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ORIGINAL COMMUNICATION

Microsurgical Anatomy of the Denticulate Ligaments and Their Relationship with the Axilla of the Spinal Nerve Roots

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The denticulate ligaments (DL), 20 or 21 pairs of meningeal extensions, spread from the lateral aspect of the spinal cord to the internal aspect of the spinal dura mater. The aim of this study is to define the specific relationship of the DL with adjacent axilla of the spinal nerve roots and to investigate the anatomical features of the DLs and their variations. The topographical anatomy of the DLs and their relationships with the adjacent axilla of the spinal nerve roots was examined on 16 formalin-fixed adult cadaveric spinal cords. The distances from the dural attachment of the DL to the axilla of the superior and inferior spinal nerve roots were measured bilaterally at every spinal level. Also the distances from the dural attachment of the DL to the lateral aspect of the spinal cord were measured bilaterally. Cervical DLs showed a triangular shape, while in the thoracic segment the ligament changes the shape to "Y." Also the most caudal DL was identified to be at the L1–2 level. Our study revealed that the distances from the dural attachment of the DL to the superior and inferior spinal nerve root axilla were different at the cervical, upper thoracic and the lower thoracic segments. Both distances to the superior and inferior spinal nerve root axilla were shown to increase from cervical to lower thoracic segments. This study provides a detailed anatomy of the DLs and their relationship with the adjacent spinal nerve root axilla. Clin. Anat. 27:733–737, 2014.

Key words: anatomy; denticulate ligament; spinal nerve roots

INTRODUCTION

Johann Jacob Huber (1707–1778) was first to describe and depict the denticulate ligament (ligamentum denticulatum) (DL) (Rengachary et al., 2008). The DLs, 20 or 21 pairs of meningeal extensions, spread from the lateral aspect of the spinal cord to the internal aspect of the spinal dura mater (Epstein, 1967; Tubbs et al., 2011). The dorsal and ventral nerve rootlets were separated from each other by the DL further dividing the spinal canal into posterior and anterior compartments (Tubbs et al., 2001).

Denticulate ligament has clear role in providing stabilization of the spinal cord within the vertebral column (Tubbs et al., 2001). Furthermore, during posterior approaches to the anteriorly or anterolaterally located intradural extramedullary spinal cord lesions, the DLs have been shown to be an anatomical landmark (Lu and Lawton, 2010; Moon et al., 2010;

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Angevine et al., 2011; Joaquim et al., 2012). During these surgeries identification of the site of the attachment is mandatory, dividing the ligament or ligaments will further help surgeon to mobilize spinal cord providing access to the lesion. The DLs are also used as important landmarks during cordotomies to localize spinal pathways (Krol and Arbit, 1993).

The aim of this study is to define the specific relationships of the DLs with adjacent axilla of the spinal nerve roots and to investigate the anatomical features of the DLs and their variations.

MATERIAL AND METHODS

The topographical anatomy of the DLs and their relationships with the adjacent axilla of the spinal nerve roots were examined on 16 formalin-fixed adult cadaveric spinal cords. Of these, five were female and 11 were male. The age at death ranged from 49 to 82 (mean 62.6 ± 9.7) years old. Spinal cords with any sign of traumatic or nontraumatic spinal pathology, or the one that belonged to patients with any neurological symptoms related to the spinal cords, spinal nerves, or severe vertebral deformities were excluded from the study.

In the supine position vertebrectomies extending from C2 to S2 were performed by using an autopsy saw (Stryker Instruments, Kalamazoo, MI). Following vertebrectomies, to identify the exact spinal cord levels the S1 spinal nerve roots were identified and marked bilaterally with silk sutures in situ. The spinal cord with its dura and spinal nerve roots, which are approximately 2 cm in length, were then removed from the fresh cadavers and fixed in formalin for 1 week. After fixation, the dura was opened along the posterior midline and all the DLs along the spinal cord were exposed. Because of the routine autopsy protocol, where the brain and the brainstem were removed before the spinal cord, first two DLs (cranial and C1–2) could not be studied. The presence of the DLs and their anatomical features were documented at all spinal levels. Microsurgical examinations and measurements were performed under a surgical microscope (Leica Wild M 695, Leica Microsystems, Wetzlar, Germany) at magnifications ranging between 3 to 40×. Measurements were taken with Fisherbrand traceable Digital Calipers (Fisher Scientific, Pittsburgh, PA).

The distances from the dural attachment of the DL to the axilla of the superior (DSN) and inferior (DIN) spinal nerve roots were measured bilaterally at every level. Also, the distances from the dural attachment to the lateral aspect of the spinal cord (DIST-R and DIST-L) were measured bilaterally at every level (Fig. 1).

