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MRI of Spinal Ligament Injury

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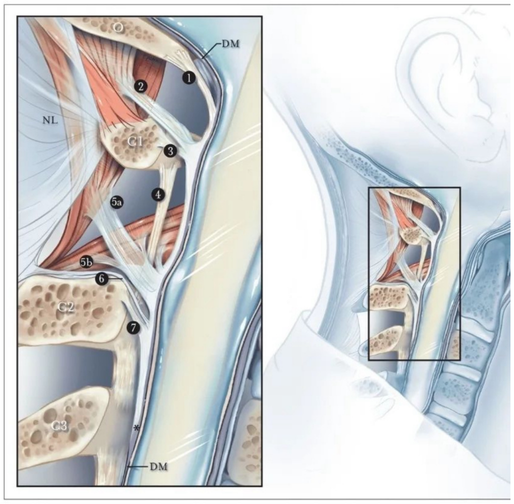

Can you identify these structures?

Syllabus

- Instructive Cases
- Anatomy
- Ligamentous Injury on MRI
- Instability
- Recommendations

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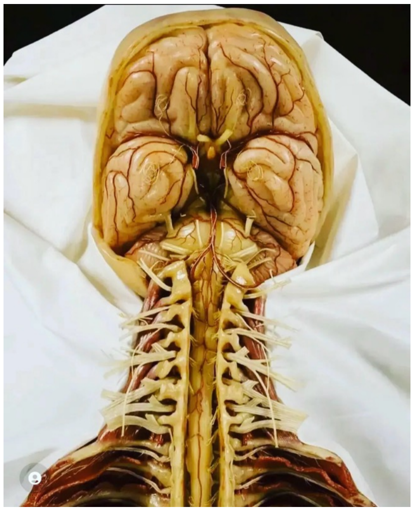

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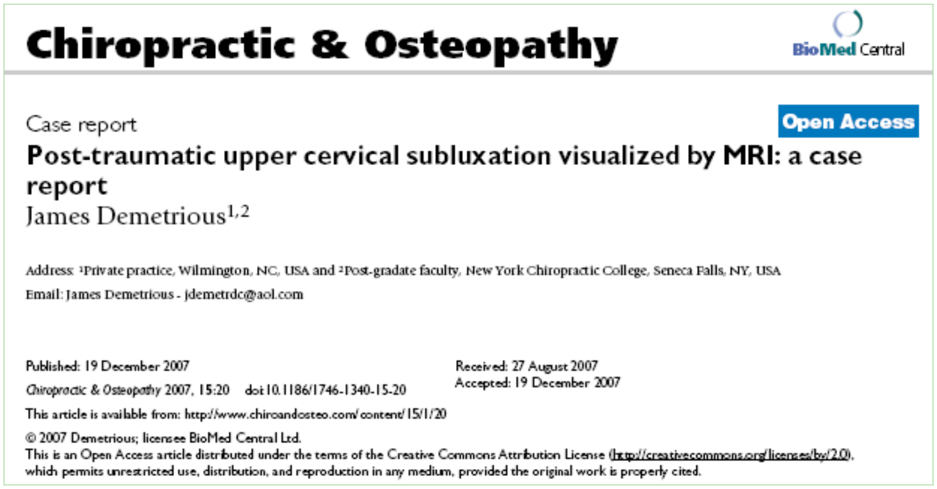
Instructive Case…



Chiropractic & Osteopathy

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Case report

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Post-traumatic upper cervical subluxation visualized by MRI: a case report

