

A comprehensive review of the sub-axial ligaments of the vertebral column: part II histology and embryology

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Received: 18 April 2015 / Accepted: 20 April 2015 / Published online: 5 May 2015
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Abstract

Background As important as the vertebral ligaments are in maintaining the integrity of the spinal column and protecting the contents of the spinal canal, a single detailed review of their histology and embryology is missing in the literature.

Methods A literature search using online search engines was conducted.

Results Single comprehensive reviews of the histology and embryology of the spinal ligaments are not found in the extant medical literature.

Conclusions This review will be useful to those who study or treat patients with pathology of the spine.

Keywords Spine · Vertebral column · Injury · Morphology · Pathology

Introduction

The sub-axial ligaments of the spinal column help stabilize the vertebral column joints. In particular, the sub-axial ligaments allow the vertebrae significant mobility within a

predetermined range while still providing the structural integrity necessary to safely house the spinal cord in the vertebral canal. These ligaments are classified as the intrasegmental and intersegmental systems. The intrasegmental system consists of ligaments that hold individual adjacent vertebrae together and include such ligaments as the ligamentum flavum, interspinous ligament, and the intertransverse ligament. Meanwhile, the intersegmental system has the responsibility of holding together multiple vertebrae using just a single ligament, but its ligaments are much longer in length compared to those of the intrasegmental system.

In order to deal with patient pathology, it is important to individually study these ligaments. In this paper, we will review the literature associated with the sub-axial ligaments regarding their histology and embryology. This review coupled with part I of our study will provide the clinician with appropriate knowledge for the vertebral column ligaments below C2.

Anterior longitudinal ligament

The anterior longitudinal ligament consists of countless closely packed collagenous fibers oriented longitudinally that cross at acute angles and are interwoven with each other with a few elastic fibers interspersed within the ligament [3, 13, 19]. This is in contrast to the posterior spinal ligaments such as the ligamentum flavum, which have a very large percentage of elastin fibers thus giving these posterior ligaments greater extensibility [19]. When the anterior longitudinal ligament is formed embryologically, its attachments are associated with cortical bone in accordance with normal ligamentous development; however, the annulus fibrosus proper is attached to the vertebral end plate with the fibers of the adult annulus fibrosus that do attach to bone being done so by being secondarily incorporated into the ring apophysis which is not a cortical

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bone [3]. Due to this developmental difference, the short deep fibers of the anterior longitudinal ligament should not be considered a part of the annulus fibrosis of the vertebral cartilage [3].

Posterior longitudinal ligament

The posterior longitudinal ligament is composed of collagenous and elastin fibers arranged in a cephalocaudal direction that are more dense and compact compared to those of the anterior longitudinal ligament [5]. There are substantially more elastin fibers than collagenous fibers allowing for more extensibility [19].

Ligamentum flavum

Upon gross examination, the ligamentum flavum (LF) appears as a broad and pale yellow ligament [1, 5, 18]. On average, it is composed of 80 % elastin and 20 % collagen with the elastic fibers being oriented parallel to the long axis of the ligament [3, 25, 26]. Yong-Hing and colleagues in 1976 obtained 51 specimens, which were stained with Gomori's aldehyde fuchsin stain to measure the elastin (stained purple) and collagen (stained green) content of these ligaments [26]. In these specimens, they found that the elastin content ranged from 50 to 80 % and the collagen content ranged from 20 to 50 % of the ligaments' composition [26]. While anteriorly the ligament is thin due to the elastic fibers, the posterior capsule of each posterior joint is thicker due to the collagenous content [26]. A study on the ultra-structure of the ligament demonstrated that the LF contains two morphologically different types of elastin fibers: elastic and elaunin fibers [25]. While the elastic fibers proper were found throughout the ligament, mainly in the central region, the elaunin fibers, which are composed of few elastin deposits interspersed with microtubules, were more prominent along the bony attachments of the ligaments [3, 25]. Very few spindle-shaped fibroblasts were also associated with the ligament [25]. The LF differs from all other ligaments of the lumbar spine, as it is the only ligament consisting of predominantly elastic fibers as opposed to collagen [3]. The LF are noted to retain their elastin content with increasing age [26]. While it was previously postulated that the elastin content of the ligament decreases and the ligament becomes more rigid in patients with spondylosis, Yong-Hing and colleagues found no evidence to support this claim; instead, they noted that there is no correlation between elastin content and age, duration of symptoms of low back or leg pain, or the presence of degenerative spondylosis [26]. They also noted that there was no evidence that with increasing age any hypertrophy, hyperplasia, or degeneration of elastin takes place [26].