Statistical Analysis

All statistical procedures were performed using SAS (SAS Institute, Release 9.3, Cary, NC). Effects of segments on DSN, DIN and DIST were tested for significance using an ANCOVA by PROC GLM. The potentially confounding effects of age and gender were addressed by fitting age as a covariate in the linear models. The data were reported as least square means ± standard deviation. Differences were considered significant at $P < 0.05$. The least squares means were compared by use of the PDIFF (probability of differences) statement in SAS.

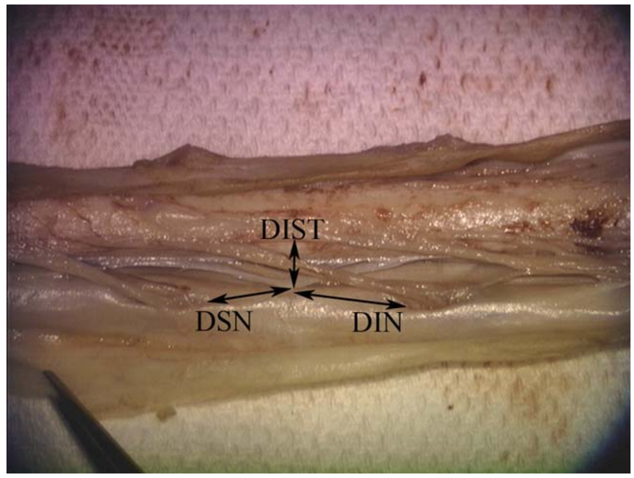

Fig. 1. Microphotograph demonstrating the measurements taken for the study. (DSN: the distance from the dural attachment of the DL to the axilla of the superior spinal nerve root; DIN: the distance from the dural attachment of the DL to the axilla of the inferior spinal nerve root; DIST: the distance from the dural attachment to the lateral aspect of the spinal cord).

RESULTS

Gross Anatomy

Denticulate ligaments were examined from C2–3 segment to L1–2 segment.

No DL was observed below the level of L1–2. The most striking observation was that cervical DLs showed a triangular shape (Fig. 2). In the thoracic segment the shape of the ligament changed to "Y" shape (Fig. 3). The DLs were not always symmetric and may be missing in some levels (Fig. 4). We observed that the DLs were missing in eight levels. Of the 16 cadavers, only five (32.2%) had DLs in the L1–2 level (Fig. 5). One duplicated DL was observed in the T7–8 level.

Two enlargements of the spinal cord, one at the level of C3–T2 (cervical enlargement) and the other one at the level of T9–L1 (lumbosacral enlargement) were observed in all the specimens.

The Distance From the Dural Attachment Side to the Axilla of the Superior Spinal Nerve Root

The mean values of the distances from the dural attachment side of the DL to the axilla of the superior spinal nerve root both for the right (DSN-R) and left (DSN-L) were summarized in Table 1.

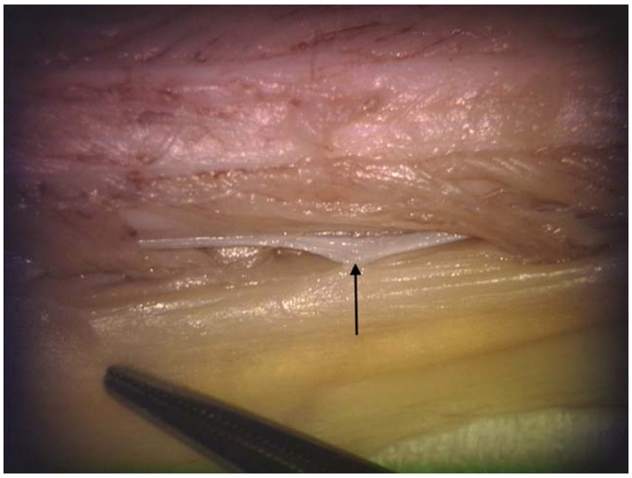

Fig. 2. Microphotograph demonstrating a triangular shaped denticulate ligament (arrow) at the C6–7 level.