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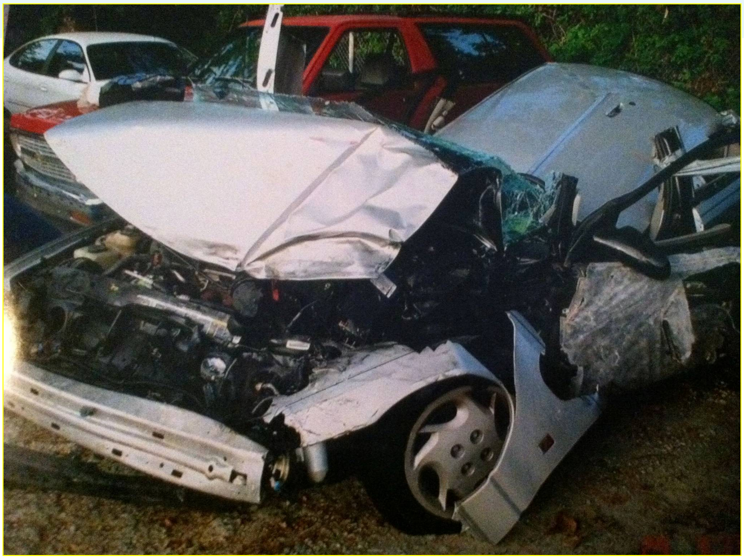
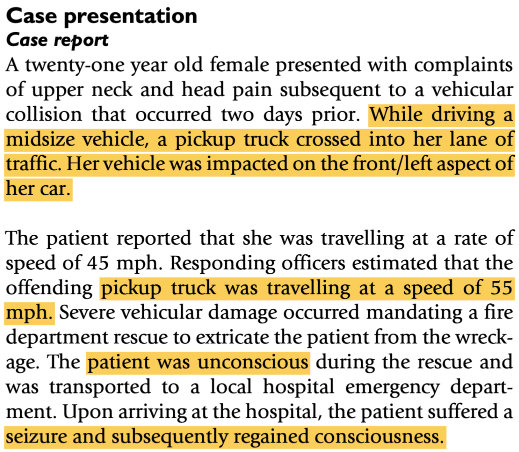


Instructive Case

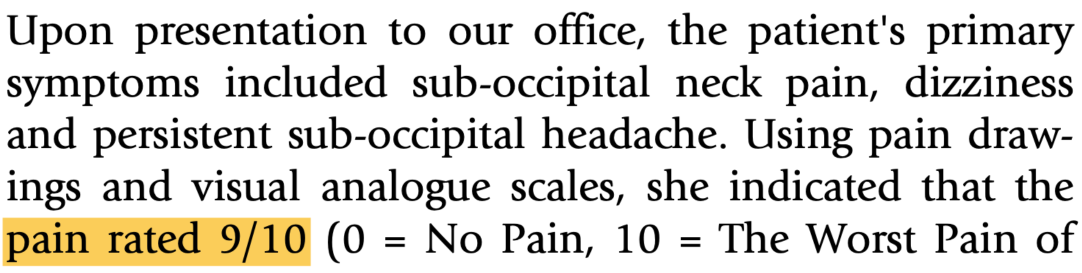


Case presentation

Case report

A twenty-one year old female presented with complaints of upper neck and head pain subsequent to a vehicular collision that occurred two days prior. While driving a midsize vehicle, a pickup truck crossed into her lane of traffic. Her vehicle was impacted on the front/left aspect of her car.

The patient reported that she was travelling at a rate of speed of 45 mph. Responding officers estimated that the offending pickup truck was travelling at a speed of 55 mph. Severe vehicular damage occurred mandating a fire department rescue to extricate the patient from the wreckage. The patient was unconscious during the rescue and was transported to a local hospital emergency department. Upon arriving at the hospital, the patient suffered a seizure and subsequently regained consciousness.



Upon presentation to our office, the patient's primary symptoms included sub-occipital neck pain, dizziness and persistent sub-occipital headache. Using pain drawings and visual analogue scales, she indicated that the pain rated 9/10 (0 = No Pain, 10 = The Worst Pain of

Examination revealed a 6'2", 175 pound athletic caucasian female. She was afebrile, her blood pressure was 122/76 and her pulse was 68 beats per minute. Visual inspection revealed guarded and restricted head and neck motion. Palpation revealed exquisite midline C2 spinous tenderness and decreased compliance of the sub-occipital musculature.

