Eur Spine J (2017) 26:382–388
DOI 10.1007/s00586-016-4640-z

ORIGINAL ARTICLE

Morphology and clinical importance of epidural membrane and periradicular fibrous tissue in lumbar spinal stenosis

Akira Miyauchi[1] · Tadayoshi Sumida[2] · Mayumi Kaneko[3] · Hideki Manabe[1] · Nobuo Adachi[4]

Received: 18 December 2015 / Revised: 31 May 2016 / Accepted: 1 June 2016 / Published online: 7 June 2016

Abstract
Purpose Compared to the ligamentum flavum (LF), morphology of the epidural membrane (EM) and the periradicular fibrous tissue (PRFT) has been largely ignored in studies of lumbar spinal stenosis (LSS). The aim of this prospective study was to elucidate the morphologies and clinical importance of the EM and PRFT in LSS.
Methods Before starting this study, neural compressive EM (c-EM) and PRFT (c-PRFT) were defined as follows based on our microsurgical experience and a literature review. The c-EM is a constriction band or membrane obstructing dural tube expansion, and the c-PRFT is a fibrous tissue that compresses the nerve root and/or restricts its mobility. This study enrolled 134 patients who underwent microscopic decompression at L4/5. The morphologies of each patient's EM and PRFT were observed and recorded. Specimens were obtained from randomly selected patients for histological evaluation.
Results The EM and PRFT exhibited a wide morphological spectrum, from a fine strand to a substantial membrane. The c-EM alone was observed in four cases, the c-PRFT alone in 37 cases, and both in three cases. The c-PRFT was more frequently observed in patients with degenerative spondylolisthesis than in those without olisthesis ($P < 0.05$). Several cases exhibited interesting histological findings including many small arteries, chondrometaplasia, ganglion-like cyst formation, and hyalinized collagen fibers.
Conclusions Some EM and PRFT transform into degenerative and substantial fibrous tissues during the process of symptomatic LSS development. Such morphological and histological changes can cause dural tear, symptomatic epidural hematoma, and/or inadequate decompression.

Keywords Epidural fibrous tissue · Epidural membrane · Clinical importance · Lumbar spinal stenosis

Introduction

The epidural membrane (EM) is an adipo-fibro-vascular tissue between the dural tube and the ligamentum flavum (LF) that forms the periradicular fibrous tissue (PRFT) along with fibrous tissues from the anterior wall of the spinal canal [1–4]. Degeneration of the LF is an important causative factor in the development of lumbar spinal stenosis (LSS). For this reason, considerable interest has been paid to its morphological or histological changes [5–7]. By contrast, the EM and PRFT have not received much attention in studies of LSS. However, their morphology and clinical importance in the degenerative lumbar spine have been discussed with regard to the effectiveness of nerve root infiltration and causes of sciatic symptoms [1–3]. The EM and PRFT have also been investigated in relation to causes of uneven onset and spread of epidural anesthesia and accidental dural puncture [8–13].

✉ Akira Miyauchi
akiramchi@yahoo.co.jp

1 Department of Orthopaedic Surgery, Hiroshima City Asa Hospital, 2-1-1 Kabeminami, Asakita-Ku, Hiroshima 731-0293, Japan

2 Department of Orthopaedic Surgery, Saka-midorii Hospital, Hiroshima, Japan

3 Department of Pathology, Hiroshima City Asa Hospital, Hiroshima, Japan

4 Division of Clinical Medical Science, Department of Orthopaedic Surgery, Programs for Applied Biomedicine, Graduate School of Biomedical Science, Hiroshima University, Hiroshima, Japan

Microscopic neural decompression for the degenerative spine has led to recognition of various morphologies of the EM and PRFT, some of which could potentially affect successful decompression procedures and surgical outcomes [4, 14, 15]. This study was designed in a prospective manner to elucidate the morphological features and clinical importance of the EM and PRFT in LSS, based on our microsurgical experience and a review of the literature.

Materials and methods

Prior to this study, we defined neural compressive EM (c-EM) and PRFT (c-PRFT) according to our microsurgical experience and a literature review (Fig. 1). c-EM was defined as a constriction band-like or membranous structure obstructing dural tube expansion. c-PRFT was defined as a fibrous tissue structure compressing the nerve root and/or impeding its mobility by holding it against the anterior wall of the spinal canal.

