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Functional morphology of the lower lumbar spine

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Summary. The lower part of the lumbar vertebral column (L3–S1) with its morphological characteristics is described in reference to its importance for the entire spine as a functional system. The main emphasis is on the detailed anatomy of the ligaments and their function in the control of movements. Special reference is made to the connection of the lumbodorsal fascia with the deeper structures. These combine with the muscles to form a damping system, which protects all parts of the spinal segment at the barriers. This mechanical system is dependent on a normal thickness of the intervertebral disc. The two parts of the facet joints (the medial part in the coronal plane and the lateral in the sagittal plane) are important in this mechanism. It is necessary to differentiate the functions of the different parts of the erector muscle of the spine. Whereas the longer (superficial) bundles bring about the coarser flexion-extension movements, the shorter (deeper) ones control the fine movements between the adjacent vertebrae. In conclusion, the topography of the vertebral canal and some possible pathological implications are described.

Key words: Lumbar spine – Facet joints – Spinal ligaments – Lumbodorsal fascia – Spinal morphology and anatomy – Biomechanics

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From a functional viewpoint, it is not appropriate to view the lower lumbar spine as a separate, isolated entity. There is a great temptation to concentrate on segmental evaluation of the individual components of the lower lumbar spine, often not realizing the importance each section of the spine plays within the context of the overall function of the entire spine.

Although lumbar spinal mechanics must be viewed as a single interactive unit, specific diagnostic insight is to be gained by a knowledge of segmental vertebral function. An understanding of the mechanics of the lumbosacral junction and the lower lumbar vertebrae is particularly useful.

The lower lumbar spine and its role in mobility

At first glance, the spine appears to be no more than a mere sequence of irregularly formed bones connected by intervertebral discs and ligaments. A total number of ten ligaments and intervertebral discs interconnect the individual spinal segments thus exactly guiding (controlling) movement between neighboring vertebrae. The facet or apophyseal joint on either side completes the spinal segment, which has been defined as the smallest unit of movement in the spine [6].

The anterior ligaments run longitudinally along the spine (Fig. 1). The anterior longitudinal ligament is connected to the anterior and lateral portion of the vertebral bodies [20], whereas the posterior longitudinal ligament envelopes the posterior portion of the vertebral bodies and the vertebral veins only to attach primarily to the intervertebral discs and the superior margins of the vertebral bodies. The lateral connections of the lateral invaginations together with the annulus fibrosus form pockets (Fig. 2) [10, 13].

The intertransverse ligaments run longitudinally in a segmental fashion between the lateral processes of the lumbar spine, i.e. the costal and accessory processes. These ligaments form a narrow canal directed medially in which run the segmental dorsal ramus of the spinal nerve and the associated vascular structures. It is not difficult to see that compressions can occur at these areas. Ossifications of the ligaments have recently been described in the literature [14].

For a long time, there has been little attention paid to the course of the posterior ligaments. It is important to note, however, that these ligaments course more in a *horizontal* than longitudinal fashion, which is of significance functionally. The interspinous ligaments start dorsally coursing downward and forward (Fig. 1). According to Prestar [12], between the fourth and fifth spinous process the inferior portion of this ligament connects to the thick lumbo-dorsal fascia (Fig. 3). Again, on first glance the functional significance of these strong connections with the lumbar joint capsule is not readily apparent. These strong, horizontal ligaments are characteristic for

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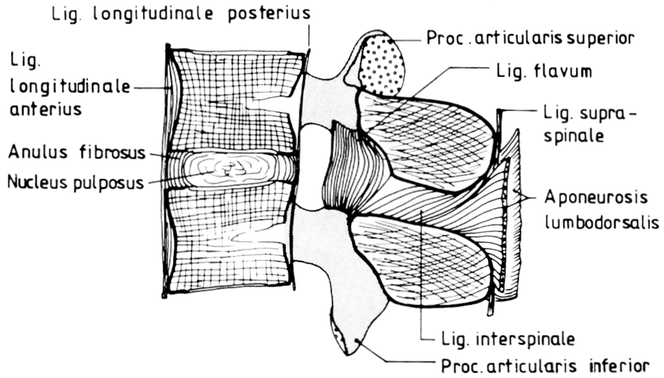


Fig. 1. Spinal segment [18]