She experienced pain and restricted motion at the cervical-cranial junction on active right cervical rotation (20°), right lateral flexion (5°), flexion (10°) and extension (15°). Careful cervical compression was performed due to increased pain in extension, neutral and flexed postures, causing localized pain to C1/2 with radiation into sub-occipital region of the head. Valsalva manoeuvre produced neck and head pain. Complete neurologic evaluation revealed no apparent abnormalities.

Chiropractic evaluation was performed. Decreased intersegmental motion and fixations were noted affecting CO/1 and C1/2. Thermographic instrumentation revealed asymmetry of heat patterns of the upper cervical spine. Flexion and extension stress x-ray views failed to reveal spinal hypermobility or increase in the Atlanto-Dental Interval that would suggest instability.

Due to the mechanism and severity of the patient's collision combined with persistent severe symptoms affecting the upper cervical spine not previously imaged, a high-resolution MRI of Occiput-C7 was ordered. The attending neuroradiologist reported a cervical spinal cord syrinx that extended from C2-C7. (Figure 1). No other abnormalities were noted.

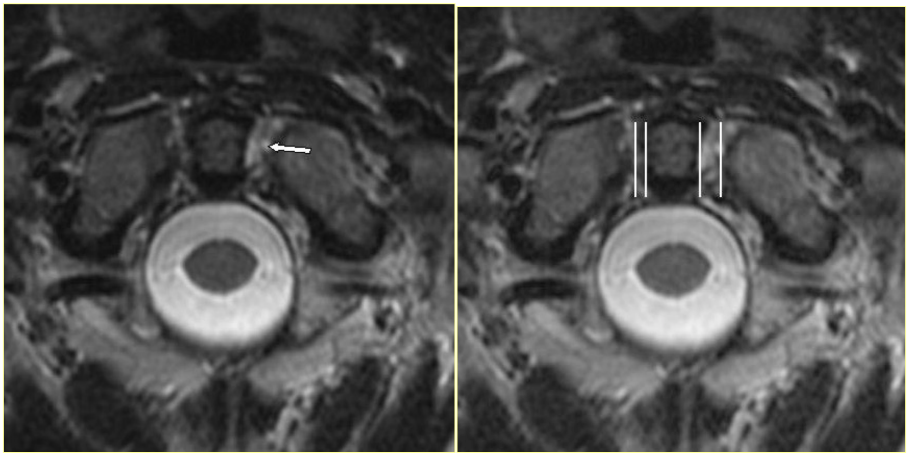
Upon over-reading the study in our office, the MRI images revealed left alar ligament disruption as evidenced by increased signal on T2 weighted images (See Figures 2 and 3). Left lateral translational subluxation was visualized. Upon re-evaluation, the neuroradiologist concurred with these opinions, suggested that additional coronal views may provide improved visualization and wrote an addendum to his report.

Case report

Open Access

Post-traumatic upper cervical subluxation visualized by MRI: a case report

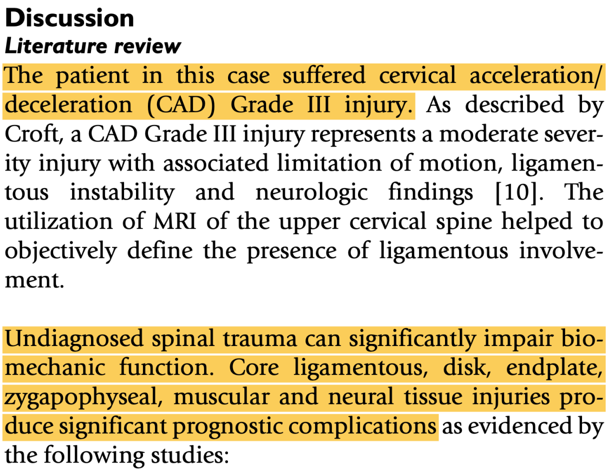
James Demetrious[1,2]



- Loss of consciousness, seizure, dizziness and headache.
- Post-traumatic chiropractic spinal subluxations affecting CO/1 and C1/2,
- Alar ligament disruption,
- Strain injuries of the sub-occipital musculature and,
- The presence of a cervical spinal cord syrinx.

