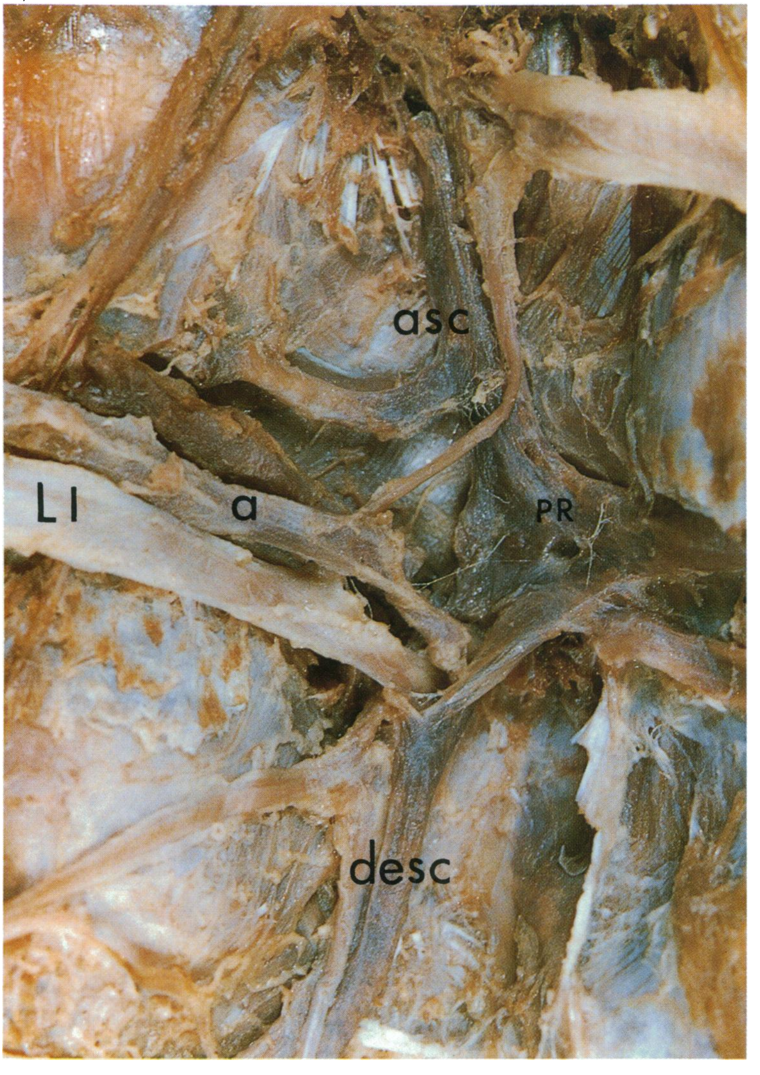

Fig. 1 (ii). The segmental artery, a, and the ventral ramus, L1, have been reflected ventrally to show the underlying venous network. The somewhat polygonal ring of veins (PR) receives tributaries from the postvertebral region. It also communicates by ascending (asc) and descending (desc) veins with similar rings, above and below. Tributaries enter the deep surface of the ring from the intervertebral foramen. Note that the emerging nerve root passes through a venous ring.

Fig. 2 (i). Lateral view of the lumbar spine of an adult specimen showing the ligaments associated with the intervertebral foramina. All foramina dissected were seen to be traversed by ligaments. The superficial ligaments were attached to the transverse processes (tp) and the intervertebral discs (d) of adjacent vertebral bodies (Scale = cm).

Fig. 2 (ii). Photograph showing the first (L1), second (L2) and third (L3) left lumbar intervertebral foramina of a 24 weeks old fetus. Ligaments subdividing the individual foramina into smaller compartments are shown. The oblique superior transforaminal ligament at L2 (arrow) was inadvertently cut. d, intervertebral disc; a, opening for spinal artery; n, opening for ventral ramus; v, opening for veins. (Scale = mm).

