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Cervical and High Thoracic Ligamentum Flavum Frequently Fails to Fuse in the Midline

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Background: **Cervical and high thoracic epidural anesthesia and analgesia have gained increasing importance in the treatment of painful conditions and as components of anesthetics for cardiac and breast surgery. In contrast to the hanging-drop technique, the loss-of-resistance technique is thought to rely on the penetration of the ligamentum flavum. However, the exact morphology of the ligamentum flavum at different vertebral levels remains controversial. Therefore, the aim of this study was to investigate the incidence and morphology of cervical and high thoracic ligamentum flavum mid-line gaps in embalmed cadavers.**

Methods: **Vertebral column specimens were obtained from 52 human cadavers. On each dissected level, ligamentum flavum mid-line gaps were recorded and evaluated with respect to shape and size.**

Results: **The following variations were encountered: complete fusion in the mid-line, mid-line fusion with a gap in the caudal part, mid-line gap, and mid-line gap with widened caudal end. The incidence of mid-line gaps at the following levels was: C3–C4: 66%, C4–C5: 58%, C5–C6: 74%, C6–C7: 64%, C7–T1: 51%, Th1–Th2: 21%, Th2–Th3: 11%, Th3–Th4: 4%, Th4–Th5: 2%, and Th5–Th6: 2%. The mean width of mid-line gaps was 1.0 ± 0.3 mm.**

Conclusions: **In conclusion, the present study shows that gaps in the ligamenta flava are frequent at cervical and high thoracic levels but become rare at the T3/T4 level and below, such that one cannot always rely on the ligamentum flavum as a perceptible barrier to epidural needle placement at these levels.**

CERVICAL and high thoracic epidural anesthesia and analgesia have gained increasing importance in the performance of cardiac[1,2] and breast[3,4] surgery. The most important anatomic landmarks for epidural anesthesia are the spinal column and adjoining connective tissue, especially the spinal ligaments (ligamentum flavum and interspinous and supraspinous ligaments). There are no direct means of evaluating these structures, because superficial palpation examines only the supraspinous ligament.

A frequently encountered problem when administering epidural anesthesia is failure to identify the epidural space. This has been reported to occur more frequently at the lumbar level when the median rather than the paramedian approach was used.[5] However, corresponding investigations at higher levels are lacking to date. At the cervical level, two methods are commonly used to confirm entry into the epidural space. The hanging-drop technique relies on the subatmospheric epidural pressure to draw solution into the needle hub. In contrast, the loss-of-resistance method relies on detection of the ability to inject solution as the needle tip penetrates the ligamentum flavum. However, the exact morphology of the ligamentum flavum at different vertebral levels remains controversial,[6–8] even though the potential impact on puncture technique is clear.[9] Specifically, it has been pointed out that the cervical ligamenta flavum may be discontinuous in the mid-line in up to 50% of cases,[8] which may allow unrecognized entry into the spinal canal and excessive needle advancement with subsequent dural puncture or cord damage. Therefore, the aim of this study was to investigate the incidence and variable morphology of cervical and high thoracic ligamentum flavum mid-line gaps in embalmed cadavers.

Materials and Methods

After receiving institutional approval, vertebral column specimens were obtained from 52 human cadavers that were the legal property of the Institute of Anatomy, Histology, and Embryology, University of Innsbruck, Innsbruck, Austria. Cadavers were preserved in a mixture of formaldehyde and carbol as previously described.[10]

Vertebral arches were detached at the pedicles of C3–T5 and removed en bloc. The dural sac and epidural connective tissue were removed by blunt dissection, and the ligamentum flavum was directly examined from anteriorly.

At each dissected level, ligamentum flavum mid-line gaps were recorded and evaluated with respect to shape and size. Size measurements were undertaken by means of a caliper with an accuracy of 0.2 mm. Summarized results are given as mean ± SD.

Results

The tissues within the spinal canal were easily removed, with only minimal adherence between adipose tissue and the inner surface of the ligamentum flavum. The ligamentum flavum appeared as an elastic structure easily distinguished by its yellowish color and smooth surface. Gaps due to lack of fusion in the mid-line were readily apparent by gentle probing. The following variations were encountered: complete fusion of the ligamen-