Prior to surgery, all participating patients were informed of the purpose of this study and gave their written informed consent, which included their agreement on the potential collection of EM and/or PRFT specimens during surgery for histological examination.

Patient characteristics are summarized in Table 1. This study enrolled 134 patients who underwent microscopic bilateral decompression via a mid-sagittal approach at L4/5 between April 2011 and March 2013. Exclusion criteria included prior lumbar surgery, spondylolysis, and concomitant disc herniation; patients who had received lumbar epidural injections, other than for a caudal block, were also excluded.

Data are expressed as the mean ± standard deviation (SD). The age at surgery was 68.9 ± 8.7 years (range from 39 to 87 years); there were 67 males and 67 females. The preoperative Japanese Orthopaedic Association (JOA) score (Table 2) was 9.2 ± 1.8 points. Degenerative spondylolisthesis (DS) was defined as an anterior translation of L4 on L5 ≥ 10 % on a standing lateral radiograph in the neutral position; 67 patients with and without DS were included. Although these two groups exhibited a significant difference in the proportion of males versus females ($P < 0.01$), there were no significant differences in

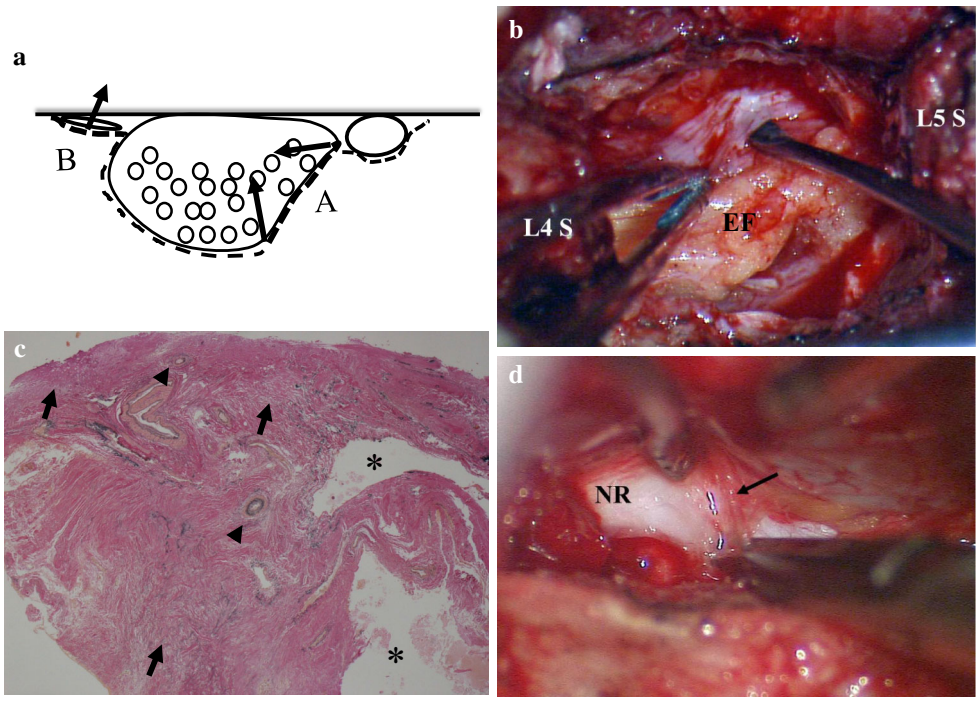

Fig. 1 The c-EM and c-PRFT. **a** Illustrations of the c-EM (*A*) and c-PRFT (*B*). The c-EM obstructs dural tube expansion, while the c-PRFT compresses the nerve root and/or impedes mobility. *Dash lines* indicate the EM and PRFT. *Arrows* indicate tensile forces acting against dural tube expansion and nerve root decompression and mobility. **b**, **c** A c-EM, a substantial and thick fibrous tissue, closely adheres to the dura, with a microspatula inserted between the c-EM and the dura. L4S and L5S denote the L4 and L5 spinous process, respectively; *EF* epidural fat. This c-EM consists mainly of hyalinized collagen fibers with chondrometaplasia (*arrows*), ganglion-like cystic formation (*asterisk*), and small arteries (*arrowheads*). Elastica van Gieson staining. **d** A c-PRFT over the nerve root (*arrow*) being cut with micro scissors to permit adequate decompression and mobility. *NR* nerve root