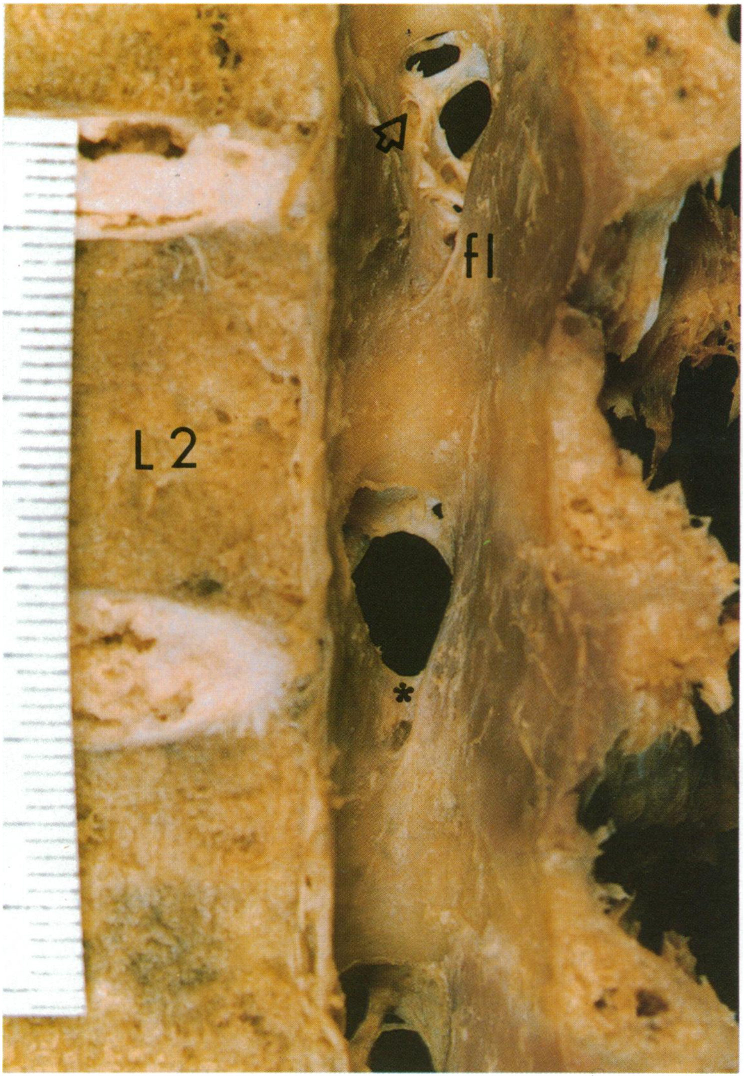

Fig. 3. Photograph of L1 and L2 intervertebral foramen viewed from the neural canal. The oblique inferior transforaminal ligament (*) crosses the inferior part of the foramen converting the inferior angle into a separate compartment. Note that in this specimen the corresponding ligament at L1 is represented by two rounded cords. L2, body of the second lumbar vertebra. The compartment for the recurrent meningeal nerve (open arrow) is bounded posteriorly by the deep anterior intraforaminal ligament. f1, ligamentum flavum. Note that from this view, the lateral (free) border of the ligamentum flavum forms the immediate posterior boundary of the intervertebral foramen. Scale = cm.

