

Dynamic Changes of the Ligamentum Flavum in the Cervical Spine Assessed with Kinetic Magnetic Resonance Imaging

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Abstract

The purpose of this article is to quantify changes in thickness of the ligamentum flavum (LF) associated with motion of the cervical spine and to compare the thickness of the LF at each cervical level using kinetic magnetic resonance imaging (kMRI). Two hundred fifty-seven symptomatic patients (129 men; 128 women) underwent kMRI in neutral, flexion, and extension positions. Midsagittal images were digitally marked and electronically analyzed by spine surgeons. Thickness of LF in the cervical region from C2–3 to C7–T1 was measured in all three positions. LF at C7–T1 was significantly thicker than C2–3 to C6–7 in neutral, flexion, and extension positions ($p < 0.05$). LF was significantly thicker in extension than in flexion at C3–4 to C6–7. LF thickness increases with extension and decreases with flexion. LF is uniquely thick at C6–7 and at C7–T1 in the extension position, which may predispose these levels to cord compression syndromes and associated neuropathies.

Keywords

- ▶ ligamentum flavum
- ▶ cervical spine
- ▶ kinetic magnetic resonance imaging
- ▶ thickness
- ▶ cord compression
- ▶ whip-lash

The ligamentum flavum (LF) is a posterior structure in the spinal canal constituted of elastic fibers that connect the laminae of adjacent vertebrae from C2 to S1. Elastin and fibrillin fibers give the LF its characteristic yellow color, which helps to distinguish it during surgery and cases of pathological thickening.¹ A thickened LF can cause narrowing of the spinal canal and compression of neural elements that may lead to clinical symptoms of radiculopathy or myelopathy.²

Thickening of the LF was first reported as a possible cause of spinal stenosis and associated complications by Elsberg in 1913.³ The precise mechanism by which the LF thickens is still a topic of controversy. Many studies have attempted to explain this mechanism in ways related to hypertrophy, calcification, ossification, inflammation, or buckling due to traumatic stresses.^{4–9} Compared with the thoracic and lumbar regions, LF ligaments in the cervical spine are broader and longer but also thinner. However, in relative terms, the LF in the cervical spine does occupy a significant proportion of the

spinal canal, and LF thickening can cause significant narrowing and subsequent clinical symptoms.^{10,11}

The majority of studies investigating the thickness of the LF have examined the lumbar region. There is a paucity of studies in the literature pertaining to changes in the thickness of the LF in the cervical region. Additionally, the authors have discovered no report that uses dynamic or kinetic magnetic resonance imaging (kMRI) technology or data to investigate dynamic changes in the thickness of LF based on the position of the cervical spine. As opposed to conventional recumbent magnetic resonance imaging techniques, kMRI, which has been utilized to assess dynamic parameters of spondylosis, allows for much more physiologically accurate and functional image procurement.^{12,13} The purpose of the present study is to observe, via the use of kMRI, if there are changes in the thickness of the LF associated with motion of the cervical spine (i.e., flexion and extension) and to compare the thickness of the LF at each cervical segment.

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Materials and Methods

Patient Population

A multi-institutional kMRI database was constructed with over 3,000 registered patients from October 2009 to April 2012, consisting of cervical, thoracic, and lumbar images. Study candidates were selected from this database based upon previously established inclusion criteria.¹² Two hundred fifty-seven patients symptomatic for neck pain or upper-extremity radiculopathy had undergone cervical kMRI in neutral, flexion, and extension positions. Subjects included 129 men and 128 women with a mean age of 53.5 (range 21 to 98) years. None of the subjects had previously undergone spine surgery or received a diagnosis of deformity. The Institutional Review Board at our institution approved this study.

kMRI Protocol

kMRIs of the cervical spine were acquired from a 0.6 Tesla magnetic resonance imaging scanner (Upright Multi-Position; Fonar Corp., New York, NY, USA) in upright weight-bearing neutral, flexion (40 degrees), and extension (20 degrees) positions, using a flexible surface coil. The magnets are separated by a 0.5-mm gap. A standard imaging protocol was used, which included sagittal T1-weighted spin-echo sequences [repetition time (TR)/echo time (TE), 671/17 milliseconds; slice thickness, 3.0 mm; field of view, 24 cm; matrix, 256 × 200; and number of excitations (NEX),

2] and T2-weighted fast spin-echo sequences (TR/TE, 3432/160 milliseconds; slice thickness, 3.0 mm; field of view, 24 cm; and NEX, 2). Axial T2-weighted spin-echo sequences were acquired with fat suppression.