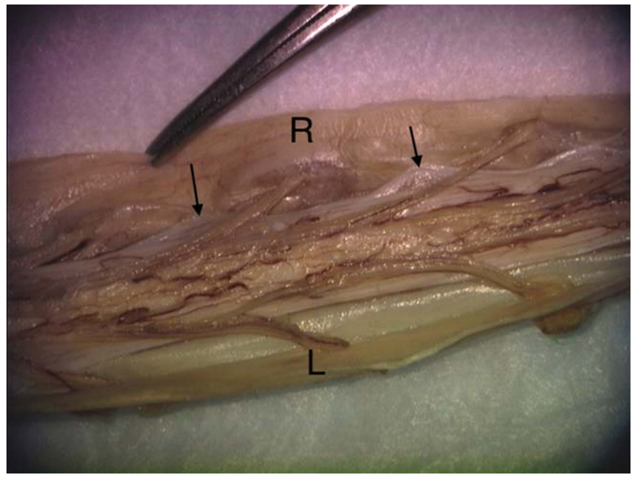

Fig. 4. Microphotograph demonstrating the missing denticulate ligaments in the left side at the T2–3, T3–4 and T5–6 levels. Arrows pointing denticulate ligaments in the right side. R: right; L:left.

In the cervical segment (C2–3 to C8–T1), mean DSN-R and DSN-L were 5.9 ± 1.7 mm and 5.8 ± 1.41 mm, respectively. In the upper thoracic segment (T1–2 to T6–7) mean DSN-R and DSN-L were 8.9 ± 2.6 mm and 8.6 ± 1.4 mm, respectively. In the lower thoracic segment (T7–8 to T12–L1) mean DSN-R and DSN-L were 10.7 ± 2.9 mm and 10.3 ± 2.8 mm, respectively. There was an increase along the cervical segment to lower thoracic segment, which was statistically significant ($P < 0.001$). The DSN-R and DSN-L were determined to be heterogeneous among the levels.

Neither the cervical nor the lumbosacral enlargements of the spinal cord caused statistically significant difference in means of DSN-R and DSN-L.

The Distance From the Dural Attachment Side to the Axilla of the Inferior Spinal Nerve Root

The mean values of the distances from the dural attachment side of the DL to the axilla of the inferior spinal nerve root both for the right (DIN-R) and left (DIN-L) were summarized in Table 1.

In the cervical segment (C2–3 to C8–T1), mean DIN-R and DIN-L were 6.1 ± 1.8 mm and 5.8 ± 1.6 mm, respectively. In the upper thoracic segment (T1–2 to T6–7) mean DIN-R and DIN-L were 8.1 ± 2.8 mm and 8.1 ± 2.6 mm, respectively. In the lower thoracic segment (T7–8 to T12–L1) mean DIN-R and DIN-L were 11.2 ± 3.9 mm and 11.1 ± 4.0 mm, respectively.

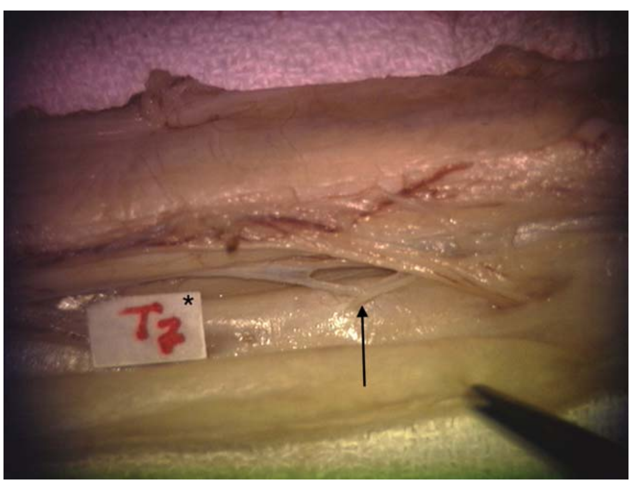

Fig. 3. Microphotograph demonstrating a "Y" shaped denticulate ligament (arrow) at the T7–8 level. *Paper sticker used to label T7 spinal nerve root.

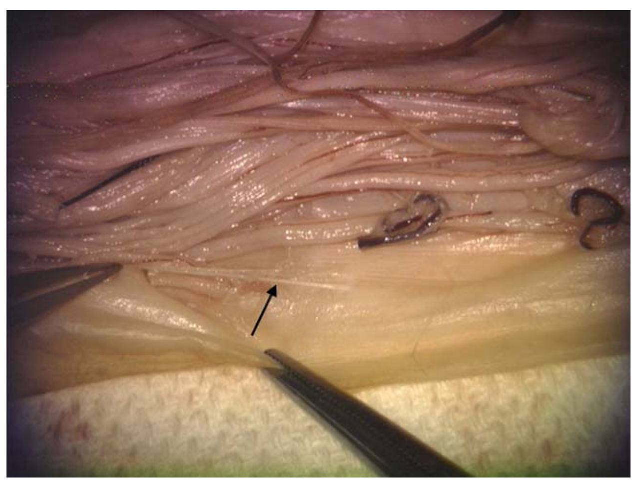

Fig. 5. Microphotograph demonstrating denticulate ligament located at the L1–2 level.