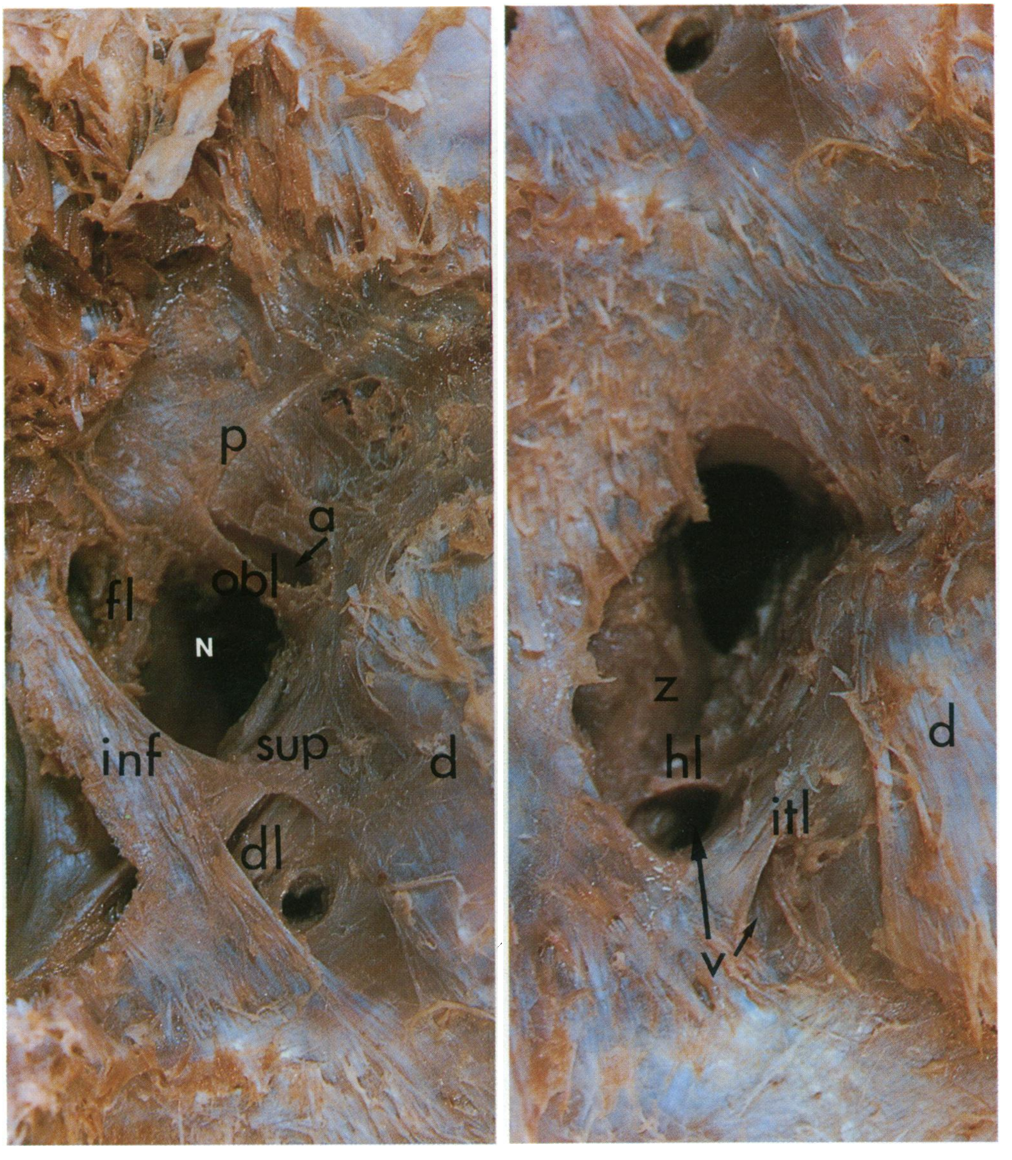

Fig. 4 (i). Photograph of the L3 intervertebral foramen showing the external ligaments. In this subject ligaments were highly developed and mostly flattened. obl, oblique superior transforaminal ligament; p, root of the pedicle; d, intervertebral disc; inf, inferior corporotransverse ligament; sup, superior corporotransverse ligament; N, opening for the ventral ramus; a, arterial opening; fl, lateral edge of ligamentum flavum; dl, oblique inferior transforaminal ligament.

Fig. 4 (ii). Photographs of the L4 intervertebral foramen with the external ligaments removed to show the lower intraforaminal ligaments. hl, horizontal transforaminal ligament; itl, lateral edge of the oblique inferior transforaminal ligament; z, anterior surface of the capsule of the zygapophyseal joint; d, intervertebral disc; v, venous compartments.