Table 1 Patient characteristics ($n = 134$)

Age at surgery (years)		68.9 ± 8.7 (39–87)	
Sex: male/female		66/68	
Symptom duration (months)		36.9 ± 53.4 (1.3–462.6)	
Preoperative JOA score		9.2 ± 1.8 (4–13)	
Subcohort	Without DS ($N = 67$)	With DS ($N = 67$)	P
Sex: male/female	45/22	22/45	<0.01[a]
% Slip	<10	17.7 ± 4.9 (10–29.6)	
Age at surgery (years)	69.7 ± 7.9 (47–87)	68.0 ± 9.4 (39–86)	0.30[b]
Symptom duration (months)	33.6 ± 37.3 (2.5–201.1)	40.3 ± 65.9 (1.3–462.6)	0.95[b]
Preoperative JOA score	9.1 ± 1.8 (4–13)	9.2 ± 1.8 (4–12)	0.80[b]

Values are shown as mean ± SD; values in parentheses represent the range

DS degenerative spondylolisthesis

[a] Chi-square test for independence

[b] Mann–Whitney *U* test

terms of age at surgery, symptom duration, or preoperative JOA score ($P = 0.30$, 0.95, and 0.80, respectively).

Either the first author or the supervisor (T.S.) performed all operations; the surgeon recorded the operative findings related to the EM and PRFT. To investigate the histological features of the EM and PRFT, specimens were obtained from 35 randomly selected patients. These samples included eight EM specimens with the LF firmly attached to both the LF and the dura, four EM specimens with the LF bridging between the central portion of the LF and the dural tube, five strand type EM specimens, and two c-EM specimens, one of which contained the PRFT. The 16 remaining EM specimens were obtained together with the LF as part of another study in which we examined the histological changes of the LF in LSS. All specimens were examined after hematoxylin-eosin and Elastica van Gieson staining.

Statistical analyses were performed with Statcel-the useful add-in forms on Excel, 2nd ed. (http://www.oms-publ.co.jp; published by OMS Ltd., Tokorozawa, Saitama, Japan). The Chi-square test for independence and the Mann–Whitney *U* test were used, with a risk of 5 % considered statistically significant.

Results

Morphological features of the EM and PRFT: operative findings

The EM and PRFT exhibited a wide range of morphological variation from loose fibrous tissues in the form of fine strands or a fragile venous plexus to a substantial membranous structure over the dura, attached to a varying degree to the LF, the dura, and/or the anterior wall of the spinal canal (Figs. 1, 2, 3).

The portion of the EM attached to the central recess of the LF constituted a relatively generous amount of fat tissue, some of which contained many vessels, and thus, required attention with respect to bleeding control (Figs. 2b, c). The lateral extension of the EM comprised the PRFT together with fibrous tissues derived from the posterior longitudinal ligament, the venous plexus, and/or the medial aspect of the pedicle.

Some EM and PRFT structures were closely attached to both the LF and the dura, which could potentially lead to dural tearing during removal of the LF (Fig. 3). In one case, the EM developed into a thick diffuse venous plexus sheet over the entire dorsal aspect of the dural tube, which was challenging in terms of bleeding control.

Four cases (3.0 %) exhibited c-EM alone and 37 cases (27.6 %) exhibited c-PRFT alone (on one side in 25 cases and on both sides in 12 cases). Only three cases (2.2 %) showed both c-EM and c-PRFT, one of which had bilateral c-PRFT. c-PRFT was observed more frequently in patients with DS than in those without DS ($P < 0.05$) (Tables 3, 4) despite the absence of any significant differences in terms of age at surgery, symptom duration, or preoperative JOA score between the two groups. Nerve roots that were anchored and/or compressed against the anterior wall of the spinal canal by the c-PRFT were all flattened, with an ill-defined border of the posterior longitudinal ligament (Fig. 1d).

