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ORIGINAL ARTICLE

Introducing the craniocervical Y-ligament

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Abstract

Purpose We examined the accessory atlantoaxial ligaments and found them to be a part of a complex ligamentous structure, which we named craniocervical Y-ligament with respect to its shape.

Methods The ligaments of the upper cervical spine were dissected in ten Thiel embalmed human cadavers. Origin and attachment of the Y-ligament were described and a detailed photo and video-documentation was carried out with the head in the neutral position, flexion, extension and rotation to study the ligament during these movements.

Results The Y-ligaments were found to be paired and symmetric in all specimens. The shape of the ligament is similar to an Y, its lateral arm connecting the atlas to the axis, its medial arm connecting the occipital bone to the axis, fusing with the two main ligaments, the alar and transverse ligaments. The lateral arm of the Y-ligament was found to be analogous to the accessory atlantoaxial ligament. During cervical flexion, both arms of the Y-ligament became taut while extension made the Y-ligaments relaxed. During rotation both Y-ligaments became taut, moving in the opposite directions in the sagittal plane while following the gliding movements of the lateral masses of the atlas.

Conclusions The craniocervical Y-ligament is a complex ligamentous structure and has a constant anatomy. Because of its shape and special arrangement, it probably plays a role in limiting both atlantooccipital and atlantoaxial movements. Acknowledgement of this ligamentous structure will help understand upper cervical stability. The present study should serve as a basis for future biomechanical and radiological studies.

Keywords Anatomy · Craniocervical junction · Accessory atlantoaxial ligament · Tectorial membrane · Alar ligament · Transverse atlantal ligament

Introduction

The ligaments of the craniocervical junction play an important role in preserving the stability of the region, and thus protecting the neural and vascular structures passing this junction. The main ligaments of the upper cervical spine, the transverse ligament and the alar ligaments have been well—and uniformly—described in the literature. On the contrary, the detailed anatomy of the tectorial membrane is still inconsistent [16] while the accessory atlantoaxial ligaments are scarcely mentioned in anatomy books [4, 10], even though both of these structures are known since more than 150 years [2]. There are only a few publications dealing with the anatomy, radiology and injury (avulsion fracture) of the accessory atlantoaxial ligament [11, 17, 18]. In this anatomical study, we found the accessory atlantoaxial ligament to be a part of a complex ligamentous structure, which was connecting the occiput with the upper two vertebras as well

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as the alar and the transverse ligaments. The Y-ligaments were located deep to the tectorial membrane and superficial to the alar and transverse ligament of the atlas when viewed from posterior. We named this complex ligamentous structure "craniocervical Y-ligament" (thereafter Y-ligament) based on its shape.

Materials and methods

We used ten human cadavers (mean age 75.4, range 61–85) to describe the detailed anatomy of the Y-ligament. The cadavers were embalmed according to Thiel, the arterial system was filled with coloured latex. The head together with the cervical spine was removed from the torsos before embalming. For the time of the preparation, the heads were fixed in a modified Halo fixation device in prone position while the cervical spine was free and could be moved manually simulating the movements of the cervical spine. A posterior approach to the craniocervical junction was made to expose the occiput and the posterior aspect of the cervical spine. The vertebral artery at its V3v and V3h segment was prepared and cut at V3h behind the lateral mass of the atlas [1]. The foramen magnum was enlarged posteriorly and the posterior arch of the atlas was removed. The dura mater, spinal cord and part of the brain were removed to gain access to the clivus and the upper cervical spine. To allow for easier measurement and preparation, the lamina and spinous process of the axis was partly or completely removed.

The tectorial membrane was visualized and its lateral borders prepared. The gap between the tectorial membrane and the origin of the Y-ligaments were developed at the level of the axis vertebral body. The tectorial membrane was divided here and prepared cranially where it was disconnected at its attachment from the clivus. The Y-ligament was defined by its origin on the postero-superior aspect of the axis vertebral body between the base of the dens and the superior articular surface of the axis, which could be easily identified. The Y-ligaments were prepared advancing in the cranial direction. The cruciform ligament and the alar ligaments were also prepared. Later on the superior and inferior longitudinal band of the cruciform ligament was removed. The dimensions of the Y-ligament were measured using an electronic caliper (Mannesmann, Germany). During the testing of the movements, the cervical spine was brought in flexion, extension, right and left rotation manually until the movement was stopped by the tension of the ligamentous and bony structures. The Y-ligament was cut close to its origin at the axis vertebral body. Its lateral and medial arms were separated and prepared to describe their contacts with the surrounding ligamentous structures and their bony attachments. Their length, thickness and width was measured with an electronic caliper. For the literature review PubMed (keyword: accessory atlantoaxial ligament, tectorial membrane) and classical anatomy textbooks as well as specific spine surgery textbooks were used.

