The Ligaments and Anulus Fibrosus of Human Adult Cervical Intervertebral Discs

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Study Design. Descriptive, microdissection study.

Objective. To determine the morphology of the human adult cervical intervertebral disc and its ligaments.

Summary of Background Data. Some studies indicate that the cervical disc is distinctly different from the lumbar intervertebral disc, yet most clinical and anatomic texts appear content with extrapolating data from the lumbar spine. A detailed three-dimensional description of the cervical intervertebral disc and its surrounding ligaments is currently unavailable.

Methods. Whole cervical spinal columns were freed from 12 human adult embalmed cadavers, and the posterior elements and soft tissues were removed. Using microdissection, the longitudinal ligaments and the fibrous components of 59 cervical intervertebral discs were resected systematically. The orientation, location, and attachments of each stripped bundle of collagen were recorded photographically and in sketches.

Results. The cervical anulus fibrosus does not consist of concentric laminae of collagen fibers as in lumbar discs. Instead, it forms a crescentic mass of collagen thick anteriorly and tapering laterally toward the uncinate processes. It is essentially deficient posterolaterally and is represented posteriorly only by a thin layer of paramedian, vertically orientated fibers. The anterior longitudinal ligament covers the front of the disc, and the posterior longitudinal ligament reinforces the deficient posterior anulus fibrosus with longitudinal and alar fibers.

Conclusions. The three-dimensional architecture of the cervical anulus fibrosus is more like a crescentic anterior interosseous ligament than a ring of fibers surrounding the nucleus pulposus. [Key words: anulus fibrosus, cervical intervertebral disc, longitudinal ligament, morphology] Spine 1999;24:619–628

The morphology and biochemistry of the lumbar intervertebral discs have been studied extensively, and several insights have emerged regarding the pathology of mechanical disorders of the lumbar disc. However, when considering cervical intervertebral discs, most authors appear to be content with extrapolating data from the lumbar spine. Conspicuous in this regard is an article that appeared in a recent issue of an eminent journal dedicated to the cervical spine. In this article, five of six figures used to illustrate cervical motion segments actually depicted lumbar motion segments. It is clear that the pathology affecting cervical intervertebral discs is different from that affecting lumbar discs. In the lumbar disc, prolapse and its congeners are common. In the cervical spine, frank prolapse is uncommon, and degenerative changes are reported to occur typically in the form of endplate sclerosis, disintegration and collapse of the disc, bulging anulus fibrosus, development of osteophytes from the margins of the vertebral body, uncovertebral or zygapophysial joints, and narrowing of the intervertebral foramina or spinal canal by chondro-osseous spurs.

More recently, postmortem studies have found that after whiplash injuries, ligamentous injuries are extremely common in the cervical spine and that herniation of the nucleus pulposus is a rare event. The lesions found in the cervical spine included bruising and hemorrhage of the uncinate region, so-called rim lesions or transections of the anterior anulus fibrosus, and avulsions of the vertebral endplate. Fundamentally to any appreciation of the mechanism causing injury to the cervical intervertebral discs is a knowledge of their normal structure. It appears that little work has been reported concerning the morphology of the cervical intervertebral disc. One limited study described the structure of the cervical intervertebral disc in terms of disc height, cross-sectional area and shape, and fiber orientation of the anulus fibrosus. Pooni et al., using x-ray crystallography on the outer lamellae dissected from the anterior face of 13 C3–C4 discs, determined that the fiber orientation was significantly less (65°) than the tilt of the fibers from the lumbar anulus fibrosus (70°).

Other studies have addressed age changes in the cervical intervertebral discs but it is conspicuous that in all instances, observations were based on frontal, sagittal, or parasagittal sections of the intervertebral discs, yet no study illustrated a transverse section through a cervical disc. Conspicuously missing in the literature is any description of the three-dimensional architecture of the cervical discs.

Anatomy textbooks imply that all intervertebral discs conform to a generic pattern of a nucleus pulposus surrounded by concentric lamellae of obliquely orientated collagen fibers forming the anulus fibrosus. A small number of studies, however, have indicated that the cervical discs are dissimilar to lumbar discs. The development of cervical discs is distinctly different from that of the lumbar discs. The nucleus at birth constitutes no more than 25% of the entire disc, not 50% as in lumbar discs. With aging, the nucleus pulposus rapidly under-
goes fibrosis such that by the third decade there is barely any nuclear material distinguishable.\textsuperscript{18,31}

In view of these disparities and the lack of any formal data on the structure of cervical discs, the current study was undertaken. It used a microdissection approach to determine the three-dimensional architecture of the cervical anulus fibrosus and its surrounding ligaments, with the objective of providing an anatomic basis for biomechanical models and studies of the cervical disc like those developed for the lumbar spine.\textsuperscript{9}