Morphological features of the EM and PRFT: histological findings

Figures 1, 2, 3 show various EM and PRFT histomorphologies. The EM and PRFT essentially consisted of adipo-fibro-vascular tissues, some of which were structurally similar to the dura or the LF. Additionally, some contained degenerative changes including hyalinized

Table 2 Scoring system for low back pain proposed by the Japanese Orthopaedic Association (maximum 15 points)

Subjective symptoms (9 points)
Low back pain
3 = None
2 = Occasional mild pain
1 = Frequent mild or occasional severe pain
0 = Frequent or continuous severe pain
Leg pain and/or tingling
3 = None
2 = Occasional mild symptoms
1 = Frequent mild or occasional severe symptoms
0 = Frequent or continuous severe symptoms
Gait
3 = Normal
2 = Able to walk further than 500 m although resulting in pain, tingling, and/or muscle weakness
1 = Unable to walk further than 500 m owing to leg pain, tingling, and/or muscle weakness
0 = Unable to walk further than 100 m owing to leg pain, tingling, and/or muscle weakness
Clinical signs (6 points)
Straight leg raising test (including tight hamstrings)
2 = Normal
1 = 30°–70°
0 = Less than 30°
Sensory disturbance
2 = None
1 = Slight disturbance (not subject)
0 = Marked disturbance
Motor disturbance (MMT)
2 = Normal (grade 5)
1 = Slight weakness (grade 4)
0 = Marked weakness (grade 3–0)

collagen fibers, myxoid changes, chondrometaplasia, and ganglion-like cyst formation. Between the central recess of the LF and the dura, we mainly observed mature fat tissue, some of which contained many small arteries (Fig. 2b, c). In the EM that was closely attached to both the LF and the dura, we noted highly degenerative changes in the LF adjacent to the EM attachment, including the focal loss of elastic fibers replaced by a proliferation of collagen fibers, cystic degeneration, and chondrometaplasia. Additionally, some portions of the EM were continuous with the LF (Fig. 3).

Discussion

The present study demonstrated a number of morphological features of the EM and PRFT in LSS. We show that these are adipo-fibro-vascular tissues with a wide range of morphological variation from fine strands to a well-developed membranous structure over the dural tube. Some cases contain many small arteries and/or a generous venous plexus, and some exhibit various degenerative changes, such as chondrometaplasia and ganglion-like cyst formation. Moreover, these tissues are attached to or are continuous with the LF, the dura, and/or the anterior wall of the spinal canal, merging with these structures to varying degrees. We also note that the portion of LF most closely attached to the EM exhibits highly degenerative changes, such as a focal loss of elastic fibers replaced by a proliferation of collagen fibers, cystic degeneration, and chondrometaplasia.

Spine surgeons have previously discussed EM and PRFT morphology and clinical importance, and have given them several different names based on various surgical experiences and/or cadaver studies [1–4, 14, 15]. In LSS patients, Solaroglu et al. described a ligamentous structure that existed between the LF and the dura, and was closely attached to both at the L5 level. They named this ligament the ATA, and emphasized that it could cause dural tearing during LF removal [14]. In another study, Shi et al. used