The anatomic dissection was carried out using loupe magnification (Zeiss, magn.: 3.4). A detailed photo-documentation was carried out using a Canon 5D digital camera, the videos were made with a 4K Sony camera.

Results

The Y-ligaments were found bilaterally in every specimen. The Y-ligaments were located deep to the tectorial membrane and superficial to the alar and transverse ligament of the atlas when viewed from posterior. They were Y-shaped with a common base and two separate arms running cranially (Fig. 1). The base of the Y originated on the postero-superior aspect of the axis vertebral body between the base of the dens and the superior articular surface. The thickness of the ligament at the level of the atlantoaxial joint (base of the Y) in the transverse plane was 5.4 ± 0.37 mm and 5.2 ± 0.45 mm, while in the sagittal plane it was 2.3 ± 0.32 mm and 2.3 ± 0.27 mm on the right and left sides.

The medial arm of the Y (Fig. 2), forming the cranial extension of the Y-ligament was running cranially in a straight line from the origin on the axis vertebral body to the clivus. At the level of the dens, it was situated in the groove formed by the transverse ligament medially and the medial aspect of the lateral mass laterally. This ligament was partly covering the transverse and alar ligaments. It was connected with ligamentous slips to the lower margin of the transverse ligament and was blended with the posterosuperior aspect of the alar ligament. It was attached to the anterior margin of the foramen magnum and to the occipital condyle just above and posterior to the attachment of the alar ligament. The length of the medial arm was measured between the origin of the ligament on the posterior surface of the axis vertebral body and its attachment on the clivus. It measured 28.3 ± 1.6 mm and 28.4 ± 1.5 mm on the right and left sides, respectively.

The lateral arm of the Y (Fig. 3) appeared as a flat, triangulated ligament. It was attached to the medial aspect of the atlas lateral mass on a line starting from below the tubercle of the transverse ligament, up to the posteromedial margin of the superior articular facet. The mean length of the lateral arm was measured between the origin of the ligament on the posterior surface of the axis vertebral body and its attachment on the middle of the atlas lateral mass. Its length was 25.9 ± 1.3 mm and 25.9 ± 1.4 mm on the right and left sides, respectively.

During flexion of the craniocervical junction, both arms of the Y-ligament became taut while extension made the Y-ligament relaxed (Fig. 4a).

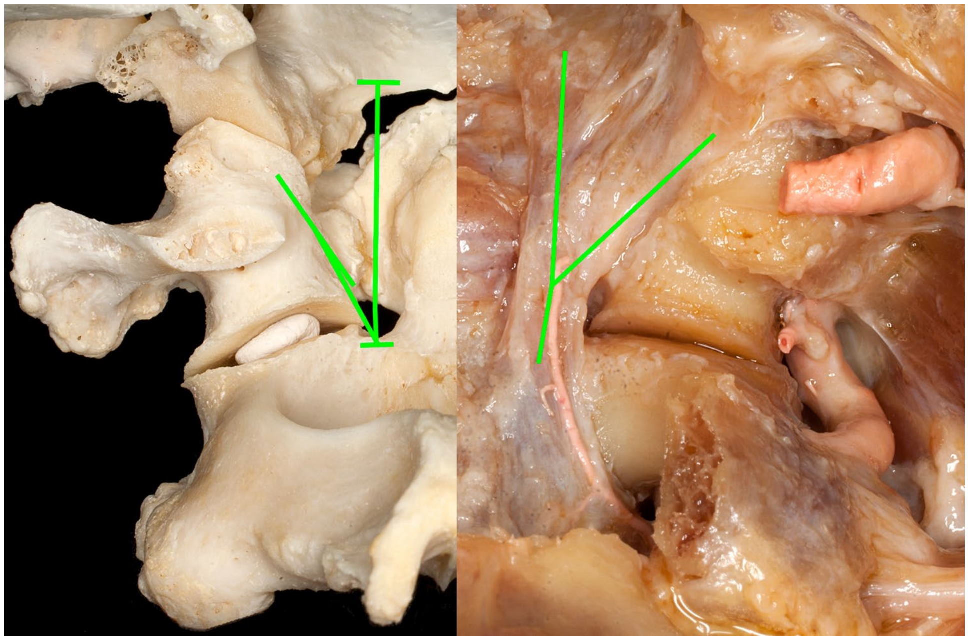

Fig. 1 Picture shows the origin and attachment of the Y-ligament on a bony specimen on the left side (posterior part of the occipital bone and posterior arch of the atlas are removed). The mirrored right side shows the ligament on a fixed specimen (besides the posterior part of the occipital bone and posterior arch of the atlas, the lamina of the axis is also removed)