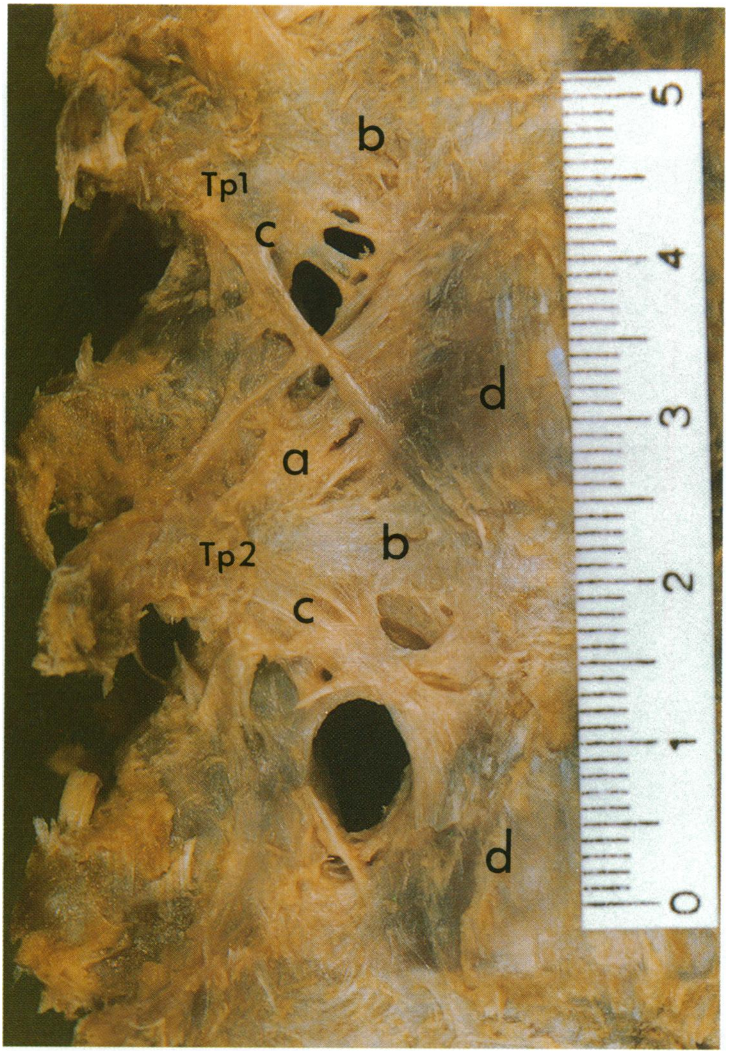

Fig. 5. The external ligaments at L1 and L2 in an adult specimen. Tp1, transverse process of L1; Tp2, transverse process of L2; d, intervertebral discs. Note the bands of ligament radiating from the roots of the transverse processes. a, ascending fibres (giving rise to superior corporotransverse ligament); b, transversely running fibres; c, descending fibres (inferior corporotransverse ligament). Ascending and descending fibres break up into smaller slips as they cross the intervertebral foramen. At the point of intersection, descending fibres cross superficial to ascending fibres. In this illustration, both flat bands and cord-like ligaments are present. Scale=cm.