LF Thickness Quantification

All of the patients demonstrated the appropriate amount of flexion and extension needed for the imaging protocol. Midsagittal slices of kMRIs in neutral, flexion, and extension positions were selected and used to measure the thickness of the LF in the cervical spine. All measurements were made at the midlevel of the intervertebral disc by drawing a line from the posterior margin of the disc to the base of the spinous process, representing the posterior border of the LF (A). A second line was drawn, co-linear to the first, from the posterior margin of the disc to the posterior border of cerebrospinal fluid, representing the anterior border of the LF (B). The difference between these two lines represents the anteroposterior (AP) thickness of the LF at the level of the intervertebral disc (→ Fig. 1). We calculated the AP thickness of the LF by the following equation: LF thickness = A – B. This procedure was repeated for each cervical disc level from C2–3 to C7–T1. Images were assessed digitally by marking lines on neutral, flexion, and extension images and measuring their length. All markings were made independently by two experienced, blinded, spine surgeons, using ImageJ (ImageJ, U.S. National Institutes of Health, Bethesda, Maryland, USA) computer analysis software.

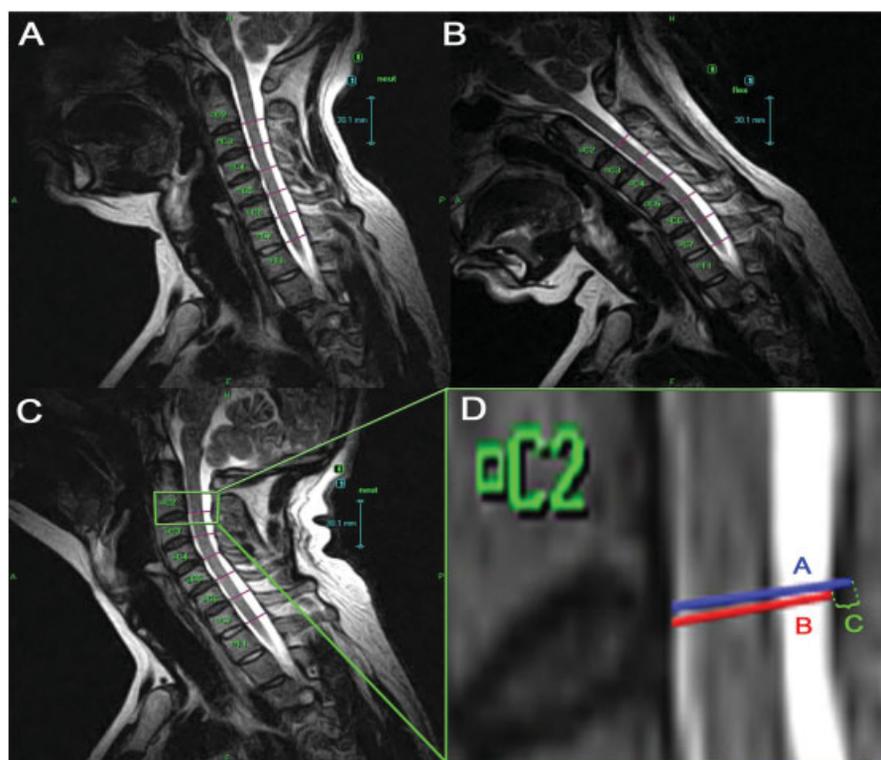


Fig. 1 Ligamentum flavum (LF) anteroposterior thickness measurement. Line A was drawn from the posterior margin of the intervertebral disc to the base of the spinous process. Line B was drawn from the posterior margin of the intervertebral disc to the posterior border of the cerebrospinal fluid. Anteroposterior thickness of LF (C) was calculated at the level of each intervertebral disc for C2–3 through C7–T1 by the equation: $C = A - B$.

Table 1 The mean thickness of ligamentum flavum according to cervical level and patient position

Disc level	Flexion (mm)	Neutral (mm)	Extension (mm)	p value (F-E)
C2-3	2.33 ± 0.86	2.43 ± 0.87	2.55 ± 1.06	p = 0.114
C3-4	2.30 ± 0.79	2.44 ± 0.87	2.70 ± 1.15	p < 0.001
C4-5	2.24 ± 0.91	2.39 ± 0.84	2.61 ± 0.98	p < 0.001
C5-6	2.19 ± 0.94	2.40 ± 0.99	2.61 ± 0.99	p < 0.001
C6-7	2.41 ± 0.98	2.67 ± 0.89	2.81 ± 0.98	p < 0.001
C7-T1	3.02 ± 0.97	3.16 ± 0.99	3.18 ± 1.00	p = 0.141

Abbreviations: E, extension; F, flexion.

Note: Values are displayed as a mean ± standard deviation.