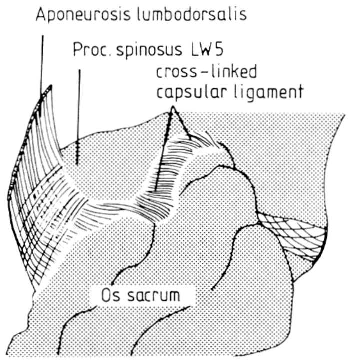


Fig. 3. Interspinous ligament in the lower lumbar spine (from [12])

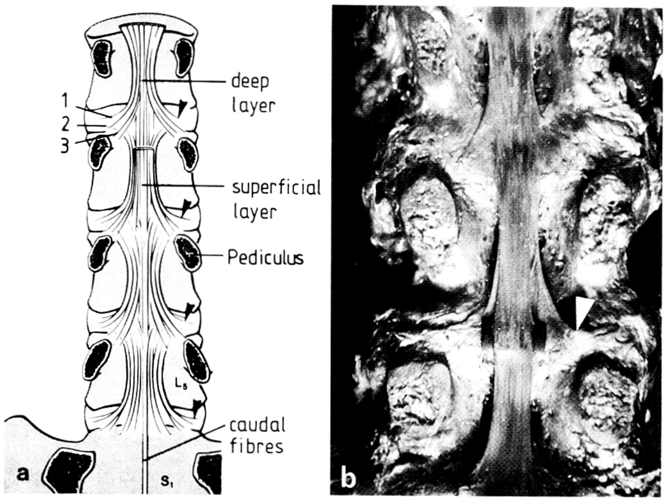


Fig. 2a and b. Attachment of the posterior longitudinal ligament of the lumbar spine. **a** Diagrammatic representation (according to [13]) *1* = Discus; *2* = Endplate; *3* = Pediculus. **b** Anatomical specimen; arrows indicate the pockets (recesses) formed by the lateral branches of the ligament and the annulus fibrosus and which invaginate into the intervertebral foramen

the lumbar spine, especially since a supraspinous ligament is practically absent in that area of the spine (Fig. 4).

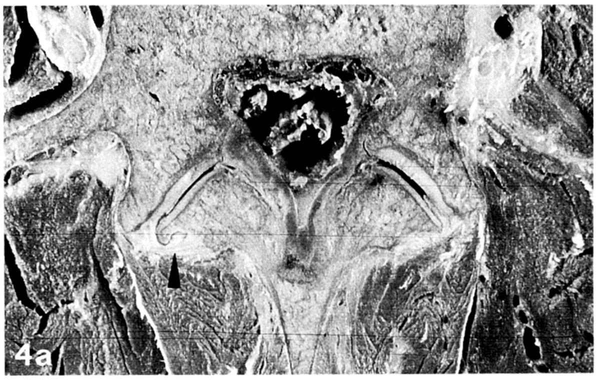
The interspinous ligaments with their connections to the joint capsules are in direct connection with the lumbo-dorsal aponeurosis [12]. Thus, tension introduced to the aponeurosis during contraction of the long and short muscles of the back may have a stabilizing effect on the vertebrae through the interspinous ligaments.

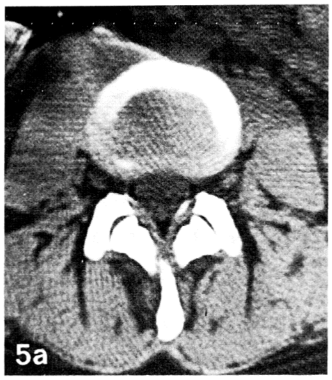
The ligaments described thus far consist primarily of collagenous fibers and little elastic fibers. In contrast, the laminae of the vertebral arches in the lumbar spine are connected by thick (up to 6 mm) elastic ligaments, primarily the yellow ligaments. The lateral aspects of these ligaments also form the posterior walls of the lateral pouches (Fig. 5) [14, 22].