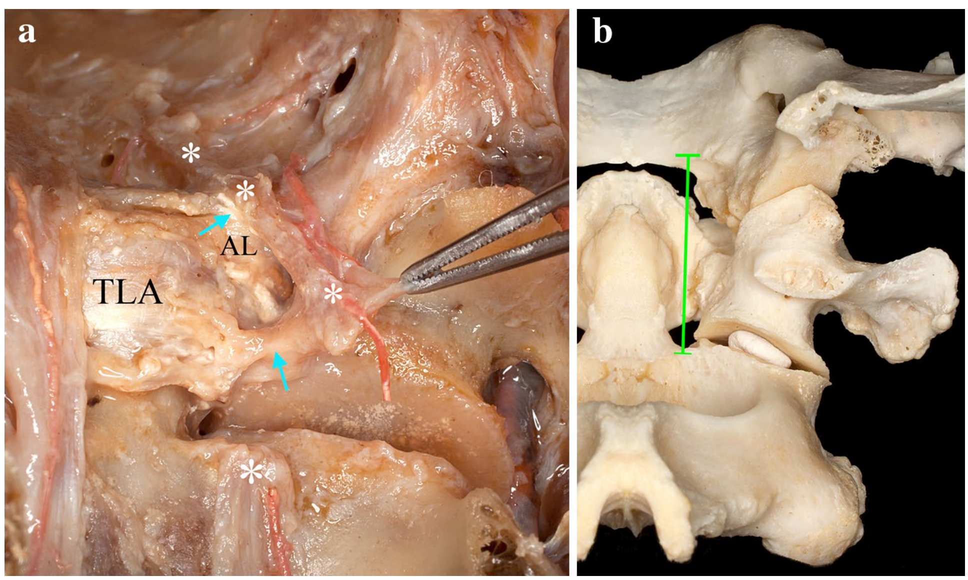

Fig. 2 **a** Shows the medial arm of the Y-ligament (marked with white asterisk), which was divided just cranial to its attachment and lifted with a forceps. The transverse ligament of the atlas (TLA) and alar ligament (AL) is marked. Their connections with the medial arm of the Y-ligament are marked with the arrows. **b** Shows the origin and attachment of the medial arm on a bony specimen

During axial rotation of the craniocervical junction, both Y-ligaments became taut, moving in the opposite directions in the sagittal plane while following the gliding movements of the lateral masses of the atlas (Fig. 4b).

Discussion

While the early anatomic studies of the nineteenth century [2, 7, 14, 15] described the anatomy of the cruciform and alar ligaments uniformly, there was no consensus on the detailed anatomy of the tectorial membrane and the accessory atlantoaxial ligaments. Anatomic descriptions of the tectorial membrane are still inconsistent regarding its origin, thickness and layers [16].

The actual anatomy books describe the tectorial membrane as the cranial extension of the posterior longitudinal ligament, attached to the body of the axis caudally and the occipital bone cranially [6, 9]. Lang described the deep portion of the tectorial membrane joining the basilar part of the occipital bone above and the posterior plane of the body of the axis below [10]. The classical anatomy book of Fick [7] divided the tectorial membrane into three parts, one medial and two lateral bands. According to Fick the medial band consists of straight fibers running vertically, is about 1 cm wide and covers the posterior aspect of the

