Reconsidering the tectorial membrane: A morphological study

ABSTRACT
Background: Published descriptions of the tectorial membrane have been inconsistent. Descriptions vary from a simple ligamentous band extending between the axis and occiput to a more complex layered structure composed of bands of fibers. The purpose of this study was to examine and document the macrostructure of the tectorial membrane.

Materials and Methods: The tectorial membrane was examined by fine dissection in 11 formalin-fixed human adult cadavers. Detailed descriptions of the macrostructure and attachments were recorded.

Results: Each tectorial membrane examined consisted of two distinct layers. The superficial layer was composed variably of three or four bands. Its fibers extend caudally over multiple spinal levels, becoming continuous with the posterior longitudinal ligament. The deeper layer routinely consisted of three bands, each being firmly adherent to the posterior aspect of the body of the second cervical vertebra. Attachments of fibers from both layers extended beyond the foramen magnum to create a semicircular attachment onto the base of the skull.

Conclusions: The tectorial membrane has a more complex structure than has been described to date in standard anatomical texts. The existence of a layered and banded composition may have implications for understanding its function and for the clinical assessment of this structure.

Keywords: Axis, cervical atlas, craniocervical anatomy, ligament, tectorial membrane

INTRODUCTION
The ligamentous structures of the craniovertebral region are vital in ensuring the stability of the craniovertebral junction, preventing subluxation and dislocation. Instabilities of this region have been associated with inflammatory disorders such as rheumatoid arthritis or seronegative spondyloarthropathies, infection of the pharyngeal region, congenital malformation, or trauma. A detailed understanding of the structures comprising this complex is essential for clinicians dealing with patients who have sustained injury to the upper cervical spine and for neurosurgeons encountering these structures during procedures where transcervical or transoral approaches may be used to access the craniovertebral region.

The tectorial membrane is arguably the least explored of the passive stabilizing structures of the craniovertebral region. Most descriptions of the tectorial membrane portray a broad ligamentous band of tissue running between two points of bony insertion. However, early reports of dissections of the craniovertebral region have been published describing the tectorial membrane as a multilayered structure consisting of distinct bands.

In an extensive examination of 85 cadavers, Cave described the tectorial membrane as having superficial and deep portions, with the deep portion consisting of distinct medial...
and lateral components. Fick draws a clear distinction between the two layers of the tectorial membrane. He described the superficial layer as consisting of fibers continuous with the posterior longitudinal ligament, whereas the deeper layer was composed of three bands of shorter fibers running between the adjacent vertebrae. Poirier et al. also described the tectorial membrane as having three distinct bundles, one central and two lateral. However, these authors considered that only the deeper layer truly comprised the tectorial membrane with the posterior layer belonging to the “communal posterior vertebral ligament.”

The existence of layers and bands in the tectorial membrane has more recently been challenged. Following the dissection of 13 formalin-fixed cadavers, Tubbs et al. reported that they were unable to find any distinct parts to the tectorial membrane, either as deep or lateral components. In view of the inconsistencies in published descriptions of the tectorial membrane, the following study was undertaken to determine the gross morphology and variations of this structure.

**MATERIALS AND METHODS**

Eleven cervical spine and head specimens were obtained from embalmed human adult cadavers aged between 69 and 91 years (mean age = 84.1 years). No specimen was involved in trauma as a cause of death.

Cervical spine columns were removed from each cadaver at the level of the C6–C7 intervertebral disc and zygoapophyseal joints. Each specimen was divested of all muscle tissues. The skull was sectioned through the occipital bone, and the brain tissue was removed. In accordance with methods previously described by Dvorak et al., a posterior wedge of approximately 140° was cut from the occipital bone. Anteriorly, the bone was sectioned by a midline cut in the coronal plane. The posterior arch of the atlas and the posterior elements C2–C6 were resected. Brainstem, spinal cord, and dura were removed to expose the tectorial membrane. Using a dissecting microscope, the tectorial membrane was examined by fine dissection. Each structure was systematically dissected by resecting its collagen fibers in small bundles. As the bundles were stripped and removed, the orientation, location, and attachment sites were recorded descriptively, photographically, and in sketches. Layers were resected to reveal deep layers which were then resected in a similar manner. Relationships of the tectorial membrane were noted. Measurement of the distance of attachment into the occiput was obtained using calipers.

**RESULTS**

The tectorial membrane was defined by an intimate and often adherent association with the dura posteriorly and by fibers extending superiorly to a curved attachment onto the occiput. Each tectorial membrane comprised two distinct layers of fibers with differing patterns of attachment.

The first (superficial) layer consisted of fibers running longitudinally in variably three (nine specimens) or four (two specimens) bands. These bands emerged from a central layer of fibers which appeared to be an upward projection from the posterior longitudinal ligament. The majority of the banded arrangement was situated within the superior component of this structure and remained visible from the point of division to the occipital insertion. Where a three-band arrangement was present, the central band assumed a “fan” shape as it ascended into the basiocciput expanding on its upward course to its semicircular attachment. The two lateral bands arched outward alongside the central band, constituting the outer aspects of the semicircle [Figure 1]. In the two specimens with a four-band arrangement, this spread of fibers in the bands was less obvious, appearing to follow a straighter line toward the points of attachment.