Chiropractic care was initiated utilizing specific adjustments targeted to vertebral subluxations of the upper cervical spine in pain-free ranges of motion. Seated Gonstead chiropractic protocols were utilized. Pre-test evaluations were performed to assess reported pain on passive ranges of motion. Due to the presumed injury of the alar ligament, the author selectively avoided pain provocative planes of motion during adjustive procedures. The patient tolerated this well without reported discomfort.

Chiropractic care was rendered at a rate of three visits per week for six weeks. Range of motion and proprioceptive ball exercises of the cervical spine that incorporated vestibulo-occular activities were provided to the patient during the second week of care. Through six weeks of care, the patient reported progressive improvement to 75% symptomatic resolution as evidenced by weekly Pain Drawings and Visual Analogue scale outcome measures. Objective benchmarks including ranges of motion, thermographic readings, postural and palpatory evaluations of muscular compliance improved.

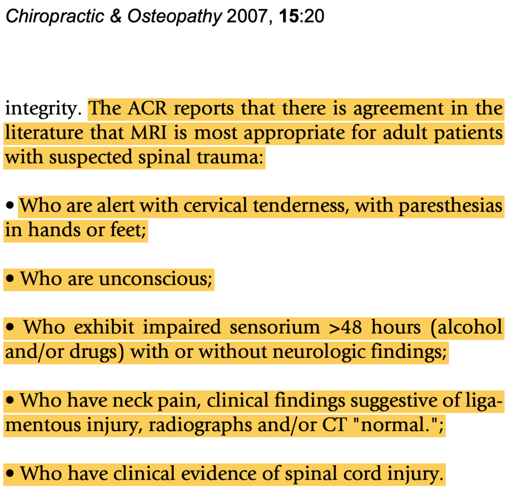


Discussion

Literature review

The patient in this case suffered cervical acceleration/deceleration (CAD) Grade III injury. As described by Croft, a CAD Grade III injury represents a moderate severity injury with associated limitation of motion, ligamentous instability and neurologic findings [10]. The utilization of MRI of the upper cervical spine helped to objectively define the presence of ligamentous involvement.

Undiagnosed spinal trauma can significantly impair biomechanic function. Core ligamentous, disk, endplate, zygapophyseal, muscular and neural tissue injuries produce significant prognostic complications as evidenced by the following studies:



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integrity. The ACR reports that there is agreement in the literature that MRI is most appropriate for adult patients with suspected spinal trauma:

- Who are alert with cervical tenderness, with paresthesias in hands or feet;
- Who are unconscious;
- Who exhibit impaired sensorium >48 hours (alcohol and/or drugs) with or without neurologic findings;
- Who have neck pain, clinical findings suggestive of ligamentous injury, radiographs and/or CT "normal.";
- Who have clinical evidence of spinal cord injury.

The decision making process to provide chiropractic adjustment to a presumed alar ligament injury was made based upon the overwhelming evidence that supports the therapeutic benefit of motion based therapies. Spinal articular structures are dependent upon movement during healing to re-establish and promote segmental motion, structural integrity, alignment of scar tissue along stress planes, improve proprioception, synovial and lymphatic fluid drainage, disc and cartilage health [24,25].

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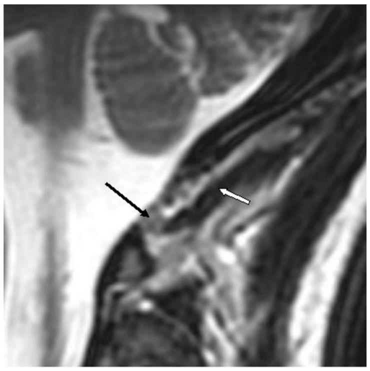


Figure 4
Sagital T2 Weighted Image – Myodural Connection (Black Arrow). Rectus Capitus Posterior Minor (White Arrow).