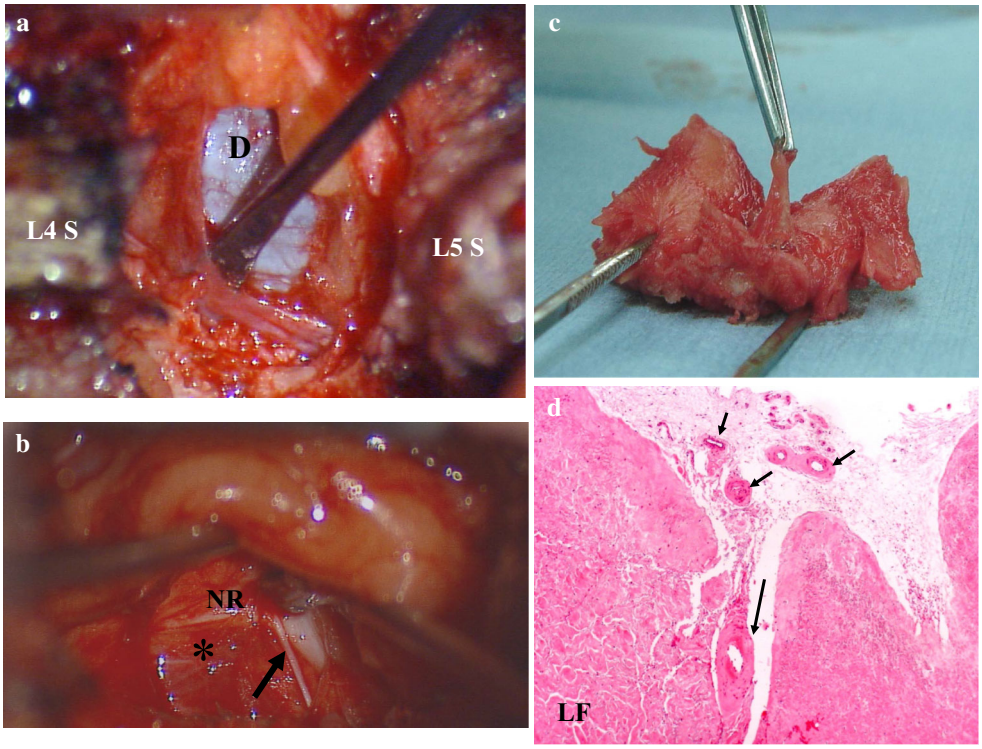

Fig. 2 Morphological variations of the EM and PRFT. **a** A substantial membrane over the dural tube. A microspatula is inserted between the EM and the dura. L4S and L5S indicate the L4 and L5 spinous process, respectively; *D* the dura. **b** A fine strand type PRFT (*arrow*), attached to the lateral aspect of the nerve root (NR), running laterally and attached to the venous plexus (*asterisk*) and the posterior longitudinal ligament. The nerve root is medially retracted with a microspatula. **c** This EM, the so-called midline fat pedicle, is lifted with forceps from the central recess of the removed ligamentum flavum. **d** This structure contains multiple small arteries (*short arrows*), with some intruding into the LF (LF, *long arrow*). Hematoxylin and eosin staining