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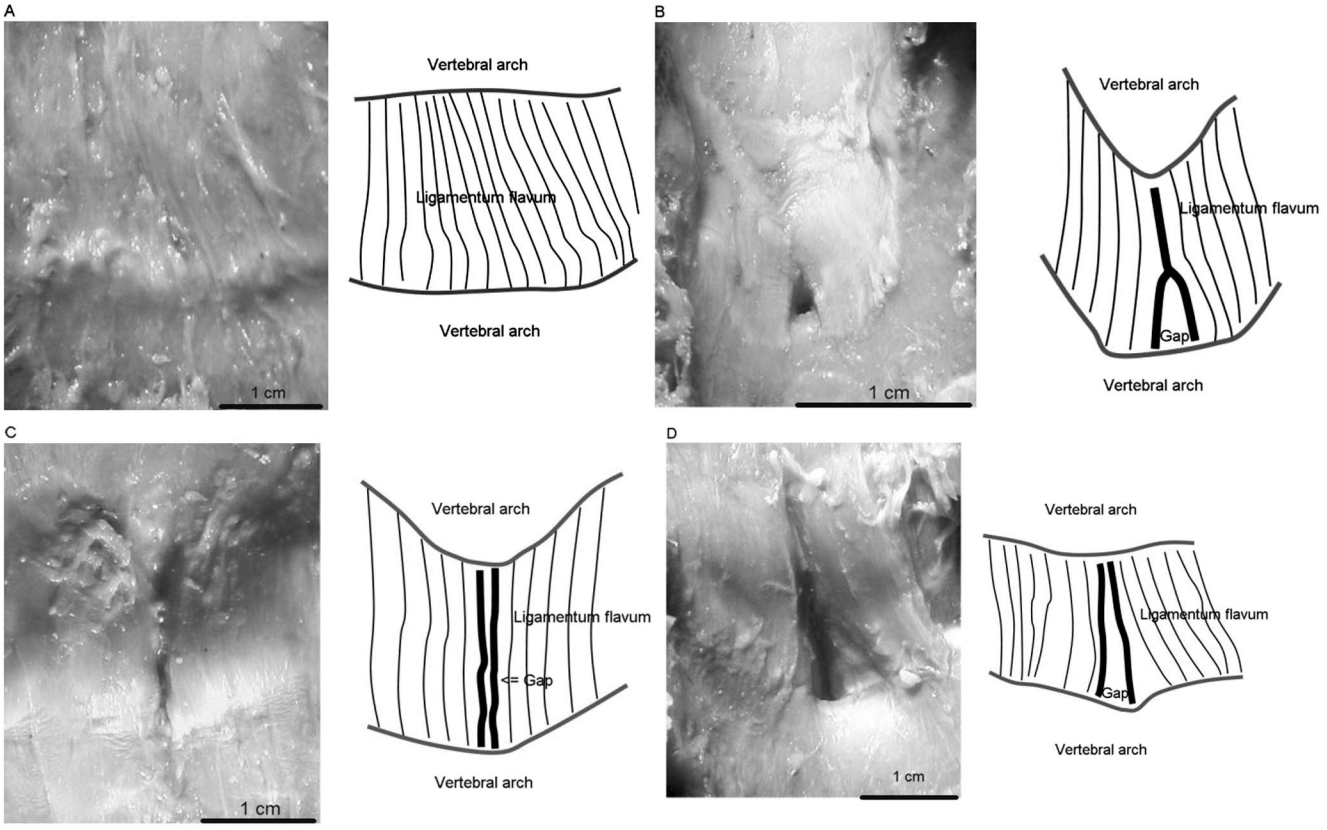

Fig. 1. Variations in ligamentum flavum morphology. The view from anteriorly depicts the upper and lower vertebral arches. The ligamentum flavum, which may fuse in the mid-line (*A*), or may feature a caudal gap for the passage of vessels (*B*) or a continuous gap (*C*), which may widen toward the caudal end (*D*). The *bar* in lower right corner indicates scale of 1 cm.

tum flavum in the mid-line, mid-line fusion with a gap in the caudal third of the ligamentum flavum, mid-line gap throughout the entire height of the ligamentum flavum, and mid-line gap that was wider in the caudal third of the ligamentum flavum. The caudal opening was most often occupied by veins connecting the posterior external vertebral venous plexus with the posterior internal vertebral venous plexus (fig. 1). Of the 52 harvested specimens, 41 featured at least one type of gap at any location. Twice, a small gap in the cranial third of a ligamentum flavum was encountered. For evaluation of frequency, these two specimens are included in the group featuring gaps in the lower third (table 1). The mean width of mid-line gaps was 1.0 ± 0.3 mm.

Detailed incidences of gap variations are given in table 1. A number of specimens damaged during harvesting

Table 1. Variations of Ligamentum Flavum Anatomy at the Investigated Levels

	C3/C4	C4/C5	C5/C6	C6/C7	C7/T1	T1/T2	T2/T3	T3/T4	T4/T5	T5/T6
	4	9	10	14	12	16	18	30	41	41
	0	2	1	1	8	22	24	19	8	8
	8	14	27	27	16	6	3	2	1	1
	0	1	1	0	7	4	2	0	0	0
Gaps/total	8/12 (66%)	17/26 (65%)	29/39 (74%)	28/42 (66%)	31/43 (68%)	32/48 (66%)	29/47 (61%)	21/51 (41%)	9/50 (18%)	9/50 (18%)

Row 1 lists the number of specimens with complete fusion, row 2 lists those with incomplete fusion with a gap in the caudal third, row 3 represents those with mid-line gaps throughout the entire height, and row 4 depicts those with mid-line gaps enlarging in the caudal third. Combined incidences of rows 2–4 are summarized as "total."

from the cadavers or during dissection were excluded from analysis.