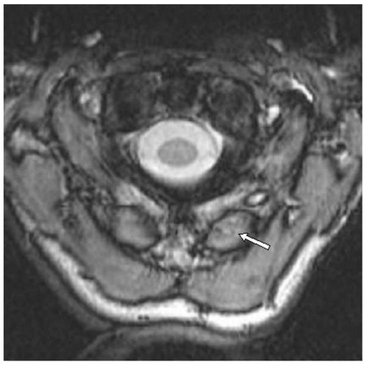
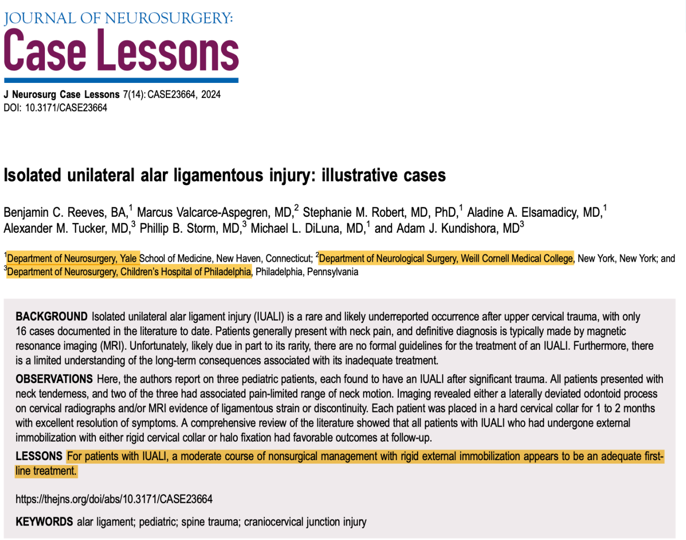


Figure 5
Axial 3D MRI – Rectus Capitus Posterior Minor (Arrow).

Figure 6
8-Way Neck Isotonic Exercise Rehabilitation.



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Isolated unilateral alar ligamentous injury: illustrative cases

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BACKGROUND Isolated unilateral alar ligament injury (IUALI) is a rare and likely underreported occurrence after upper cervical trauma, with only 16 cases documented in the literature to date. Patients generally present with neck pain, and definitive diagnosis is typically made by magnetic resonance imaging (MRI). Unfortunately, likely due in part to its rarity, there are no formal guidelines for the treatment of an IUALI. Furthermore, there is a limited understanding of the long-term consequences associated with its inadequate treatment.

OBSERVATIONS Here, the authors report on three pediatric patients, each found to have an IUALI after significant trauma. All patients presented with neck tenderness, and two of the three had associated pain-limited range of neck motion. Imaging revealed either a laterally deviated odontoid process on cervical radiographs and/or MRI evidence of ligamentous strain or discontinuity. Each patient was placed in a hard cervical collar for 1 to 2 months with excellent resolution of symptoms. A comprehensive review of the literature showed that all patients with IUALI who had undergone external immobilization with either rigid cervical collar or halo fixation had favorable outcomes at follow-up.

LESSONS For patients with IUALI, a moderate course of nonsurgical management with rigid external immobilization appears to be an adequate first-line treatment.

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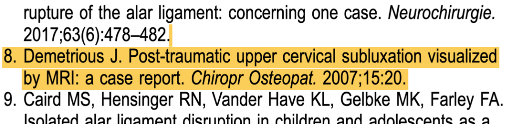
KEYWORDS alar ligament; pediatric; spine trauma; craniocervical junction injury



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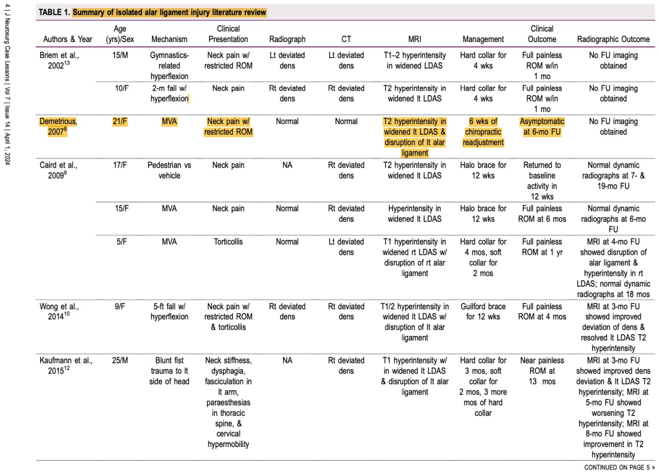