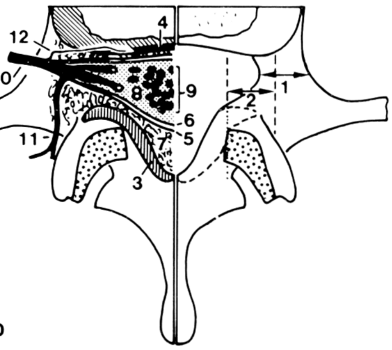
The intervertebral disc plays a central role in the function of a spinal segment (Fig. 1). Earlier studies have demonstrated [15] that the disc's function is less that of shock absorption than the transmission of forces to the neighboring vertebral bodies so as to allow appropriate vertebral position changes. Again, it would be inappropriate to view the function of the disc in an isolated manner. Under normal conditions the disc pressure induces appropriate tension in the ligaments which in turn then allow optimal spinal movement. It should be remembered that tension in the ligaments gradually increases with spinal movement towards a particular limit (barrier), which prevents high loading forces from developing (i.e. at the facet joints or the margins of the vertebral bodies). Often the muscles are unable (overtaxed) to prevent undue loading stress at the limit of movement in a joint, especially when there is abrupt displacement. If there is compression of the disc (intervertebral instability [6]), this important function of gradual motion limitation is partially or completely lost.

The facet joints provide the necessary support during and at the limit of movement so that discs and ligaments can perform their function. One of the facet joint's function is the absorption and transmission of some of the static loading forces applying at the spine. This is also true for the lower lumbar spine which can be demonstrated via CT scans (Fig. 5). These joints are comprised of two components, namely a smaller joint component which is located medially and anteriorly and a larger posterior component. The anterior portion is more involved in absorbing static loading forces [7, 8, 14], whereas the posterior portion plays a significant role in the absorption of rotatory force components generated with rotation movement [14, 16, 17]. Thus, the facet joints act not unlike lever-points [14]. Figure 6 demonstrates the coordinated action of facet joints and the "horizontal" ligaments with their attachments at the disc. This coordinated interplay allows adequate limitation of movement in the rotation and sagittal directions.

As mentioned above a certain degree of internal disc pressure is required to maintain appropriate tension in the ligaments. If the ligaments are not appropriately taut, final movement in a vertebral segment, for instance, will not be limited adequately leading to a more abrupt, or







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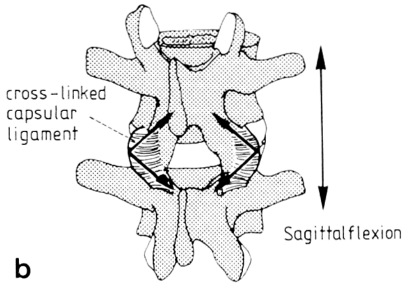
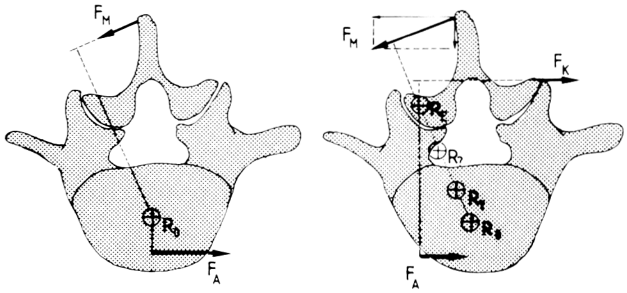


b

Fig. 4a and b. Supporting fibers at the joint capsule: the so called "horizontal fibers" in the lumbar spine (*arrow*). **a** Anatomical specimen. **b** Schematic representation of tension forces involved when there is gradual approach of the limit in flexion (the sagittal plane)

Fig. 5a and b. CT scans of the lower lumbar spine. **a** CT exposure, **b** schematic representation of the bony limits and the related soft tissues. *1* = intervertebral foramen; *2* = lateral recess; *3* = posterior longitudinal; *4* = ligament; *5* = dura mater; *6* = arachnoid mater; *7* = epidural space; *8* = subarachnoid space; *9* = cauda equina; *10* = spinal nerve; *11* = dorsal root; *12* = meningeal branch



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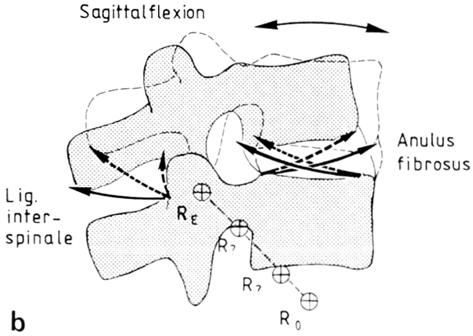