### Methods

Fifty-nine cervical intervertebral discs were obtained from 12 embalmed cadavers of men and women with a mean age of 63.4 years (range, 39–82 years) (Table 1). No specimen was involved in trauma as a cause of death. Whole cervical spinal columns were removed from each cadaver by disarticulation of the atlas at the occipital condyles and disarticulation through the C7–T1 intervertebral disc and zygapophysial joints. After removal of muscles and fascia, the posterior elements and the C7–T1 intervertebral disc and zygapophysial joints. After the atlas at the occipital condyles and disarticulation through the cervical anulus fibrosus and its surrounding ligaments, with the objective of providing an anatomic basis for biomechanical models and studies of the cervical disc like those developed for the lumbar spine.

#### Table 1. Specimens Studied by Age and Gender

<table>
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<tr>
<th>Subject</th>
<th>Discs Studied</th>
<th>Age</th>
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<tr>
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On dissection of the cervical discs, four distinct structures were encountered: 1) elements that could be assigned to the anterior or posterior longitudinal ligaments whose fibers were characterized by having attachments to the respective anterior or posterior surfaces of the vertebral bodies, 2) periosteofascial tissue overlying the uncovertebral area, 3) a structure interpreted as intrinsic fibers of the anulus fibrosus because the fibers were attached to the superior and inferior surfaces or edges of the vertebral bodies and did not extend onto the external surface of the bone, and 4) a deep core of undissectable fibrocartilaginous material.

#### Anterior Longitudinal Ligament

The anterior longitudinal ligament of the cervical vertebral column was defined by fibers that attached to the anterior surfaces of the vertebral bodies. This ligament comprised four layers of fibers distinguished by their patterns of attachment.

The first (superficial) layer consisted of fibers that ran longitudinally, crossing several segments, and that were attached to the central areas of the anterior surfaces of the vertebral bodies (Figure 1). Rostrally, they were attached firmly to the anterior tubercle of the atlas. Below this level, they covered the middle two quarters of the anterior surfaces of the vertebral bodies. Densely aggregated from side to side in the upper cervical spine where the anterior longitudinal ligament is narrow, these fibers were less densely packed at lower levels where the anterior longitudinal ligament expands laterally.

The fibers of the second (intermediate) layer also were longitudinal, but distinctly shorter than the superficial fibers. They covered one intervertebral disc and inserted onto the anterior surfaces of the adjacent vertebral bodies, but never further than half way up or down that surface (Figure 1).

The third (deep) layer consisted of even shorter longitudinal fibers that spanned one disc but attached just cranial or caudal to the inferior or superior margins of the adjacent vertebral bodies (Figures 1 and 2).

The fourth layer consisted of fibers with an alar disposition. They formed a thin curtain over each intervertebral disc. Arising from the anterior surface of the vertebra above, close to its inferior margin, these fibers passed inferiorly and laterally over the disc to insert into the vertebra immediately below its superior margin. The most lateral of these fibers reached the summit of the uncinate process and arose from the vertebra above at a point where the lateral longitudinal ridges on the anterior surface of the vertebral body met the enchancurce for the uncinate process (Figures 1 and 3). These fibers were considered to be components of the anterior longitudinal ligament rather than components of the anulus fibrosus because they attached to the anterior surfaces of
the vertebral bodies rather than to their inferior and superior surfaces or edges.

**Posterior Longitudinal Ligament**

The posterior longitudinal ligament covered the entire floor of the cervical vertebral canal and consisted of distinct superficial, intermediate, and deep layers. The superficial layer contained two elements: 1) central, longitudinally directed fibers that spanned a variable number of segments, and 2) lateral extensions that swept out from the central band to cross an intervertebral disc and attach to the base of the pedicle one or two segments below (Figures 4 and 5). Centrally, all fibers of the superficial layer were attached to the central posterior surfaces of the vertebral bodies. Resection of these fibers revealed longitudinally disposed tubercles on the central, posterior surface of the vertebral bodies to which they attached.

The intermediate layer of the posterior longitudinal ligament consisted of longitudinal fibers that spanned only one intervertebral disc. These fibers, restricted to a...
position close to the median plane, were attached to the posterior surfaces of the adjacent vertebral bodies just caudally or cranially to the tubercles on the posterior surfaces of the vertebral bodies (Figures 4 and 6).