TABLE 1. Summary of isolated alar ligament injury literature review

Authors & Year	Age (yrs)/Sex	Mechanism	Clinical Presentation	Radiograph	CT	MRI	Management	Clinical Outcome	Radiographic Outcome
Briem et al., 2002[13]	15/M	Gymnastics-related hyperflexion	Neck pain w/ restricted ROM	Lt deviated dens	Lt deviated dens	T1–2 hyperintensity in widened LDAS	Hard collar for 4 wks	Full painless ROM w/in 1 mo	No FU imaging obtained
	10/F	2-m fall w/ hyperflexion	Neck pain	Rt deviated dens	Rt deviated dens	T2 hyperintensity in widened lt LDAS	Hard collar for 4 wks	Full painless ROM w/in 1 mo	No FU imaging obtained
Demetrious, 2007[8]	21/F	MVA	Neck pain w/ restricted ROM	Normal	Normal	T2 hyperintensity in widened lt LDAS & disruption of lt alar ligament	6 wks of chiropractic readjustment	Asymptomatic at 6-mo FU	No FU imaging obtained
Caird et al., 2009[9]	17/F	Pedestrian vs vehicle	Neck pain	NA	Rt deviated dens	T2 hyperintensity in widened lt LDAS	Halo brace for 12 wks	Returned to baseline activity in 12 wks	Normal dynamic radiographs at 7- & 19-mo FU
	15/F	MVA	Neck pain	Normal	Rt deviated dens	Hyperintensity in widened lt LDAS	Halo brace for 12 wks	Full painless ROM at 6 mos	Normal dynamic radiographs at 6-mo FU
	5/F	MVA	Torticollis	Normal	Lt deviated dens	T1 hyperintensity in widened rt LDAS w/ disruption of rt alar ligament	Hard collar for 4 mos, soft collar for 2 mos	Full painless ROM at 1 yr	MRI at 4-mo FU showed disruption of alar ligament & hyperintensity in rt LDAS; normal dynamic radiographs at 18 mos
Wong et al., 2014[10]	9/F	5-ft fall w/ hyperflexion	Neck pain w/ restricted ROM & torticollis	Rt deviated dens	Rt deviated dens	T1/2 hyperintensity in widened lt LDAS w/ disruption of lt alar ligament	Guilford brace for 12 wks	Full painless ROM at 4 mos	MRI at 3-mo FU showed improved deviation of dens & resolved lt LDAS T2 hyperintensity
Kaufmann et al., 2015[12]	25/M	Blunt fist trauma to lt side of head	Neck stiffness, dysphagia, fasciculation in lt arm, paraesthesias in thoracic spine, & cervical hypermobility	NA	Rt deviated dens	T1 hyperintensity w/ in widened lt LDAS & disruption of lt alar ligament	Hard collar for 3 mos, soft collar for 2 mos, 3 more mos of hard collar	Near painless ROM at 13 mos	MRI at 3-mo FU showed improved dens deviation & lt LDAS T2 hyperintensity; MRI at 5-mo FU showed worsening T2 hyperintensity; MRI at 8-mo FU showed improvement in T2 hyperintensity