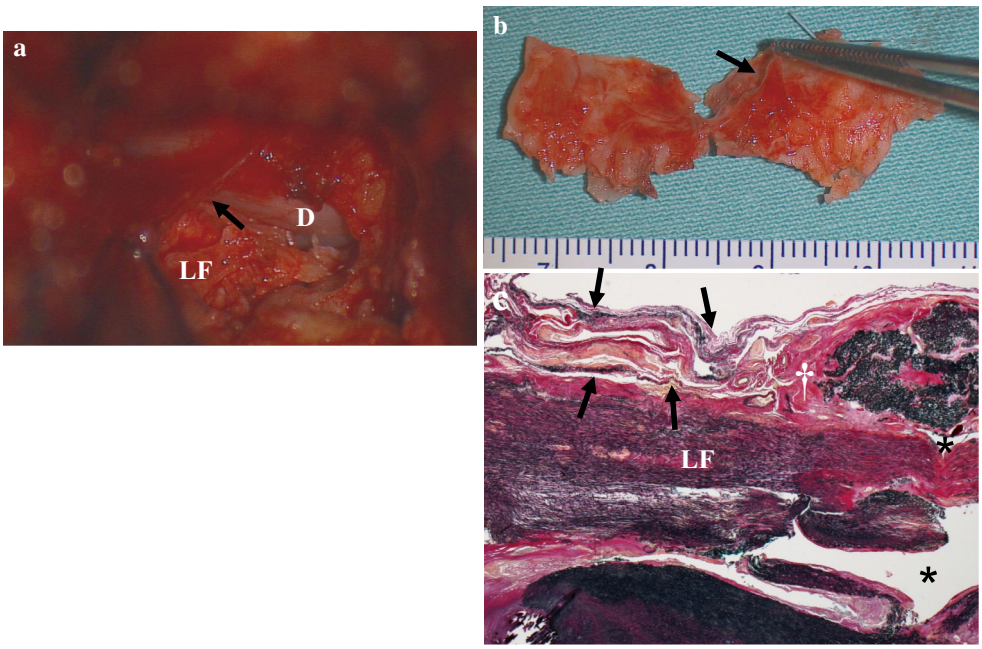

Fig. 3 **a** An EM firmly attaching to both the ligamentum flavum (LF) and the dura (D) (*arrow*). The LF is lifted from the dura, and the EM attachment to the LF is held up using forceps. **b** The EM is lifted with forceps from the ventral surface of the removed LF. **c** The EM (*arrows*) is continuous with the LF. The portion of the LF adjacent to the EM attachment shows focal loss of elastic fibers replaced by a proliferation of collagen fibers (*cross*) and cystic degeneration (*asterisk*). Elastica van Gieson staining

Table 3 The c-EM and c-PRFT

	All patients ($n = 134$)	Without DS ($n = 67$)	With DS ($N = 67$)
c-EM alone, *n* (%)	4 (3.0)	3 (4.5)	1 (1.5)
c-PRFT alone, *n* (%)	37 (27.6)	13 (19.4)	24 (35.8)
One side, *n*	25	10	15
Both sides, *n*	12	3	9
Both, *n* (%)	3 (2.2)	1 (1.5)	2 (3.0)
c-PRFT			
One side, *n*	2	1	1
Both sides, *n*	1	0	1

DS degenerative spondylolisthesis

Table 4 The c-PRFT

	All patients ($n = 134$)	Without DS ($n = 67$)	With DS ($n = 67$)	
None, *n* (%)	94 (70.1)	53 (79.1)	41 (61.2)	$P = 0.044$[a]
One side, *n* (%)	27 (20.1)	11 (4.5)	16 (23.9)	
Both sides, *n* (%)	13 (9.7)	3 (4.5)	10 (14.9)	

DS degenerative spondylolisthesis

[a] Chi-square test for independence

the term meningovertebral ligament, and pointed out that its close linkage to epidural vessels could lead to epidural hematoma during decompression procedures [15].

Spencer et al. investigated the nerve root-attaching fibrous tissues that derived from the anterior wall of the spinal canal, and named them the dural ligaments. They proposed that the tethering effects of these ligaments on the nerve root could potentially cause pressure-induced neuropathy under a protruding disc [1]. Kikuchi et al. focused on the structure enveloping the nerve root, termed the epiradicular sheath. Their findings highlighted that the sheath can retain contrast material and local anesthetic around the nerve root, consequently, producing a therapeutic effect, as well as providing functional diagnostic value in the treatment of radicular symptoms [2].

While morphological and histological changes of the LF have attracted much attention in the development of LSS [5–7], those of the EM and PRFT have been largely ignored. The EM and PRFT initially develop as delicate epidural fibrous tissues, as observed during surgery for lumbar disc herniation in younger patients. However, during the process of symptomatic LSS development with aging, repetitive damage and repair of epidural tissues under static and dynamic compression, and spondylosis deformans, some EM and PRFT transform into degenerative and substantial fibrous tissues with adhering to surrounding structures and epidural scarring. Such morphological changes of the EM and PRFT can increase the risk of a negative outcome following surgery or decompression procedures in LSS. Dural tearing can be insidiously caused during the removal of degenerative LF, and arterial bleeding into a closed space formed by the EM and the dura could develop into postoperative symptomatic epidural hematoma [15].

While a c-EM and c-PRFT can cause neural compression and/or contribute to postoperative symptomatic scar tissue formation, there exists some controversy regarding how these pathologies are defined, and whether their management is necessary for successful decompression. In the present study, our definitions of a c-EM and c-PRFT were primarily based on the perspective of the experienced surgeon, rather than on objective data. Detachment and/or partial removal of these tissues from the dura may inflict further damage on the compressed nerve tissues, with the possibility of dural tearing. c-PRFTs were observed more frequently in patients with DS than in those without DS, which may be an innocent fibrotic finding due to the intervertebral hump and instability associated with DS. Clarification of the presence and clinical importance of the c-EM and c-PRFT requires further experimental data regarding their compressive and tethering forces against the dural tube and nerve root, as well as comparative studies of LSS groups with and without c-EM and c-PRFT management.