Supraspinous ligament

The supraspinous ligament consists of three parts: the superficial layer, the middle layer, and the deep layer [3]. The superficial layer consists of longitudinally running collagenous fibers that span three to four successive spinous processes that varies considerably in size from extremely thin fibrous bundles to a robust band that is 5–6 mm wide and 3–4 mm thick with most of these ligamentous layers exhibiting intermediate forms [3]. The middle layer consists of approximately 1-mm-thick intertwining tendinous fibers of the dorsal layer of thoracolumbar fascia and aponeurosis of the longissimus thoracis [3]. The deep layer consists of very strong tendinous fibers derived from aponeurosis of the longissimus thoracis that are also located in the middle layer [3]. As these tendinous fibers pass along to their insertions on the lumbar spinous processes, they combine in a parallel fashion that creates the appearance of a supraspinous ligament while clearly maintaining their identity as tendons [3].

Interspinous ligaments

The interspinous ligament (ISL) consists of three distinct parts composed of type 1 collagenous tissue and cells lying in rows between the collagen fiber bundles: ventral, middle, and dorsal [3, 6, 25]. The ventral portion of the ISL may be regarded as a posterior extension of the ligamentum flavum and consists of fibers passing posterocranially from the LF to the anterior half of the lower border of the spinous process above [3, 6]. This portion contains some elastic fibers with increasing numbers as the bundle blends with the LF [6, 25]. The middle portion is the major component of the ISL and consists of purely collagenous fibers that traverse from the anterior half of the upper border of the spinous process below to the posterior half of the lower border of the spinous process above [3, 6]. Finally, the fibers of the dorsal portion of the ISL are purely collagenous and attach to the posterior half of the upper border of the spinous process below and pass behind the posterior border of the upper spinous process into the SSL or the medial tendons of the erector spinae muscle [3, 6]. It has been argued that only the ventral and middle portions of the ISL constitute true ligaments, as they have bony attachments [3]. The dorsal portion of this ligament does not fit this criterion as it does not attach to bone at its cranial end but rather blends with the SSL [3]. There are also more overall cells seen in the ISL compared to the LF with fibroblasts aligned in rows between the collagen bundles in the central part of the ligament and chondrocytes near the bone attachments of the ligaments [25].

Intertransverse ligament

The intertransverse ligament consists of collagen fibers that are not as densely packed or as regularly oriented as fibers of

true ligaments [3]. Embryologically, the intertransverse ligaments arise from the tissue that separates the epaxial musculature, i.e., erector spinae, transversospinal muscles, splenius, and suboccipital muscles, and hyaxial musculature, i.e., abdominal muscles, limb muscles, and diaphragm [3].

Iliolumbar ligament

The existence of the iliolumbar ligament in neonates and children has been questioned as one study found it to be present only in adults and to be represented by a bundle of muscle in neonates and children whose cellular content decreases and is gradually replaced by ligamentous tissue near the transverse process and spreads toward the ilium [3, 20]. By the third decade the structure is substantially ligamentous with a large proportion of collagen fibers, but by the fifth decade, the iliolumbar ligament contains no residual muscle and begins to exhibit hyaline degeneration [3]. By the sixth decade, fatty infiltration combined with hyalinization and myxoid degeneration and calcification begins to permeate through the iliolumbar ligament [3].