The deep layer of the posterior longitudinal ligament consisted of short fibers that spanned each intervertebral disc. These fibers arose from the posterior surface of the upper vertebra just above its inferior border and passed inferiorly and somewhat laterally to reach the vertebra below, immediately below its superior margin. Laterally, the fibers of this layer extended in an alar fashion as far as the posterior end of the base of the uncinate process (Figures 4 and 6). The deep layer was considered to be a component of the posterior longitudinal ligament rather than a component of the anulus fibrosus because its fibers attached to the posterior surfaces of the vertebral bodies rather than to their inferior and superior surfaces or edges.

**Periosteofascial Tissue**

Periosteofascial tissue covered the area of the lateral clefts in the uncovertebral region. This tissue was so named because it was continuous with the periosteum over the posterior lateral aspect of the vertebral body and pedicles but became distinctly fascial as it left the bone. It consisted of unorganized fibrous connective tissue embedded with fat and a large number of blood vessels. Posteriorly, having covered the uncovertebral cleft, the fascia disappeared deep to the free, lateral edge of the alar portion of the posterior longitudinal ligament that covered the cartilaginous core of the underlying disc. Anteriorly, the fascia disappeared deep to the alar portion of the anterior longitudinal ligament to interweave with the outer fibers of the anterolateral portion of the anulus fibrosus (Figure 7).

**Anulus Fibrosus**

The structure of the anulus fibrosus was different in its anterior and posterior parts. The anterior part was thick toward the median plane, but progressively thinner when traced to the uncinate processes, such that in a top view, the anterior anulus was crescentic in form (Figure 8). The posterior part consisted of only a thin layer of collagen fibers.

Covering the anterior aspect of the anulus fibrosus was a thin layer of collagen fibers that was transitional between the deepest fibers of the anterior longitudinal
ligament and the most superficial layers of the anulus (Figures 9A and 10A). Their orientation was like that of the deepest fibers of the anterior longitudinal ligament, in that in the paramedian region they passed inferiorly but diverged laterally, whereas more laterally the fibers assumed an alar disposition passing inferiorly and laterally. However, unlike the definitive fibers of the anterior longitudinal ligament, their attachments were to the edges of the vertebral bodies, not to their anterior surfaces.

Deep to these transitional fibers, the fibers of the anulus fibrosus proper arose from the superior surface of the lower vertebra. The most lateral fibers arose from the apex and anterior surface of the uncinate process and passed upward and medially to insert into the inferior surface of the vertebral body above, opposite where the ipsilateral anterior longitudinal ridge meets the anterior margin (Figures 9B and 10B). Progressively, more medial fibers arose from the upper surface of the lower vertebral body and passed upward and medially into the inferior surface of the vertebra above. Toward the midline, these fibers interwove with the corresponding fibers of the opposite side. These fibers did not pass one another in separate laminae, but were distinctly and tightly interwoven, as in a decussation (Figures 9B and 10B).

Deeper into the anterior anulus, fibers in successive layers repeated this pattern of central interweaving, but individual fibers became difficult to trace within and through the weave. However, progressively deeper fibers were increasingly restricted to attachments closer to the midline (i.e., fewer fibers in successive layers arose from regions toward the uncinate processes on each side. This feature produced the crescentic appearance of the anulus when viewed from above (Figure 8).

Beyond 2 to 3 mm from the surface of the anterior anulus, collagen fibers were increasingly embedded with what was assumed to be proteoglycans to form a homogeneous fibrocartilaginous mass that had a pearly appearance and the consistency of soap (Figure 9D and 10C). These fibers defied microdissection. However, when the vertebral bodies were separated by blunt dissection, it was apparent that this mass consisted of la-
mellae that could not be dissected because the dominant tissue was a proteoglycan matrix. Deeper still, the fibrocartilage became more homogeneous and less laminated, forming what was interpreted to be the nucleus of the disc.

The posterior anulus was different in character from the anterior anulus. It extended between the bases of the uncinate processes on each side and consisted of one set of vertically orientated collagen fibers that ran between the facing surfaces of opposing vertebral bodies (Figures 8, 11, and 12). This layer was not more than 1 mm thick, and deep to it lay the homogeneous fibrocartilaginous core.

In this context it should be noted that anterior to each uncus the fibrocartilaginous core was covered by the most peripheral fibers of the anterior anulus. The posterior anulus covered only the posteromedial aspect of the

Figure 10. Photographs showing three depths of the anterior anulus fibrosus. A, Transitional layer. B, Deeper layer. C, The fibrocartilaginous core of the disc (fc).

Figure 11. The posterior anulus fibrosus. A, The longitudinal fibers of the anulus fibrosus. B, The fibrocartilaginous core of the disc deep to the posterior anulus.