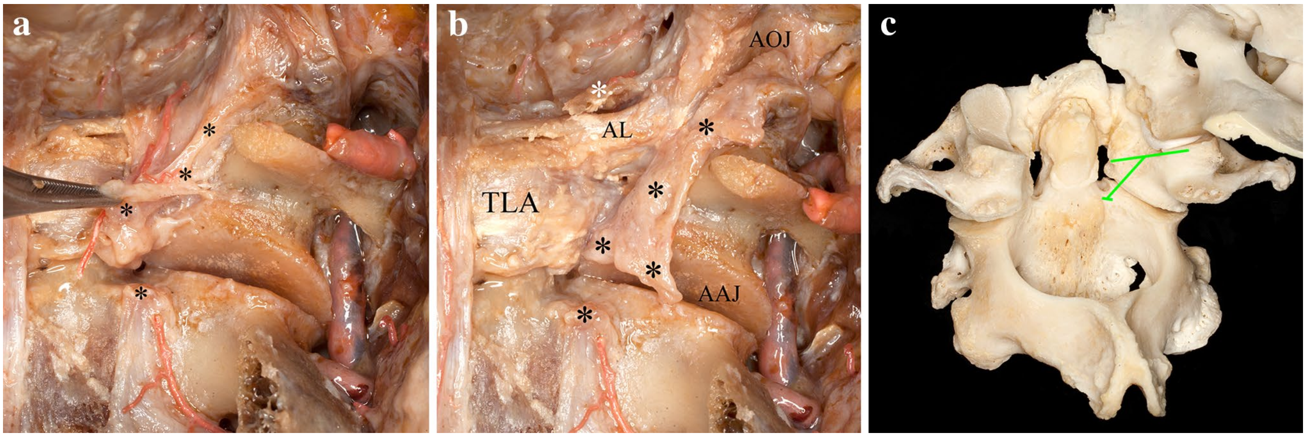

Fig. 3 **a, b** Shows the lateral arm of the Y-ligament (marked with black asterisks), which was divided just cranial to its attachment and lifted with a forceps in a and also separated from the cut medial arm (white asterisk) on **b. c** Shows the origin and attachment of the lateral arm on a bony specimen. *TLA* transverse ligament of the atlas, *AL* alar ligament, *AOJ* atlantooccipital joint, *AAJ* atlantoaxial joint

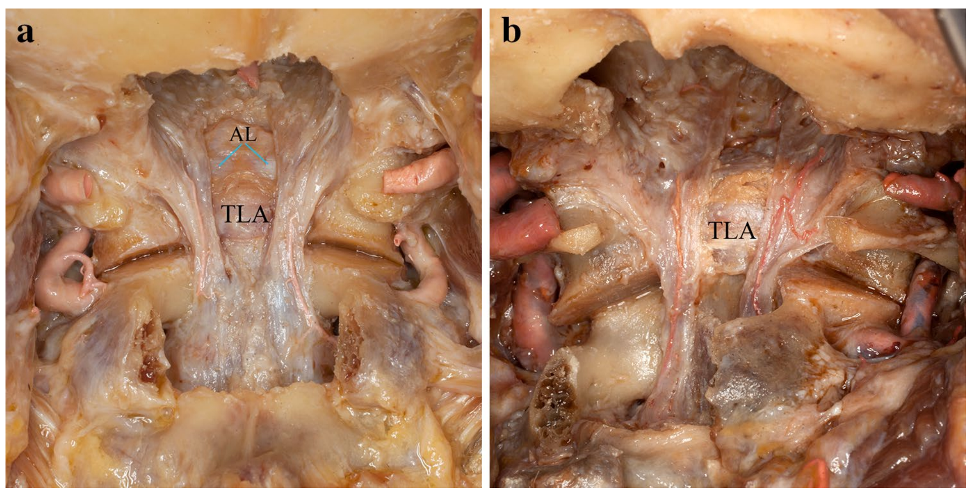

Fig. 4 Pictures showing the craniocervical junction during flexion (**a**) and left rotation (**b**)

dens overhanging on the sides. The two lateral parts are diverging running cranially consisting of stronger fibers, which support the joint capsules of the atlantooccipital and atlantoaxial joints. Some specially strong fibers are going from the vertebral body of the axis to the medial aspect of the lateral mass of the atlas [7] and were regarded as deep layers of the tectorial membrane [13]. According to some authors, these same ligaments were considered as separate ligaments and they became known as the accessory atlanto-axial ligaments. They were first described by Arnold in 1851 (Arnold's ligament) as the lower side-ligaments of the dens (ligamenta lateralia inferiora dentis epistrophei) [2]. Arnold described the attachment point of this ligament on the atlas lateral mass as "a small tubercle on the medial aspect of the inner-side on the inferior articular process of the atlas". This description is probably incorrect as the only tubercle on the medial aspect of the atlas lateral mass is the tubercle serving as attachment point for the transverse ligament. Later anatomy books describe the accessory atlantoaxial ligament as a strengthening ligament of the atlantoaxial joint [3, 5, 8]. The accessory atlantoaxial ligament was considered as an independent ligament connecting not only the axis to the atlas but also to the occipital bone, and thus named accessory atlantal-axial-occipital ligament by Tubbs, its size being 29 mm long and 5.5 mm wide based on a cadaver study [17]. One radiologic study on the accessory atlantoaxial ligament measured the mean dimensions of the atlantoaxial segment of the ligament 2.8 × 1.8 mm on MRIs, the thinner atlantooccipital part's mean dimensions were 1.6 × 1.2 mm on the right and 1.8 × 1.4 mm on the left side [18]. The extent of the ligament was similar to our results for the lateral arm of the Y-ligament.