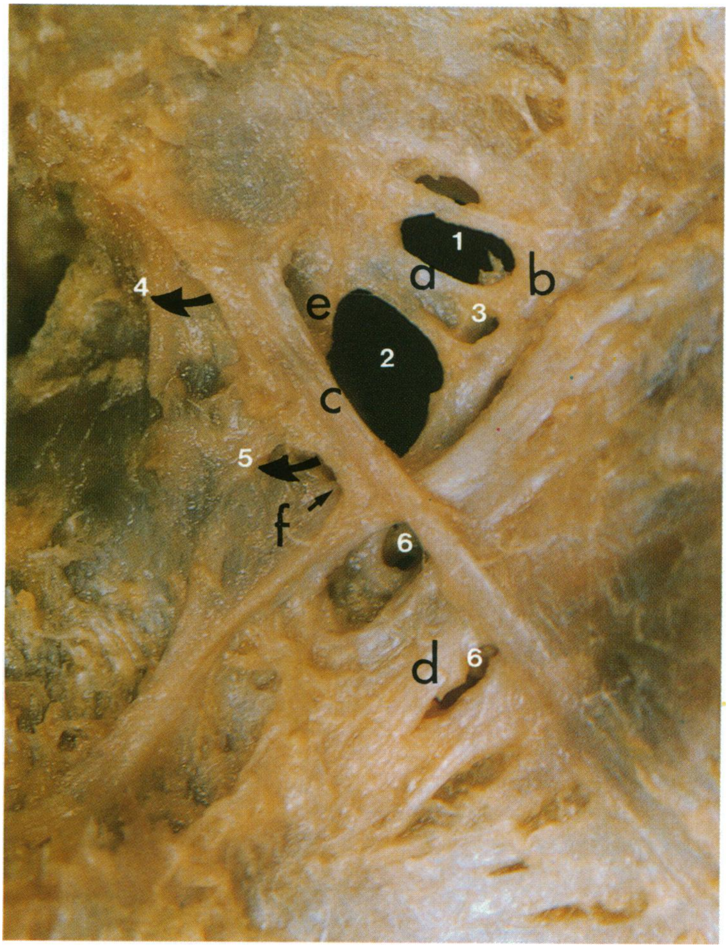

Fig. 6 (i). A close-up view of the L1 intervertebral foramen to show the compartments of the lumbar intervertebral foramen. a, oblique superior transforaminal ligament; b, deep anterior intraforaminal ligament; c, inferior corporotransverse ligament (note the slip attaching the posteromedial surface of this ligament to the mammillary process); d, superior corporotransverse ligament; e, ligamentum flavum; f, horizontal transforaminal ligament;

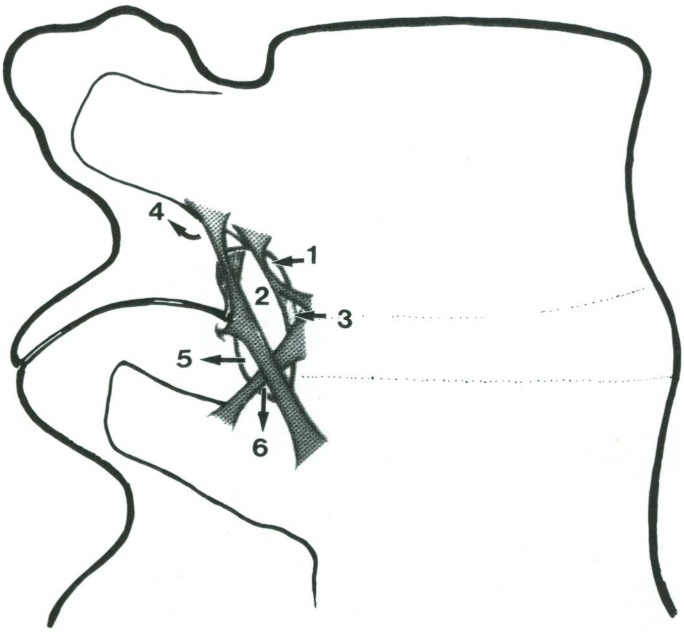

Fig. 6 (ii). Schematic diagram showing the attachments of the ligaments of the external aspect, and their contribution towards the partitioning of the foramen. 1, compartment for the spinal artery; 2, compartment for the ventral ramus of the spinal nerve; 3, compartment for the recurrent meningeal nerve – this compartment also transmits a small branch of the segmental artery; 4 and 5, tunnels transmitting the medial and lateral divisions of the dorsal primary ramus respectively, and accompanying vessels; 6, compartment for veins.

DISCUSSION

Bourgery (1832) described radiate ligaments passing forwards from the anterior aspects of the roots of the lumbar transverse processes to the lateral surfaces of the vertebral bodies. The possible functional relationship between these ligaments and the lumbar intervertebral foramina has been alluded to by Golub & Silverman (1969). In their report, these authors confirmed the earlier observations of Larmon (1944) and Magnuson (1944) that the intervertebral foramen at L5 was sometimes crossed by an anomalous ligament. They also gave detailed descriptions of ligaments that were often found at other lumbar levels. Later reports by Macnab (1977) and Bachop & Hilgendorf (1981) supported the observations of Golub & Silverman (1969). There seems to be a unified impression from these accounts that the ligaments occur in a random pattern and distribution, and are often not symmetrical on the two sides of the same spine.