The distinct morphological features of the EM and PRFT that we describe can be already used as key landmarks for successful decompression procedures. Adhesion between the LF and the dura occurs with the interposition

of the EM and PRFT, and hence, the LF should be carefully elevated from the dura to improve identification of the EM or PRFT. Then, these tissues should be cut after bipolar coagulation of any conspicuous vessels close to the ventral surface of the LF. This procedure is beneficial in terms of confirming and localizing the close adhesion site between the LF and the dura, as well as for preventing dural tearing and inadvertent bleeding [14, 15]. If the adhesion is too close to be safely detached, the locally adhered portion of the LF can be thinned and left on the dura.

The present study demonstrated morphological and histological features of the EM and PRFT in LSS with suggestions as to their clinical importance. One limitation of this study is that the findings are restricted to the L4/5 level, with further investigations needed to prove our hypotheses. However, a sound understanding of the anatomical features of the EM and PRFT can assist in the safe and adequate decompression of LSS, especially in the limited field afforded by minimally invasive surgery.

Conclusion

The EM and PRFT can transform into degenerative and substantial fibrous tissues in association with spondylotic changes, which may affect the performance of safe and adequate decompression procedures and potentially contribute to unsatisfactory surgical outcomes in LSS. Morphological and histological changes of the LF have attracted considerable attention in the pathology of LSS, and those of the EM and PRFT also merit special attention in performing successful decompression as well as in a sound understanding of LSS pathology.

Compliance with ethical standards

Conflict of interest No external funding was received or used to support this study. None of the authors has any conflicts of interest to report that are directly related to the specific subject matter of this manuscript.

References

1. Spencer DL, Irwin GS, Miller JA (1983) Anatomy and significance of fixation of the lumbosacral nerve roots in sciatica. Spine 8:672–679
2. Kikuchi S, Hasue M, Nishiyama K et al (1984) Anatomic and clinical studies of radicular symptoms. Spine 9:23–30
3. Wiltse LL, Fonseca AS, Amster J et al (1993) Relationship of the dura, Hoffmann's ligaments, Batson's plexus, and a fibrovascular membrane lying on the posterior surface of the vertebral bodies and attaching to the deep layer of the posterior layer of the posterior longitudinal ligament—an anatomic, radiologic, and clinical study. Spine 18:1030–1043
4. Miyauchi A, Sumida T, Manabe H et al (2012) Morphological features and clinical significance of epidural membrane in the cervical spine. Spine 19:E1182–E1188
5. Beamer YB, Garner JT, Shelden CH (1973) Hypertrophied ligamentum flavum. Arch Surg 106:289–292
6. Yoshida M, Shima K, Taniguchi Y et al (1992) Hypertrophied ligamentum flavum in lumbar spinal canal stenosis. Spine 17:1353–1360
7. Abbas J, Hamoud K, Masharawi YM et al (2010) Ligamentum flavum thickness in normal and stenotic lumbar spines. Spine 35:1225–1230
8. Luyendijk W (1976) The plica mediana dorsalis of the dura mater and its relation to lumbar peridurography (canalography). Neuroradiol 11:147–149
9. Savolaine ER, Pandya JB, Greenblatt SH et al (1988) Anatomy of the human lumbar epidural space: new insights using CT-epidurography. Anesthesiol 68:217–220
10. Blomberg RG, Olsson SS (1989) The lumbar epidural space in patients examined with epiduroscopy. Anesth Analg 68:157–160
11. Hogan QH (1991) Lumbar epidural anatomy. Anesthesiol 75:767–775
12. Richardson J, McGurgan P, Cheema S et al (2001) Spinal endoscopy in chronic low back pain with radiculopathy. Anaeshesia 56:454–460
13. Igarashi T, Hirabayashi Y, Seo N (2007) Epiduroscopic findings. The pain clinic 19:171–177
14. Solaroglu I, Okutan O, Beskonakli E (2011) The ATA and its surgical importance: a newly described ligament lying between the dural sac and the ligamentum flavum at the L5 level. Spine 36:1268–1272
15. Shi B, Li X, Li H et al (2012) The morphology and clinical significance of the dorsal meningovertebral ligaments in the lumbosacral epidural space. Spine 37:E1093–E1098