We found two possible explanations for the different descriptions of the tectorial membrane and the accessory atlantoaxial ligaments. First, preparative work at this level, including removal of the tectorial membrane, preparation of the ligaments connecting the atlanto-ocipital and atlantoaxial joints is quite difficult. There are only a few publications based on anatomical preparations [10, 17]. The preparative anatomy has nowadays lost its importance and so the number of clinical anatomy labs where detailed anatomical preparations could be performed is decreasing. The illustrations of the newer anatomy textbooks are not based on anatomic preparations any more but are mostly simplified and made by copying the existing anatomy books, which results in considerable distortion and information loss.

Second, we changed the preparation-technique and instead of removing the tectorial membrane from the clivus and dissecting it caudally, we divided the tectorial membrane behind the body of the axis (between the origin of the Y-ligament at the base of the dens and the inferior endplate of the axis vertebra) and prepared it cranially up to its attachment on the clivus. This way the medial arm of the Y-ligament was preserved. Anatomists before were mostly using the top-down preparation technique and probably removed the medial arm of the Y-ligament together with the fibers of the tectorial membrane. The lateral arm of the Y-ligament was preserved using the "top-down" technique because of its attachment on the atlas and led to the description of the accessory atlantoaxial ligament.

Comparing our present work with the previous anatomical studies, the lateral arm of the Y-ligament is equivalent with the accessory atlantoaxial ligament, while the medial arm of the Y-ligament was probably considered by previous authors as the deep layer of the tectorial membrane. However, there are certain reasons why we would suggest regarding the Y-ligament as a separate entity (or we need to deny the accessory atlantoaxial ligament as separate anatomic structure too). First, medial and lateral arms of the Y-ligament have the same origin on the axis. This was the most important definition of the Y-ligament in this study. Second, the Y-ligament attached more laterally on the occipital condyle than the hypoglossal canal, which is universally accepted as the lateral border for the attachment of the tectorial membrane. Third, when the tectorial membrane is viewed from posterior, the lateral arm of the Y-ligament is visible below and laterally to the lateral borders of the tectorial membrane at the level of the lateral mass of the atlas.

Probably the main function of the Y-ligament together with the alar ligaments is to restrict rotation in the atlantoaxial joint while flexion is limited by both arms of the Y-ligament in both the atlantooccipital and atlantoaxial joints. Up to now, the exact function and clinical importance of the Y-ligament are unknown. Future biomechanical studies are planned to define to what extent this ligament contributes to the stability of the craniocervical junction.

We found a branch of the vertebral artery entering the C2–3 foramen and running cranially on the Y-ligament, deep to the tectorial membrane in our specimens. This finding was already mentioned by Sherk and Parke [12]. Tubbs et al. were not able to see such vessels in their study, in their study the vessels were not injected and filled which makes the preparation of the vessels of this diameter very difficult [17].

Conclusion

The craniocervical Y-ligament has a constant anatomy. The shape of the ligament is similar to an Y, its lateral arm connecting the atlas to the axis, its medial arm connecting the occipital bone to the axis, fusing with the other two main ligamens, the alar and transverse ligament of the atlas on its way. Because of its shape and special arrangement, it should play a role in limiting both atlantooccipital and atlantoaxial movements. Acknowledgement of this ligamentous structure will probably rewrite our present knowledge on upper cervical stability. The present study should serve as a basis for future anatomical, radiological and biomechanical studies.

Author contributions G Bodon: project development, data collection and management, manuscript writing, data analysis. K. Kiraly: project development, data collection and management, manuscript editing, data analysis. M. Tunyogi-Csapo: manuscript writing and editing. B. Hirt: manuscript writing and editing. H.J. Wilke: manuscript writing and editing. J. Harms: project development, manuscript writing and editing. L. Patonay: project development, manuscript writing and editing.

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Compliance with ethical standards

Conflict of interest Authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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