Luk et al. studied 33 iliolumbar ligaments in cadaver specimens from birth to the ninth decade of age as well as premature stillborn babies and neonatal specimens [15]. They found on gross examination that the ligaments from the cadavers in the first decade were mostly muscular in appearance with no identifiable ligamentous structure between the transverse process and iliac crest [15]. In the second to fourth decade, the appearance of a tough and glistening ligament was apparent even though there was still some muscle seen among the ligamentous fibers [15]. In the fifth decade and onward, the ligament contains no muscle but increasing amounts of fatty infiltration are clearly visible [15].

With electron microscopy, the neonatal ligament was found to be entirely muscular with no demarcation seen from adjacent quadrates lumborum muscles and no evidence of collagen fibers seen [15]. Using special stains such as Masson trichome stain, aggregates of collagen fiber cores were seen in specimens from the first decade onward. These collagen bundles first appeared near the attachment of the ligament to the transverse process and extending gradually to the ligament's insertion at the iliac crest [15]. By the end of the second decade, the ligament was seen to be entirely collagenous and clearly demarcated from the rest of the quadrates lumborum muscle; however, some persisting muscle fibers were seen near the iliac end of the ligament in one of the three specimens from the fourth decade [15]. Specimens from the fifth decade showed hyaline degeneration with specimens from the sixth decade and on showing fatty infiltration [15]. These secondary degenerative changes such as hyalinization, myxoid degeneration, and calcification were demonstrated in 70 % of specimens from the sixth decade onward [15]. At no stage of

development in the specimens from this study were elastic fibers observed [15].

In conclusion, the study by Luk et al. showed that the iliolumbar ligament did not exist at birth but developed gradually in the first decade and achieved full differentiation in the second decade [15]. With no collagen fibers seen in the neonatal specimens but the appearance of these fibers within the normal muscle fibers suggest that the iliolumbar ligament is formed by metaplasia of some fibers of the quadrates lumborum muscle due to the stresses created at the lumbosacral junction while in the erect posture [15].

In contrast, though, one study found the iliolumbar ligament to be present by 11.5-week gestation in a fetus [3]. However, this embryological study was not able to examine fetuses over 16.5 weeks of age, leaving a gap between that age and infancy with the only reported data in that age range from other studies that stipulate that the ligament was muscular rather than ligamentous [3].

Radiology/imaging of the subaxial ligaments

There has always been an accepted concept that there are three columns of support in the thoracic and lumbar spine with the same principles being applied to the C3-C7 vertebral level in the cervical spine [2]. The anterior column consists of the anterior vertebral body, the anterior longitudinal ligament, and the anterior annulus fibrosis; the middle column consists of the posterior vertebral body, the posterior longitudinal ligament, and the posterior annulus fibrosis; and the posterior column consists of the posterior elements of the spine, ligamentum flavum, interspinous ligaments, supraspinous ligaments, and facet joint capsules [2]. The stability of the spine is provided by the intact osseous and ligamentous structures such that in the event of trauma to the spine, clinical instability may occur if the spinal ligaments and bones lose their ability to maintain their normal alignment between vertebral segments while under a physiological load; such an instability could lead to further injury, pain, or deformity that could ultimately require surgical stabilization [2].

Magnetic resonance imaging has been shown to be helpful in detecting ligamentous injuries following spinal trauma with successful MR imaging depending on several factors [2]. One of these factors is time; however, no research has yet defined an optimal time to get imaged but common thinking suggests a time of less than 72 h after occurrence of injury [2]. The reasoning behind this 72-h rule is that the resorption of the edema or hemorrhage reduces the sensitivity of MR imaging to reveal injuries; specifically, the T2 signal hyperintensity produced by the edema or extravasation of blood into the injured extradural tissues provides an excellent contrast medium thus allowing for improved vision of the ligaments that are usually of low signal intensity on imaging sequences [2]. In

the event of spinal trauma, the typical MR imaging usually includes a T1-weighted, fast spin-echo T2-weighted, gradient-echo, and fast spin-echo inversion-recovery images all for the sagittal plane while in the axial plane, the protocol should include gradient-echo or T2-weighted images [2]. Ultimately, ligaments are best seen on the gradient echo and T2-weighted sequences [2].