Discussion

The present study investigated the incidence and shape of cervical and high thoracic ligamentum flavum mid-line gaps. The main result is that depending on the vertebral level, up to 74% of ligamenta flava are discontinuous in the mid-line. The incidence of gaps was highest in the cervical region and decreased toward the thoracic region.

The ligamentum flavum is a structure composed of elastic fibers. At each level, it inserts on the inferior and anteroinferior aspects of the respective cranial vertebral arch and on the superior edge and posterosuperior surface of the respective caudal lamina.[11] Developmentally, the ligamentum flavum is a paired structure formed during the tenth to twelfth week of gestation.[12] Viewed in axial section, it extends from the roots of the articular processes to the mid-line, reinforcing the anterior capsules of the zygapophyseal joints. Intervals for the passage of veins connecting the posterior external vertebral venous plexus with the posterior internal vertebral venous plexus have been described.[11] The left and right parts of the ligamentum flavum fuse inconsistently in the mid-line, although the exact incidence at the cervical and upper thoracic levels has not previously been determined. The incidence of failure to fuse in the mid-line is reportedly approximately 50% in the cervical region,[8] which is markedly more frequent than previous investigations of the lumbar region suggested.[13] The ligamenta are thinnest at the cervical and high thoracic levels. Their static and dynamic functions are to preserve upright posture and to act synergistically with the autochthonous muscles of the back in regaining the upright position after spine flexion.[11]

Direct dissection has been described as a valid tool in the investigation of spinal ligament anatomy and function.[14,15] Furthermore, results from high-resolution imaging studies of the ligamentum flavum at the lumbar level and dissection studies yielded comparable results concerning the incidence of mid-line gaps.[8,16] The exact incidence of mid-line gaps in lower cervical and high thoracic ligamenta flava has been controversially discussed. Panjabi *et al.*[17] described the ligaments to be continuous in the mid-line in all instances in a cadaver study dissecting only six specimens. A study of 28 cadavers using cryomicrotomy found fusion of the cervical ligamenta flava "in about half of cases" and characteristic gaps in the mid-line through which veins enter the epidural space.[8] Results of the present study support and substantially expand these findings, in as much as the exact morphology, size, and frequency have been described. It is noteworthy that there is considerable variation in the incidence of mid-line gaps when comparing cervical and upper thoracic intervertebral spaces. At the cervical level, the present study could demonstrate an incidence of mid-line gaps throughout the entire length of the ligamentum flavum of more than 50%, whereas the thoracic levels examined featured a much lower incidence (2–20%) of mid-line gaps. Frequently, gaps in the lower third of the upper thoracic ligamentum flavum were observed, which were occupied by vessels connecting the aforementioned venous plexuses. The assumption that a cervical mid-line gap between the right and left parts of the ligamentum flavum represents the natural state[8] is, at least at the cervical level, supported by findings of the present study.

Absence of a continuous ligamentous arch formed by the ligamenta flava may imply that the actual loss of resistance is indeed brought about by the supraspinous and interspinous ligaments.[8,9] In contrast to the ligamentum flavum, however, these ligaments are composed of collagenous fibers. Therefore, the distinct elastic resistance offered by the ligamentum flavum before entering the epidural space when using the loss-of-resistance technique may be blunted or even absent. The size and elasticity of the ligamentum flavum, in combination with mid-line gaps exceeding sizes of 1 mm, may mean that when using the mid-line approach, the gaps could be responsible for a failure to recognize a loss of resistance in some patients.

Finally, some potential limitations of the present study should be addressed. The clinical implications of our findings remain to be ascertained in studies identifying the frequency of entering the subarachnoid space without penetrating the ligamentum flavum in cervical epidural or high thoracic anesthesia. The ligamentum flavum is a tough tissue that withstands displacement during dissection. However, removal of the posterior elements from the vertebral column may have altered the overall degree of tension of the ligamenta flava. We cannot eliminate a potential artifact resulting from the embalming or dissection process, but this is unlikely to be a significant factor, because studies on nonembalmed material yielded similar findings.[8] Furthermore, we performed dissections with great care so as to avoid any damage to the ligamentum flavum; if such damage was noted, the specimen was excluded from measurement.

In conclusion, the present study shows that gaps in the ligamenta flavum are frequent at the cervical and high thoracic levels but become rare at the T3/T4 level and below, such that one cannot always rely on the ligamentum flavum as a perceptible barrier to epidural needle placement at these levels.

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