TABLE 1. The Summary of the Measurements

Level	DSN-R (mean ± SD) (mm)	DSN-L (mean ± SD) (mm)	DIN-R (mean ± SD) (mm)	DIN-L (mean ± SD) (mm)	DIST-R (mean ± SD) (mm)	DIST-L (mean ± SD) (mm)
C2–3	5.3 ± 1.4	5.9 ± 1.4	7.4±2.7	5.3 ± 1.4	2.7 ± 0.5	2.7 ± 0.6
C3–4	6.4 ± 2.1	6.0 ± 1.6	5.5 ± 1.5	5.1 ± 1.1	2.9 ± 0.6	2.4 ± 0.4
C4–5	5.9 ± 1.6	5.9 ± 1.1	5.6 ± 1.8	5.2 ± 1.1	2.6 ± 0.4	2.3 ± 0.5
C5–6	5.1 ± 1.6	5.3 ± 1.1	6.1 ± 1.2	5.8 ± 1.4	2.3 ± 0.4	2.4 ± 0.4
C6–7	5.0 ± 1.2	5.2 ± 1.3	6.5 ± 1.5	6.8 ± 1.8	2.1 ± 0.4	2.1 ± 0.5
C7–8	6.5 ± 1.5	6.3 ± 1.4	5.2 ± 1.3	6.0 ± 1.2	2.5 ± 0.4	2.3 ± 0.6
C8–T1	7.0 ± 1.9	6.2 ± 1.5	6.0 ± 1.7	6.8 ± 2.3	2.3 ± 0.4	2.3 ± 0.4
T1–2	8.3 ± 2.9	8.5 ± 3.2	6.2 ± 2.6	5.8 ± 1.3	2.6 ± 0.6	2.5 ± 0.5
T2–3	9.6 ± 2.7	9.0 ± 2.1	7.3 ± 3.2	7.4 ± 2.7	2.6 ± 0.6	2.3 ± 0.5
T3–4	8.2 ± 2.5	8.7 ± 2.9	9.0 ± 3.4	8.1 ± 2.3	2.3 ± 0.6	2.3 ± 0.4
T4–5	9.7 ± 1.8	8.9 ± 3.3	8.4 ± 2.5	9.2 ± 3.3	2.5 ± 0.6	2.5 ± 0.6
T5–6	8.9 ± 2.4	8.4 ± 2.0	9.0 ± 2.4	9.1 ± 2.2	2.2 ± 0.3	2.2 ± 0.2
T6–7	8.6 ± 2.9	8.3 ± 1.5	8.5 ± 1.8	9.4 ± 2.0	2.4 ± 0.5	2.3 ± 0.3
T7–8	9.2 ± 2.7	8.9 ± 1.6	10.0 ± 2.7	9.1 ± 2.4	2.6 ± 0.8	2.4 ± 0.5
T8–9	11.4 ± 2.5	10.5 ± 3.0	8.5 ± 2.1	9.2 ± 2.5	2.3 ± 0.4	2.5 ± 0.5
T9–10	10.3 ± 2.8	10.3 ± 3.1	9.7 ± 2.9	9.6 ± 2.9	2.3 ± 0.4	2.5 ± 0.4
T10–11	11.3 ± 2.7	11.0 ± 2.5	10.9 ± 2.6	10.0 ± 2.8	2.5 ± 0.4	2.4 ± 0.4
T11–12	12.7 ± 3.3	12.5 ± 2.6	12.8 ± 4.0	12.9 ± 5.0	2.7 ± 0.6	2.4 ± 0.4
T12–L1	9.5 ± 2.5	8.7 ± 2.5	15.4 ± 4.3	15.7 ± 2.9	3.1 ± 1.1	3.2 ± 0.8
L1–2	7.2 ± 1.5	5.3 ± 1.1	18 ± 2.4	20.3 ± 4.0	3.7 ± 2.0	3.9 ± 1.8

DSN-R: The distance from dural attachment side to the superior spinal nerve root axilla in the right side; DSN-L: The distance from dural attachment side to the superior spinal nerve root axilla in the left side; DIN-R: The distance from dural attachment side to the inferior spinal nerve root axilla in the right side; DIN-L: The distance from dural attachment side to the inferior spinal nerve root axilla in the left side; DIST-R: The distance from dural attachment to the lateral aspect of the spinal cord in the right side; DIST-L: The distance from dural attachment to the lateral aspect of the spinal cord in the left side; SD: standard deviation.

There was an increase along the cervical segment to lower thoracic segment, which was statistically significant ($P < 0.001$). The DIN-R and DIN-L were determined to be heterogeneous among the levels.