Superiorly, fibers attached from 5 to 20 mm (mean 10.6 mm, standard deviation [SD] 4.6 mm) past the foramen magnum onto the anterior internal surface of the occiput. Inferiorly, fibers of all bands spanned over several segments, blending into the posterior longitudinal ligament overlying levels from C2 to C6. Some attachments were evident on some specimens onto the posterior aspects of the vertebral bodies of the axis and C3. Present in most specimens was a communicating band extending to a deeper layer. In the majority of specimens, this occurred via a central band of dense connective tissue over the level of the axis. Less frequently, small bands of dense connective tissue could be discerned diving to the deeper layer from lateral bands.

![Figure 1: (a) The superficial layer of the tectorial membrane viewed from the posterior aspect and (b) with margins of the individual bands highlighted](image-url)
The second (deeper) layer consisted of three clearly discernible bands of longitudinally running fibers in all specimens [Figure 2]. This layer passed over the atlas in each specimen with minimal or no attachment to it as it traversed toward its attachment onto the basiocciput. Inferiorly, each of the three bands consisted of a broad projection arising from strong attachment directly onto the posterior aspect of the vertebral body of the axis. Each of the bands remained separate along their course such that the left lateral band attached distinctly to the left side of the posterior aspect of the vertebra, the right band arising from the right side of the posterior aspect of the vertebra, and the central band attaching in a broad area centrally.

As it ascended, the central band assumed a “fan” shape, broadening as it passed over the atlas. As the band crossed the level of the odontoid process, the fibers angled and traveled anteriorly, broadening anterolaterally to extend beyond the foramen magnum and create a semicircular attachment onto the internal surface of the basiocciput, with fibers attaching from 8 to 22 mm anterior to the foramen magnum (mean 13.2 mm, SD 4.9 mm).

The lateral bands ascended partially covered by the central “fan” such that the medial portion of the lateral bands lay beneath the lateral portions of the central band. Following removal of the central band, the geometry of the lateral bands could be more clearly discerned [Figure 3]. Each lateral band ascended along the posterolateral aspect of the axis. At the level of the upper one-third of the odontoid process, the fibers diverged such that each lateral band arced both medially and laterally. Medially, the fibers from each side converged and formed an arch over the tip of the odontoid process. Laterally, the fibers continued to their attachment onto the lateral aspect of the basiocciput. The lateral attachment extended to encompass the internal occipital surface around the jugular foramen.

While the lateral bands in the majority of specimens could be seen to pass over the medial aspects of the atlanto-occipital and lateral atlantoaxial joints, two specimens displayed identifiable attachments of some fibers onto the medial aspects of the atlanto-occipital joints. Although the tectorial membrane is generally mobile over the atlas, three specimens were observed to provide some, although not extensive, direct attachment onto the medial aspect of the lateral mass of the atlas from the lateral bands of the deep layer of the tectorial membrane.

**DISCUSSION**

The notion that the tectorial membrane is simply a broad layer of tissue suspended between two points of bony adherence is clearly incorrect. These dissections demonstrate that the tectorial membrane is a multilayered structure composed of longitudinally running fibers. Each specimen examined was composed of two distinct layers of dense tissue. The fibers comprising each layer gathered into clear bands. Typically, a three-band arrangement was present in each layer, although a four-band arrangement was an observed variant in the superficial layer. The presence of a banded structure suggests that the tissue may be capable of resisting forces from differing directions corresponding to the longitudinal axes of the bands themselves. This description of the tectorial membrane as a structure composed of superficial and deep layers with distinct elements within each layer bears a strong similarity to descriptions published in the early part of the

![Figure 2](image_url) - (a) The deep layer of the tectorial membrane viewed from the posterior aspect and (b) with margins of the central and lateral bands highlighted

![Figure 3](image_url) - (a) The deep lateral bands of the tectorial membrane viewed from the posterior aspect and (b) with the margins of the bands highlighted. The central band has been removed to show the medial and lateral paths of the cranial portion of the structure
The tectorial membrane has frequently been described as an upward extension of the posterior longitudinal ligament. Our results suggest that the superficial layer of the tectorial membrane is continuous with the posterior longitudinal ligament, but the deeper layer has no connection with this structure inferiorly. Specimens in this study frequently contained numerous fibers which were observed to be continuous over several segments. These fibers were observed to blend into the posterior longitudinal ligament between the levels of the third and sixth cervical vertebrae. Poirier et al. provided a similar description of the relationship between the layers of the tectorial membrane and the posterior longitudinal ligament. The conclusion of these authors was that only the deep layer should be recognized as the tectorial membrane, with the superficial layer considered being part of the posterior longitudinal ligament. While it cannot be disputed that the fibers of the superficial layer of the tectorial membrane are continuous with the posterior longitudinal ligament, the marked differences between the tectorial membrane and the posterior longitudinal ligament in fiber orientation and attachment make considering them as one anatomical entity difficult. The posterior longitudinal ligament in the adult cervical spine has been demonstrated to consist of three distinct layers. The fibers of the deeper two layers span only one segment each in attaching vertebra to vertebra, whereas the superficial band contains central fibers passing longitudinally, which span a variable number of segments and lateral extensions passing inferolaterally at each level to attach at the base of the pedicle one or two vertebral segments below their origin. This contrasts with the observed distribution of fibers in the superficial layer of the tectorial membrane. The findings from the current dissection series indicate that the fibers generally ascend centrally. However, rather than maintaining a distinctly longitudinal orientation, they diverge to form a “fanshaped” arrangement which continues toward its attachment onto the occiput. No significant central bands of fibers were observed attaching unisegmentally onto the atlas. Extensive attachment between the atlas and axis would not be expected given the independence of movement of the atlas with respect to the axis to permit a paradox motion between these adjacent segments. At the level overlying the atlas, lateral components are evident. These pass superolaterally to a broad attachment onto the basiocciput, opposite to the fiber direction described for the lateral elements of the posterior longitudinal ligament.