b

Fig. 6a and b. Coordinated interplay between the ligaments and joints in the lower lumbar spine [16]. **a** Change in position of point of rotation and therefore torque during rotation motion. **b** Displacement and ligamentous fibers involved in sagittal flexion. F_M = force supplied by muscle; F_K = pull by the "horizontal" fibers of the joint capsule; R_O = point of rotation in the neutral position; $R_?$ = points of rotation during motion; R_E = point of rotation at end of motion (barrier, lever-point; [16]); F_A = force by the fibers of the annulus fibrosus

less smooth engagement at the limit of movement. A certain level of joint gapping is inherent in the vertebral articular processes [4, 14, 19], which, especially when the "braking" function of the ligaments is diminished, contributes to greater stress at the weaker structures such as the margins of joint cartilage. It should therefore become evident that when ligaments fail the muscles of the back, especially the short ones, take on a significant role in assuring normal range of motion and pressure distribution in a spinal segment [5].

The short and long muscles of the back (Fig. 7) are arranged such, starting from the spine and moving outward, that the mono-segmental muscles (short rotator muscles) are covered by plurisegmental muscles, including the long rotator muscles, the multifidus, iliocostalis and longissimus muscles. The function of the deep muscles is more that of fine, regulatory movement, and which is supported by the lumbodorsal aponeurosis. Overall or gross posture of the spine as a whole is primarily effected by the longer muscle bundles, which may be reflected in the name of the "erector muscles" of the trunk.

The spine and its protective function for nerves and vessels

Since the spinal cord in the adult ends at the L2–L3 level, the only structures surrounded by the pia mater in the lower lumbar spine are the radicular filaments, the cauda equina. These filaments run almost vertically and exit through the corresponding intervertebral foramen. These radicular filaments, by forming the ventral and dorsal roots, come into close proximity of the more lateral recesses of the vertebral foramen. This smooth transition area between the spinal canal and the intervertebral foramen is not unlike the form of a funnel with the smaller end directed laterally (Figs. 5 and 8). In addition to the pia mater which surrounds both the ventral and dorsal roots, the arachnoid mater and dura mater reach into the intervertebral foramen for some distance as well. The lower edge of the recess created by the soft meninges actually is a very sharp structure, known as the arachnoid angle. It can be readily seen on myelography. The cerebrospinal fluid reaches the spinal ganglion through the lateral recess, at about which level the pia mater changes over to the perineurium. Apparently this is a location for resorption of spinal fluid.

The upper and lower corner of the lateral recess, i.e. the roof and floor of the intervertebral foramen, respectively, are formed by the pedicles of two adjoining vertebral arches. The anterior wall of this funnel is, in some part at least, made up of the lateral portion of the posterior longitudinal ligament. Also, moving more laterally, the contribution from the anulus fibrosus becomes increasingly more prominent. In the lower portions of the spine it is made up of mostly anulus-fibrous

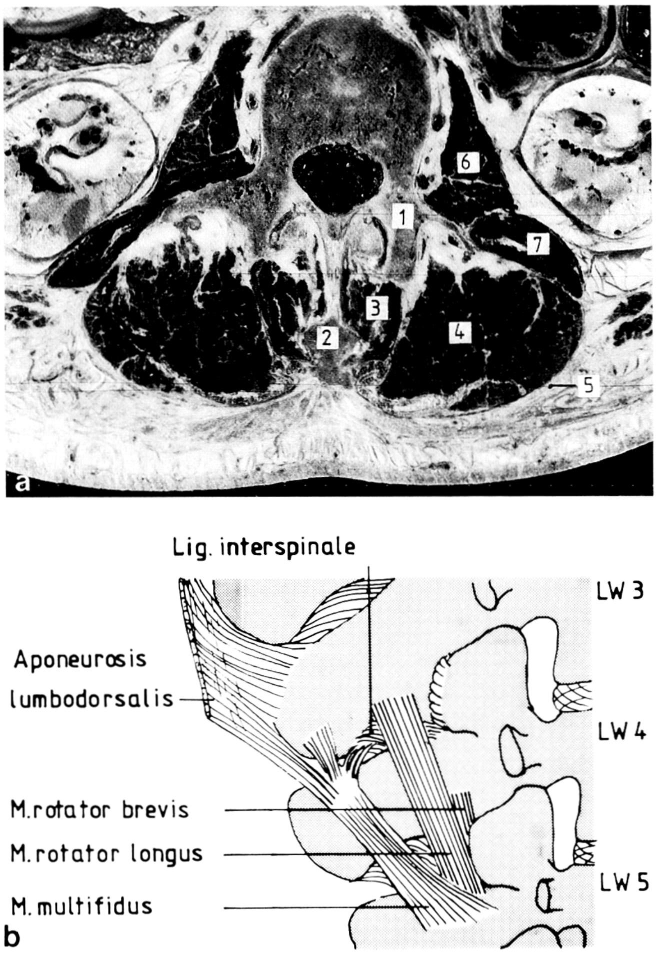
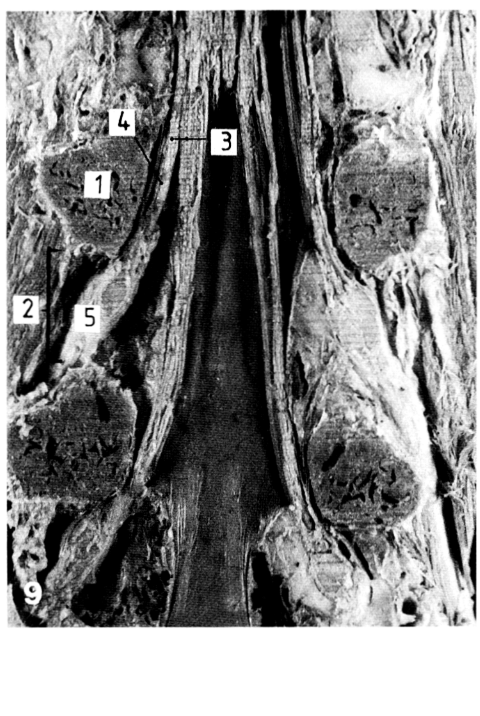