Neither the cervical nor the lumbosacral enlargements of the spinal cord caused statistically significant difference in means of DIN-R and DIN-L.

The Distance From the Dural Attachment to the Lateral Aspect of the Spinal Cord

The mean distances from the dural attachment to the lateral aspect of the spinal cord were summarized in Table 1. There was no statistically significant difference between the distances among the levels and segments. Also, the cervical and the lumbosacral enlargements of the spinal cord caused no statistically significant difference in means of DIST-R and DIST-L.

DISCUSSION

In the human vertebral canal the spinal cord is anchored on each side by the DL (Millen and Woollam, 1961; Epstein, 1967). These 20 or 21 pair of ligaments arises from the lateral aspect of the spinal cord and attach to the dura mater (Epstein, 1967; Tubbs et al., 2011). The DLs were located between ventral and dorsal nerve roots and dividing the spinal canal into anterior and posterior compartments (Tubbs et al., 2001). The most rostral DL attaches intracranially at the foramen magnum. This first or the highest DL travels between the vertebral artery and the ventral rootlets of the C1 spinal nerve anteriorly and the spinal accessory nerve and the dorsal rootlets of C1 posteriorly (Tubbs et al., 2011). The most caudal of the DLs merges within the pia mater of the filum terminale and attaches the adjacent dura (Kershner and Binhammer, 2002). Anatomy textbooks mention that the last DL is located at the T12–L1 level (Hollinshead, 1982; Williams and Newell, 2005). Also, Ceylan et al. (2012) reported that no DL was found at the lumbar segment in their study. In our study, the most caudal DL was found to be located in the L1–2 level (31.2%) or most commonly in the T12–L1 level (68.8%). Present study is the first to determine the anatomical location of the most caudal DL relevant to the spinal level.

Previous studies as well as anatomical textbooks mentioned that all DLs were triangular in shape (Teng, 1965; Epstein, 1967; Nicholas and Weller, 1988; McCormick and Stein, 1990; Williams and Newell, 2005; Ceylan et al., 2012). In contrary, our study shows that in the cervical segment all DLs were triangular in shape; but as soon as thoracic segment begins DLs changed their shape to "Y."

Histological examinations of the DLs revealed that these ligaments are consisting of thick longitudinal collagen fibers, which merge with subpial collagen medially and attach to the fibrous dura laterally (Nicholas and Weller, 1988; Ceylan et al., 2012). Each DL is covered by a leptomeningeal layer that is continuous with the pia and arachnoid (Nicholas and Weller, 1988). The DLs have been assumed to provide spinal cord stability within the spinal canal, as shown by some experimental studies (Tubbs et al., 2001, 2011).

The DLs are important landmarks for surgeries relevant to the spinal cord. The DLs can be used to differentiate anterior aspect of the spinal cord from the posterior aspect. As DLs separate the posterior from the anterior spinal nerve roots, they provide a landmark for identifying the anterior and posterior spinal nerve roots (Teng, 1965). The L1 sensory roots lie upon the DL located at the T12–L1 level, which may be used as a landmark for their identification (Elsberg, 1916). Also, these paired DLs are constant landmarks for locating the midline point, which is a safe entry zone for the spinal cord (Ceylan et al., 2012). Lesions involving the anterior or anterolateral spinal cord surface are challenging for surgeons. Posterolateral approaches with DL sectioning and cord rotation have been described for ventral spinal cord pathologies (Lu and Lawton, 2010; Moon et al., 2010; Angevine et al., 2011; Joaquim et al., 2012). Sectioning the DL allows safer and gentle spinal cord rotation and retraction. Furthermore the DLs are also used as important landmarks during cordotomies to localize spinal pathways (Krol and Arbit, 1993).

This study, the anatomy of the DLs according to the adjacent axilla of the spinal nerve roots was studied. Our study revealed that the distances from the dural attachment of the DL to the superior and inferior spinal nerve root axilla were different among the cervical, upper thoracic and lower thoracic segments. Both distances to the superior and inferior spinal nerve root axillas were shown to increase from cervical to lower thoracic segments. This was thought to be caused by the enlargement of the vertebral bodies from cervical segment to the lumbar segment of the vertebral column. However, the lengths of the DLs and the distances from the dural attachment of the DL to the superior and inferior spinal nerve root axilla were not affected from the cervical and lumbosacral enlargements of the spinal cord.

CONCLUSIONS

A detailed anatomy of the DLs with their relationship with the adjacent spinal nerve root axilla is provided. This study is the first to determine the anatomical location of the most caudal DL as L1–2 level, as well as Y shape DL for thoracic levels.

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