Statistical Analysis

Mean and standard deviations of LF thickness were calculated for each cervical level in neutral, flexion, and extension positions. Data did not demonstrate a normal distribution and therefore was tested for statistical significance using the Shapiro-Wilk test and Kruskal-Wallis test. When the two methods produced significantly different results, the data were compared using the Mann-Whitney U test and corrected using Bonferroni inequality. LF thickness underwent intergroup comparisons according to level (C2-3 through C7-T1) and postural position (neutral, flexion, extension) using the Mann-Whitney U test. The standard of statistical significance was set at p < 0.05. All statistical analyses were performed using SPSS version 17.0 (SPSS, Inc., Chicago, Illinois, USA) computer analysis software.

Results

► **Table 1** and ► **Fig. 2** display the mean AP thickness of the LF according to position and by each level.

► **Fig. 3** illustrates the change in thickness of the LF with patient posture by each cervical level. When we compared LF thickness at each level in flexion, neutral, and extension, we found no significant change in thickness at the C2-3 and C7-T1 levels (p > 0.05). However, at the C3-4, C4-5, C5-6, and

C6-7 level, comparison of the thickness of the LF in extension versus flexion exhibited statistically significant differences (p < 0.05).

► **Fig. 4** illustrates the significant differences in LF thickness between the distal two cervical levels and the remaining proximal levels in the three positions studied. When we compared all cervical levels in the extension position, the thickness of LF at C2-3, C3-4, C4-5, C5-6, and C6-7 were all significantly different from the C7-T1 level (p < 0.05). When we compared all cervical levels in the flexion position, the thickness of LF at C2-3, C3-4, C4-5, C5-6, and C6-7 were all significantly different from C7-T1 (p < 0.05). And when we compared all cervical levels in the neutral position, the thickness of LF at C2-3, C3-4, C4-5, C5-6, and C6-7 were all significantly different from C7-T1 (p < 0.05).

Discussion

Spinal anatomy research has revealed that the LF thickens progressing distally from the occiput to sacrum. This change in thickness, however, does not exhibit a homogenous pattern. Sakamaki et al have reported on this increase within the lumbar region.¹⁴ Our study, using kMRI, supports the understanding that the LF at levels C2-3, C3-4, C4-5, and C5-6 changes very little from cephalad to caudad. However, the

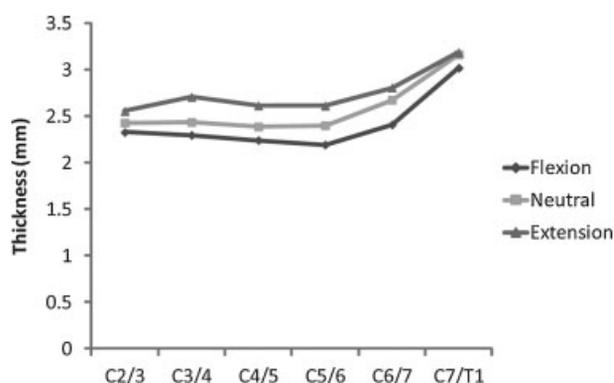


Fig. 2 Mean anteroposterior thickness of the ligamentum flavum at each level. The ligamentum flavum is thicker at each level during extension as compared with neutral, and thicker in neutral as compared with flexion.

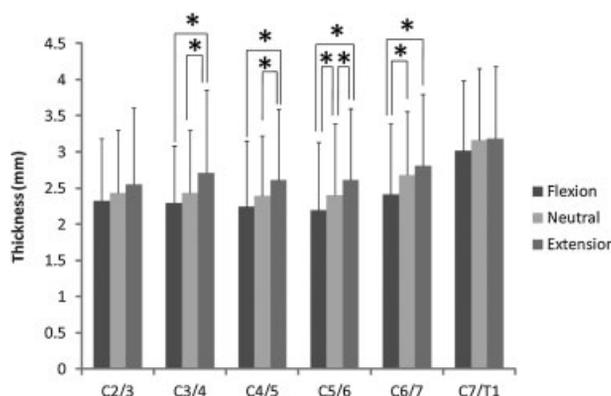


Fig. 3 Ligamentum flavum thickness changes with changing position. Middle cervical levels demonstrate significantly greater thickness in extension as compared with neutral and flexion. *Statistically significant differences.