The inferior attachments of the tectorial membrane have been described as the posterior surface of the vertebral body of the axis, the posterior longitudinal ligament, and the dorsal surface of the odontoid process. In accepting that the superficial layer is indeed a component of the tectorial membrane rather than the posterior longitudinal ligament, the current findings support the first two of these descriptions. The deeper layer has an extensive and strong attachment onto the posterior aspect of the vertebral body of the axis from both its central and lateral components. There was, however, no indication in any specimen of any attachment onto the posterior surface of the odontoid process.

Fick described an attachment of a cluster of fibers extending superolaterally from the tectorial membrane to the inner surface of the atlas, providing strong stabilization to the atlantoaxial joint. The existence of an extensive attachment onto the atlas was not supported by our findings. Attachments onto the atlas were not consistently present and were of insufficient magnitude to be ascribed any functional significance.

The occipital attachments of the tectorial membrane have variously been described in textbooks and published journal articles as the anterior edge of the foramen magnum, the clivus, or the base of the skull on the upper surface of the occipital bone. In each specimen examined in this series, the occipital attachment occurred beyond the foramen magnum. The attachments were diffuse and extensive. Lateral attachments onto the occiput frequently extended further than the hypoglossal canal, contradicting the statements of Romanes. As previously indicated by Tubbs et al., attachment around and even lateral to the jugular foramen was common to significant proportions of fibers originating in the lateral bands.

Both Cave and Fick provide descriptions of the lateral portions of the tectorial membrane, contributing to the medial aspects of the atlanto-occipital joints and the lateral atlantoaxial joints. Only two specimens in this series were noted to have attachments onto the atlanto-occipital joints. No specimen was observed to contribute to the lateral atlanto-axial joints. These findings indicate that attachments into these joints are inconsistent. When these connections are present, they are not considered to be of sufficient magnitude to be an important component in the stabilization of the medial aspects of the atlanto-occipital joints. These findings also differentiate the lateral components of the tectorial membrane from the accessory atlanto-axial ligaments which have been described as passing superolaterally from the body of the axis to substantially attach to the posterior aspect of the lateral mass of the atlas and the lateral atlanto-axial joints.
before terminating on the occipital bone.\textsuperscript{16,25,37,38} While some authors have considered the accessory atlanto-axial joint to be a lateral extension of the tectorial membrane,\textsuperscript{38} the differing course of the fibers, particularly as they approach their superior attachment, and the lack of demonstrated substantial attachment to the atlas and lateral atlanto-axial joints suggest these to be entirely separate structures.

The longitudinal orientation of the fibers of the tectorial membrane passing over the odontoid process and continuing anteriorly would support its previously described function as a limiting structure during cranio cervical flexion\textsuperscript{26,39} while accommodating vertical translation of the atlas upon the axis resulting from the biconvex nature of the articulation. The curved nature of the structure may suggest that the tectorial membrane potentially plays a role in limiting cranio cervical axial rotation. As the structure passes over the odontoid process, it angles anteriorly toward its insertion onto the internal surface of the occiput. This places both layers of the tectorial membrane into a more horizontal plane. The fibers of the superficial layer and the central band of the deeper layer diverge and arc laterally toward their broad semicircular insertion. The lateral bands of the deeper layer arc both medially and laterally. This potentially places all fibers in a position to resist rotation of the occiput with respect to the axis in either direction. These observations are consistent with the report of a previous biomechanical study where changes in the range of cranio cervical rotation were recorded before and after transection of the tectorial membrane.\textsuperscript{31} However, any role of the tectorial membrane in limiting cranio vertebral rotation based on descriptive anatomical observation remains speculative in the absence of specific investigation of any potential role through well-designed, experimental biomechanical analysis to appropriately examine whether such a limiting function exists.

CONCLUSIONS

The tectorial membrane is a complex and substantial structure containing a far greater tissue volume than the deeper ligaments of the cranio cervical complex. Clinical assessment of the structures of the cranio vertebral region is predicated on an understanding of their morphology. By enhancing knowledge of the structure of the tectorial membrane, an improved understanding of the potential contribution to instability created by injury to this structure might be achieved.

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Conflicts of interest
There are no conflicts of interest.

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