With an MRI's ability to accurately identify a ligamentous injury, any area of discontinuity in a ligament represents a disruption in the ligament [11, 12, 24]. However, a ligament can also be stripped away from an underlying structure while still remaining intact; such an occurrence is exhibited as increased T2 or short-tau inversion sequences (STIR) signal deep to the ligament. Since the posterior longitudinal ligament (PLL) is not as well defined as other ligaments, any injury to these ligaments can be identified as increased T2 or STIR signal within the complex [4].

The anterior longitudinal ligament is represented as a low signal and linear structure along the anterior portion of the vertebral body cortex and intervertebral discs [4].

Meanwhile, the posterior longitudinal ligament is a low-signal and linear structure along the posterior portion of the vertebral body and intervertebral discs; the PLL is best seen on T2-weighted images because of the adjacent bright cerebrospinal fluid [4]. While an MRI is recommended for evaluating soft tissue structures such as ligaments, ossification/calcification of the posterior longitudinal ligament is a relatively common disorder that is best visualized using computed tomography (CT), an imaging modality that is superior to MRI at identifying hard tissue structures such as bone or calcified ligaments.

The posterior ligamentous complexes, which include the interspinous ligament, ligamentum flavum, and the facet joint capsular ligaments, are not as well defined on MRI as the anterior longitudinal ligament (ALL) or PLL [12, 21].

MR imaging shows the ligamentum flavum as an intermediate signal-intensity structure on images obtained with short and long repetition times (TRs) [7]. Sagittal short TR images were effective for evaluating relationships between the ligamentum flavum, spinal canal, and nerve roots [7]. Degenerative changes in the ligamentum flavum appeared as changes in shape or thickness of the ligaments on MR images [7]. Calcification and fat infiltration, which were well depicted on anatomic sections, were not visualized on MR image [7]. However, should any ossification of the ligamentum flavum occur, a CT scan will demonstrate such a calcification in the posterior column and lead a physician to interpret this as a possible pathology.

The iliolumbar ligament is readily identifiable on axial lumbar spine MRI and always arises from L5 thus suggesting that its position can be used to confidently assign lumbar levels in patients [8].

MR images showed the anterior sacroiliac ligament-anterior capsular complex as a hypo-intense, linear, or

minimally curved structure approximately 2 mm in thickness and traversing the sacroiliac (SI) joint anteriorly [9].

Ultrasound imaging can be used to identify the posterior ligaments of the sacroiliac joint with the ultrasound being useful to detect any pathological change associated with pain and to guide steroid injection in these ligaments [14].

In general, MR imaging is the preferred modality to image the ligaments of the sub-axial spine because ligaments are soft tissue structures that tend to stand out when viewed against the highly visualized cerebrospinal fluid in the subarachnoid space. However, should the ligaments become ossified as is common in elderly individuals, the preferred modality switches from MR imaging to CT scanning as this imaging modality is the better option between the two for visualizing bones and structures with compositions similar to bones such as those ligaments with ossification due to calcium buildup.

Pathology

Anterior longitudinal ligament

A whiplash (severe hyperextension) injury is commonly associated with acceleration/deceleration injuries that cause stretching of the spine and its ligaments especially the anterior longitudinal ligament, as the ALL is the only ligament that will limit extension of the vertebral column [18]. Another injury seen in the ALL is diffuse idiopathic skeletal hyperostosis (DISH or Forestier disease), a very rare condition in which hyperostosis/calcification of the anterior longitudinal ligament in the cervical region occurs [13]. Other ligaments of the spinal are also usually affected with this pathology. This condition has been shown to be associated with dysphagia due to the esophageal compression by the calcified ALL and radiculomyelopathy due to the associated stenosis of the cervical spine [17].