Fig. 7a and b. Short and long back muscles. **a** Anatomical specimen. **b** Schematic representation of the deep layers of the short and long muscles of the back. *1* = pedicle; *2* = spinous process; *3* = medial deep muscles; *4* = lateral muscles; *5* = lumbodorsal aponeurosis; *6* = psoas muscle; *7* = quadratus lumborum muscle

Fig. 8a and b. Topographical representation of the lateral recess. **a** Cut in the median plane; please note the inferiorly directed nerve roots. **b** Sagittal section with adjoining recesses

Fig. 9. Frontal cut through the lower lumbar spine with representation of the course of some nerve roots. Please note the diagonal course of the individual exiting nerve root and the ganglion in the intervertebral foramen. *a* = pedicle; *2* = intervertebral foramen; *3* = roots; *4* = fixation of the roots at the periosteum of the pedicle; *5* = spinal ganglion ▼



material. The posterior wall is in some instances compressed by the more posterior yellow ligaments, which cover the anterior portion of the joint capsule in a spinal segment to a great extent (Fig. 1).

Loss of disc space or extreme lordotic posture may both lead to compression at the intervertebral foramen, namely because the intervertebral disc and the ligamentum flavum can be pressed against the foramen. Even though not reported frequently in the literature, it should be noted that bony spurs can develop, especially at the attachment of the ligamentum flavum. These spurs, which may measure up to a few millimeters, can lead to compression of the intervertebral foramen, especially the lower portion.

The epidural space is filled with fat and the internal vertebral venous plexus. In anatomical preparations, quite frequently this plexus is filled with coagulation material. According to Clemens [2], this plexus is the connection between the veins of the vertebral body, the basovertebral veins, and the circumferential venous plexus. The veins of this plexus do not contain valves, thus blood flow can be regulated in accordance with localized pressure changes.

Also in the epidural space is located the meningeal branch of the spinal nerve. According to Delank [3] and Bogduk [1] this branch is reported to contain vegetative and afferent fibers and supplies the meninges in a plurisegmental fashion. Furthermore, this branch also innervates the anterior portions of the facet joints. The joints are also supplied by fibers of the dorsal ramus of the spinal nerves.

Of particular clinical interest is the exact course of the nerve root in the intervertebral foramen (please see also [10, 11]). The superior root is located laterally in the lateral recess and then, after taking a sharp turn, courses along the inferior vertebral incision in order to finally enter the foramen. In contrast to the superior root, the inferior root descends sharply in the recess and then reaches the inner side of the pedicle of the next vertebra below (Fig. 9). Thus, it should become apparent that with disc changes in the lower lumbar spine, the individual nerve root may become affected in at least two segments. This fact may assume great significance, especially when formulating a differential diagnosis.

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