The attachments of the individual bands of ligaments observed in the present study correspond generally to those described by Golub & Silverman (1969). There are major differences, though, between the present report and the earlier studies regarding the incidence and topography of these ligaments. Evidence from the fetal and adult material in the present study shows that the various ligaments probably coexist at all levels from L1 to L4 and on both sides of the spine though there could be slight intersegmental and individual variation in their topography. It seems reasonable to suggest, therefore, that these ligaments are probably normal features of the intervertebral foramen and not anomalous structures as has been reported. Hence it appears unlikely that in the normal spine the ligaments would be a source of encroachment; in fact it may be inferred that by partitioning the intervertebral foramen into individual (neural and vascular) compartments, these ligaments segregate and protect the contents. This is thought to be an important function, because as Maurice-Williams (1981) pointed out, the neural complex (nerve roots and the dorsal root ganglion) is pulled several millimetres out of the foramen during flexion of the lower limb and is retracted during extension. Considering that the nerve takes 35–50% of the available space in the intervertebral foramen (Sunderland, 1980), it is conceivable that during movements that are accompanied by 'physiological narrowing' of the foramen, e.g. rotation (Hadley, 1949; Sunderland, 1980), or dorsal flexion and lateral flexion (Sunderland, 1980), there could be encroachment of the mobile nerve on other contents of the foramen. Nevertheless, Crelin (1982) has stressed that alterations in foraminal dimensions during movement do not normally expose the contents to the risk of impingement. It seems logical to conclude, therefore, that the presence of these ligaments is compatible with normal function of the lumbar spine. For this to hold true, there must be a mechanism by which these apparently unyielding ligaments may accommodate the contents of the foramen at rest and during complex movements of the spine. The superior and inferior corporotransverse ligaments, intersecting opposite the exit of the foramen form the inferior boundary of the compartment for the spinal nerve. Both ligaments cross the intervertebral as well as the zygapophyseal joints. It can thus be envisaged that movements that would tend to cause outward excursion of the neural complex (lateral flexion, rotation) will be accompanied by relaxation of these ligaments. Thus the likelihood of the nerve root impinging upon taut foraminal ligaments would be obviated. The corollary of this is that if the ligaments were unable to relax (either as a result of secondary changes like oedema or calcification, or as a sequel to intervertebral or zygaphophyseal joint disease) their impingement upon the nerve could be a possibility, especially during physiological narrowing of the foramen.

The spinal artery located in the antero-superior angle of the foramen, and the vertebral veins located mainly inferior and antero-inferior to the nerve are protected by unyielding ligaments bridging the inferior and superior vertebral notches respectively. The weight of morphological evidence suggests that the vascular elements within the foramen do not move significantly during spinal movements. The presence of strong ligaments separating these structures from the mobile nerve ensures that encroachment is prevented.

There appears to be no direct evidence that these ligaments exert pressure on the related vessels, but in a review of patients presenting with lumbar spinal stenosis, Verbiest (1975) noted that pathological narrowing of the intervertebral foramina was invariably accompanied by intermittent claudication. The cause of the vascular insufficiency was not discussed; however Rothman & Simeone (1982) have suggested that direct ischaemia of the cauda equina could be the reason. Morphological evidence brought by Ratcliffe (1980), and confirmed in the present study, shows that the segmental artery gives off several branches that enter the intervertebral foramen. Our results have shown further that these arteries pass through ligamentous compartments within the intervertebral foramen. In developmental spinal stenosis, Verbiest (1954, 1975) stated that morphological narrowing of the neural canal and the intervertebral foramen occurs in the second or third decade even though the genetic defect is present at birth. Presumably this results from abnormal postnatal growth and maturation of the vertebrae. Assuming that the ligaments associated with these vertebrae would develop *pari passu*, it is not unlikely that anomalous development of the ligaments could result. It is therefore probable that maldevelopment of these ligaments in these circumstances and the resultant pressure on related arteries could account for the ischaemic phenomena.

The reasons for the observed individual differences in the extent of development and maturation of the foraminal ligaments are not clear. In a recent study of the iliolumbar ligament, Luk, Ho & Leong (1986) reported that the ligament does not exist *per se* at birth. They suggested that it develops gradually by metaplasia from the quadratus lumborum muscle in the first decade, attains full differentiation in the second decade and continues to mature with advancing age in response to local stresses and strains. There is no evidence that this reflects the general pattern of development of ligaments in the lumbar region; the findings in the fetal material examined in the present study appear to be at variance with this theory. There is nevertheless a need for further work on the development and maturation of ligaments associated with the intervertebral foramina.

SUMMARY

Lumbar intervertebral foramina have been studied by dissection of fetal and adult cadaveric spines.

The results show that these foramina are crossed by ligaments which subdivide the opening into smaller compartments for the structures traversing it. At L1–L4, there appears to be a basic pattern of arrangement of the ligaments. The bands are tougher in the upper lumbar region and become steadily thinner caudally. Evidence from the study suggests that these ligaments are probably normal components of the intervertebral foramen.

The significance of these findings is discussed.

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