Posterior longitudinal ligament

Since the PLL weakly resists hyperflexion of the vertebral column and thus helps prevent/redirect posterior herniation of the nucleus pulposus, any damage to the PLL such as from whiplash injury or acute spinal trauma could lead to acute localized pain from intervertebral disc herniation as the nucleus pulposus impinges on the posterior longitudinal ligament, which is saturated with nociceptive nerve ends [18]. Another pathology seen with the PLL is ossification of the PLL, which is associated with the elderly and ultimately could lead to radiculomyelopathy [13].

Ligamentum flavum

During hyperextension, the ligamentum flavum could protrude into the spinal canal and could compress the cord if the spinal canal is narrow from spinal stenosis, PLL ossification, ligamentum flavum ossification, etc. [13]. While it has been postulated that the elastin content decreases and the ligamentum flavum becomes more rigid in spondylosis, this theory has been disproved by Yong-Hing in 1976 [26].

Supraspinous ligament

It is relatively well noted that the supraspinous ligament is absent at the lumbosacral junction [6]. As such, this absence allows for increased mobility of the spine in this region and thus could possibly be a factor in the etiology of the musculoskeletal disorders and back pain that is highly prevalent in this region [6]. Also, supraspinous ligament injury is also possible in acute spinal trauma such as seen in whiplash injury.

Interspinous ligament

While spinal trauma could cause interspinous ligamentous damage, a more commonly seen pathology of the interspinous ligament is spinal degenerative changes that may lead to spinal instability and a herniated nucleus pulposus possibly causing radiculopathy and other painful spinal symptoms [25].

Intertransverse ligament

Spinal trauma from whiplash is the most common cause of pathology to the intertransverse ligament. Also seen is a strain of the intertransverse ligament that could be a cause of upper, mid, or lower back pain.

Facet capsular ligament

Whiplash is the most common pathological producing process affecting the facet capsular ligament. There are also reported cases of ossification of the facet capsular ligaments.

Iliolumbar ligament

Any damage to the iliolumbar ligament that renders it unable to stabilize the lumbosacral joint is a common cause of low back pain.

Anterior sacroiliac ligament

During pregnancy, relaxation of the sacroiliac ligaments causes the interlocking mechanism of the sacroiliac joint to become less effective thus allowing for greater rotation of the pelvis and contributes to the lordotic posture seen during

pregnancy; however, this relaxation is not just limited to the pelvis as the possibility of SI joint dislocation increases during late pregnancy [18].

Interosseous sacroiliac ligament

Damage to the interosseous sacroiliac ligament can result in posterior flaring, i.e., diastasis of the sacroiliac joint [3].

Posterior sacroiliac ligament

Damage to the long posterior sacroiliac ligament can result in increased counter-nutation or backward rocking of the sacrum with respect to the ilium [3]. Also, any edema, swelling, or enlargement of the long posterior sacroiliac ligament can cause compression of the S1, S2, and/or S3 nerve and result in ischemic zones to the compromise of the microvascular supply resulting in possible low back pain [16, 23].

Sacrotuberous ligament

Damage to the sacrotuberous ligament increases the amount of nutation/forward rocking of the sacrum with respect to the ilium [22]. Also, any edema, swelling, or enlargement of the sacrotuberous ligament can cause compression of the S1, S2, and/or S3 nerve and result in ischemic zones to the compromise of the microvascular supply resulting in possible low back pain [23].

Superior costotransverse ligament

As described earlier in the paper, the SCTL is a very solid ligament and plays an important role in maintaining lateral stability between adjacent vertebrae with any lack of the SCTL resulting in an increased susceptibility to damage from excessive strain resulting in instability of lateral balance [10]. Overall, any damage or lack of the costovertebral ligaments could ultimately result in increased excursion of the ribs in relation to the vertebrae either during inspiration or expiration. This could also result in increased susceptibility of the thoracic organs to injury should the ribs not be attached to form a strong “box” incasing the thoracic organs.

Conflict of interest The authors have no conflict of interests to report.

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