Figure 12. A, Photograph showing the posterior anulus fibrosus (af). Deep to it lies the fibrocartilaginous core of the disc (fc). B, The fibrocartilaginous core fully revealed by resection of the posterior anulus.
fibrocartilaginous core. Superoposteriorly to the uncus, no anulus fibers covered the core, which was covered only by the periosteofascial tissue described earlier (Figure 8).

**Fibrocartilaginous Core**

In the uncovertebral region, clefts extended into the fibrocartilaginous core. The clefts opened under the periosteofascial tissue covering the uncovertebral region and penetrated the core to different extents. In younger specimens, the clefts extended only partially into the core, whereas in older specimens, the clefts totally transected the posterior two thirds of the disc, occasionally leaving an isolated posterior central plug of fibrocartilage deep to the posterior anulus (Figure 13).

**Discussion**

Readers may be as startled as the investigators were by the results of this study; the structure of the cervical discs does not match the descriptions they currently have received in the literature. The cervical discs are not like lumbar discs. The cervical anulus fibrosus does not consist of concentric lamellae of collagen fibers that uniformly surround the nucleus pulposus, and that exhibit alternating oblique orientations. Rather, the cervical anulus is crescentic, being thick anteriorly but tapering in thickness laterally as it approaches the uncovertebral region.

Over the anterior end of the uncovertebral region there is only a single layer of obliquely orientated fibers covering the fibrocartilaginous core of the disc. Laterally over the uncovertebral region there is no substantive anulus. Only a flimsy layer of periosteofascial tissue covers the fibrocartilaginous core, disappearing deep to the alar portions of the anterior and posterior longitudinal ligaments. Posteriorly, the anulus fibrosus is not multilaminated like the anterior anulus of cervical discs or the posterior anulus of lumbar discs, nor does it consist of obliquely orientated fibers. It is represented only by a thin set of vertically running fibers.

In no region of the cervical anulus fibrosus do successive lamellae exhibit alternating orientations. A cruciate pattern occurs only in the anterior portion of the anulus where obliquely orientated fibers, upward and medially, interweave with one another. This weave is what may have been regarded in x-ray crystallography studies as alternating layers, but it is not produced by alternate lamellae.

Skeptical individuals might argue that the current study was confounded by the use of elderly cadavers and that the features observed were the consequence of degenerative or age-related changes. However, all the specimens exhibited the same morphology including the samples taken from the 39-year-old individual and the two other individuals younger than 50 years of age. Moreover, even though age changes might be expected to cause desiccation and fibrosis of the disc, and perhaps disruption and attrition of collagen fibers, they cannot be expected to alter the orientation and attachments of collagen fibers.

Therefore, although it might be conceded that age changes could result in thinning of the anulus fibrosus by absorption of deeper layers of collagen into the nucleus, they cannot alter the geometry of those anulus elements that remain. Accordingly, the cervical discs are rendered different from the lumbar discs by certain key features: Anteriorly, the cervical anulus consists of interwoven, alar fibers, whereas posteriorly, the anulus lacks any oblique fibers and consists exclusively of vertically orientated fibers. In essence, the cervical anulus has the structure of a dense, anterior intersosseous ligament with few fibers to contain the nucleus pulposus posteriorly. That role is subserved by the overlying posterior longitudinal ligament. Posterolaterally, the nucleus is contained only by the alar fibers of the posterior longitudinal ligament, under which or through which nuclear material must pass if it is to herniate (Figure 6).

The vertical orientation of the posterior anulus of cervical discs has not been reported before, but a similar observation has been made for thoracic discs. The absence of an anulus over the uncovertebral region is not a new observation because previous studies have shown that in this region collagen fibers are torn by 15 years, or as early as 9 years or 7 years, leaving clefts that progressively extend across the back of the disc. Rather than an incidental age change, this disruption has been interpreted either as enabling or resulting from rotatory movements of the cervical vertebrae. Axial rotation of a typical cervical vertebra occurs around an oblique axis perpendicular to the plane of its facets. The uncovertebral clefts are necessary to allow the posterior corners of the vertebral body to swing laterally as they pivot around the dense, intersosseous portion of the anterior anulus.
The results of the current study have biomechanical and clinical ramifications. For biomechanists, the different anatomy of the cervical anulus fibrosus means that the model devised for lumbar discs cannot be applied to the neck. A separate and new model must be devised for the cervical discs. For clinicians, a question can be raised about the etiology and mechanism of cervical discogenic pain. Such pain cannot be ascribed to posterolateral fissures in the anulus fibrosus, as it is in the lumbar spine, because in cervical discs the posterolateral anulus is lacking. Considering the structure of the cervical anulus, the possibilities that emerge for mechanisms of discogenic pain are strain or tears of the anterior anulus, particularly after hyperextension trauma, and strain of the alar portions of the posterior longitudinal ligament when stretched by a bulging disc.