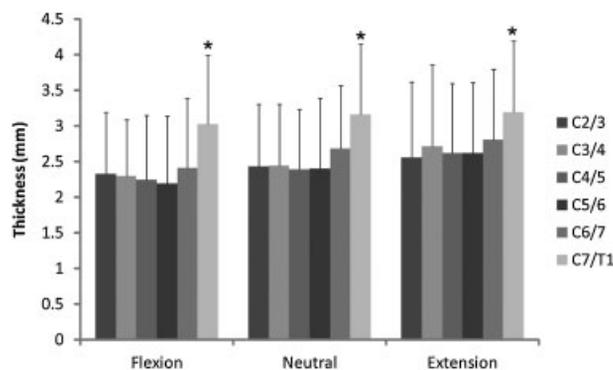


Fig. 4 Ligamentum flavum thickness is different throughout the cervical spine. The distal cervical spine, especially C7, demonstrates a significantly greater thickness as compared with the remaining proximal cervical spine. *Statistically significant differences.

midsagittal kMRI images show that at the C6–7 level, the LF becomes significantly thicker. This pattern of LF thickening is even more pronounced at C7–T1 when assessed in the neutral position. The kMRI data for LF thickness in both flexion and extension positions indicate little change between cervical levels except at C7–T1, where the LF becomes discernibly thicker with extension.

We would expect that because the LF is a posterior morphological structure made of elastin fibrous connective tissue, it would become thinner in segmental changes due to flexion movement and conversely thicker with extension movement. Capogna et al reported no statistically significant difference in the thickness of the LF between flexed and supine positions within the lumbar region.¹⁵ Our data support this pattern at some cervical levels; however, the measured values showed statistically significant differences at other cervical levels. When we compared the changes in the thickness of LF between neutral and flexion positions, we found no significant difference at levels C2–3, C3–4, C4–5, and C7–T1, whereas there was a significant difference at both the C5–6 and C6–7 levels. Therefore, the kMRI data supports the understanding that flexion of the neck causes posterior structures in the cervical spine, including the LF to distract at levels C5–6 and C6–7. The LF tissue thins during flexion of the neck. When we compared changes in the thickness of LF tissue between neutral and extension positions, we found no statistically significant difference at levels C2–3, C6–7, and C7–T1, but the data demonstrated significant differences at levels C3–4, C4–5, and C5–6.

We found more dynamic change in the thickness of the LF when measuring thickness through the full range of motion. There are statistically significant differences in the thickness of the LF between flexion and extension at levels C3–4, C4–5, C5–6, and C6–7. This asserts that during extension, there is compression of the posterior structures of the cervical spine when compared with flexion. Future research will have to be done to elucidate the possibility of this relationship.

It is still debatable whether thickening of the LF tissue during extension can be attributed to buckling. Some authors

have reported that thickening may be related to inflammatory changes, transforming growth factor- β 1, or increased proteinase inhibitor concentration.^{16–19} Others have put forward that disc degeneration and loss of disc height, reduced elasticity, and/or ossification of ligamentous tissue can result in buckling of the LF.^{5,20,21} kMRI offers unique insight into this discussion because it allows for visualization and measurement of the difference in LF thickness between vertebral levels in neutral, flexion, and extension positions. Our study supports that there is thickening of the LF at some vertebral levels as the position of the spine changes.

We have established baseline measurements for changes seen in the LF on kMRI with motion in the flexed and extended positions. We have corroborated what many clinicians believe occurs with the LF with motion—thickening in extension, except at the C7–T1 level where there is little change. However, the presence of millimetric changes may affect the repeatability of findings, and further studies will be necessary to determine the impact of these changes on the spinal canal and the clinical significance.

Our approach to measuring changes in thickness of the LF using kMRI, although novel, does present limitations due to the low resolution of kMRIs and the lack of dynamic axial images. Magnetic resonance imaging has also been shown to exaggerate the apparent size of the spinal cord compared with other imaging techniques, thus the degree of stenosis in these areas may be overstated.²² Additionally, literature has shown that it is, arguably, much less challenging to measure the thickness of the LF when using axial magnetic resonance images.²³ Lack of a control group consisting of asymptomatic patients was another limitation for this study. Finally, molecular mechanisms of LF hypertrophy are not addressed here, only the gross appearance and possible clinical risk associated with greater AP thickness consuming space in the spinal canal.

Many hypotheses explain the thickening of the LF including age-related changes and the gradual replacement of elastin fibers in the ligaments with collagen.^{24,25} Chokshi et al reported that degenerative diseases caused asymmetrical thickening of the LF,⁹ and Safak et al found no association in the thickness of the LF with respect to gender or age.²⁶ Whether these changes occur diffusely or segmentally is unclear. Nevertheless, the kMRI data from this study reveal that the thickness of the LF does change with respect to the distal cervical levels as well as in the extension position of the spine's range of motion. With the anatomical observations from this study and recognition of the effect that LF thickness may have on cervical canal space, we hope to open new avenues into the understanding, treatment, and prevention of cervical spine stenosis and associated neurological conditions.

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