Even though the current study was based largely on elderly specimens, the results are sufficiently striking to call for an immediate revision of prevailing notions about the structure of cervical discs. What remains to be explored is whether this distinctive structure is evident at all ages or whether younger discs have components different from or additional to those seen in the elderly. In particular, if a posterior anulus is lacking only in elderly discs, when does the attrition of the posterior anulus commence, and why?

References

This detailed study of cervical discs from 12 adult cadavers (aged 39 to 83 years) comes from two institutions, both highly respected for anatomic study and research. It deals with a topic much neglected in recent years, the unique structure of adult cervical discs. Radiologists and surgeons dealing with the cervical spine and anatomists who teach this subject in should be aware of its unique structure. This article contains new information on the detailed structure of adult cervical discs and their ligaments, but I doubt that well-informed radiologists will be as “startled” as the authors about the main findings, the absence of an intact posterior anulus fibrosus, and the presence of transverse fissuring from the uncovertebral clefts through the “central core.” Cervical discography has fallen into disfavor in many quarters, but those who still practice it often see a posterior fissure system outlined by centrally injected contrast, showing a “bipartite disc,” except for the anterior anulus (McCormick CC, personal communication). This commentator, with LT Twomey, has been describing and illustrating the posterior transverse fissures in bipartite middle aged and elderly cervical discs at scientific conferences and in book chapters for the past 10 years.1–4 Before that, Tondury and Penning (cited by the authors) gave good descriptions of the age-related anatomy of cervical discs, based on Tondury’s series of 150 spines aged from 20 to 90 years.5 He showed that cervical discs are often bipartite in older subjects, even those as young as 33 years—though he emphasized the age-related variation—in his large series. Despite this, it would still be true that many scientists and clinicians still regard the cervical disc as a smaller copy of the lumbar disc, and, as the authors point out, clinical texts and texts on anatomy are content to regard them as essentially similar.

This study confirms that adult cervical discs are very different from lumbar discs. This was evident in our autopsy studies of cervical spines, which included histologic studies of 32 spines6 and a sagittal sectioning study of 180 spines ranging from infancy to old age,7 but our studies are not directly comparable with the detailed, dissection-based study of the “three-dimensional architecture” of the discs and ligaments by Mercer and Bogduk. The authors confirm that only the crescentic anterior anulus of adult discs persists as an intact structure, with age-related variability of penetration of the transverse clefts into the original posterior anulus and the nucleus or “core.” They go further and suggest that the structure of the anulus is likely to be unique at all stages of development—a doubtful conclusion in a study that excludes immature discs. Their descriptions of the longitudinal ligaments are interesting and informative. The strength and structure of these ligaments are important for a number of reasons, e.g., in relation to the containment of some posterior herniations by the layered, posterior longitudinal ligament (they do not mention its relation to the anterior internal vertebral venous plexus) and in relation to the order of failure of anterior structures in neck extension injuries. The anterior anulus fails before the anterior longitudinal ligament.6 The longer fibers of the anterior longitudinal ligament would be more compliant than the shorter fibers of the anterior anulus. The first and second layers discussed by the authors correspond to the anterior longitudinal ligament as I have regarded it, with superficial fibers spanning several segments and shorter fibers spanning one full segment; both can be traced into the anterior periosteum. I also have observed the interchange of fibers with the anterior anulus (the authors’ transitional fibers). I have regarded layers 3 and 4 as superficial parts of the anulus, but I note that the authors distinguish layer 4 from the anulus partly by the particular orientation of its fibers.

Mercer and Bogduk have described the unique anatomy of the adult cervical disc in more detail than have authors of previous studies. To be fair to the (false) accounts of cervical discs in anatomy texts, many anatomists approach anatomy from a developmental perspective. This also has its merits, because in fetuses, infants, children, adolescents, and even in many young adults, freshly cut cervical discs, viewed in midsagittal section, show central swelling of a nucleus or central core, surrounded by an anulus, much like lumbar discs. The uncovertebral clefts are not true joints, as they do not appear posterolaterally until adolescence. As described by Tondury,5 from the third or fourth decade onwards, fissures penetrate medially from these clefts in response to the shearing forces of cervical movements, with attrition of the posterior anulus and central core, producing the dramatic contrasts with lumbar discs described in this article. The preservation of the posterior longitudinal ligament from this attrition is probably related to the greater compliance of its longer fibers; I would maintain that the connective tissue geometry in the disc can change in adults, just as bones remodel in response to altered loading.

References
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