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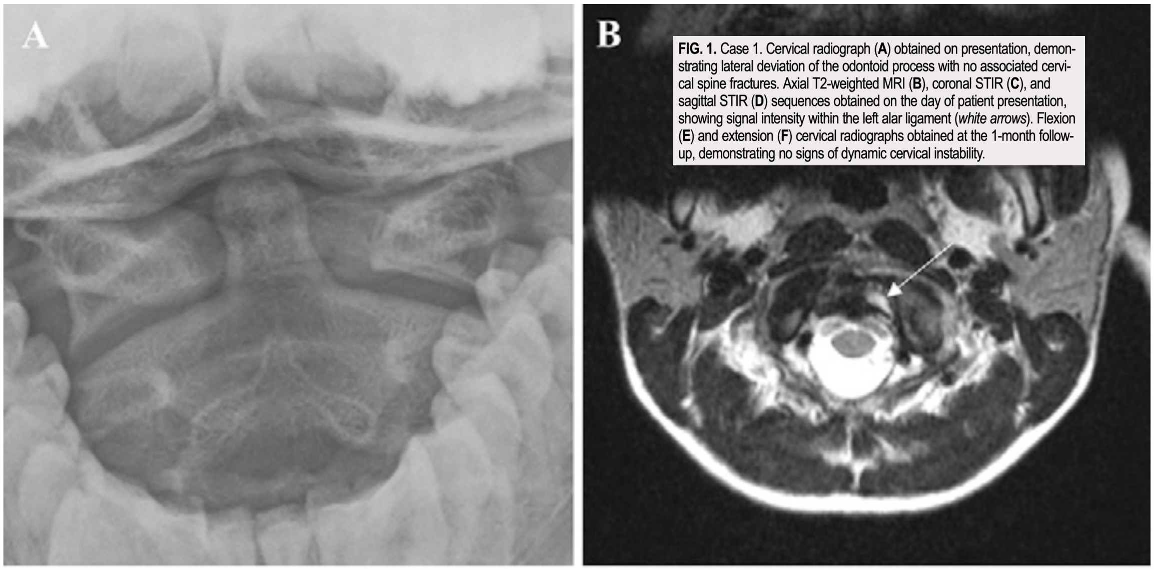
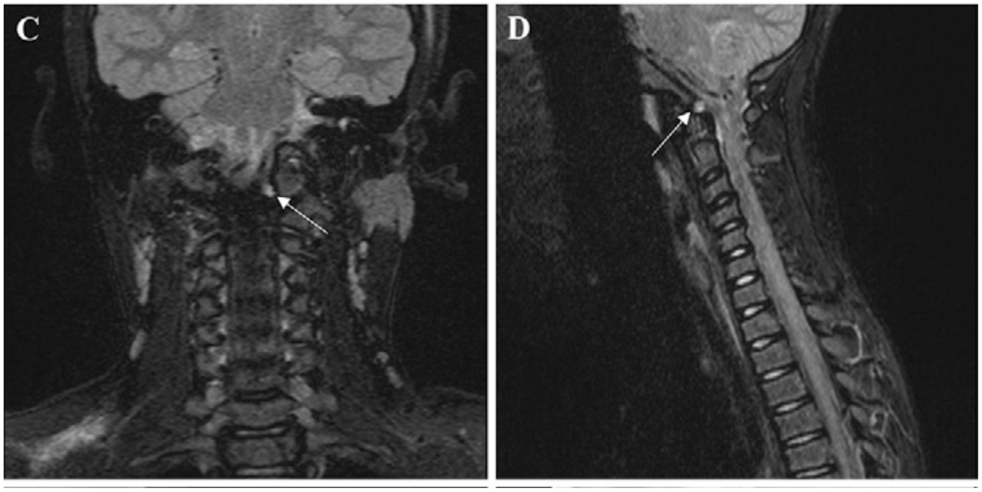


FIG. 1. Case 1. Cervical radiograph (**A**) obtained on presentation, demonstrating lateral deviation of the odontoid process with no associated cervical spine fractures. Axial T2-weighted MRI (**B**), coronal STIR (**C**), and sagittal STIR (**D**) sequences obtained on the day of patient presentation, showing signal intensity within the left alar ligament (*white arrows*). Flexion (**E**) and extension (**F**) cervical radiographs obtained at the 1-month follow-up, demonstrating no signs of dynamic cervical instability.



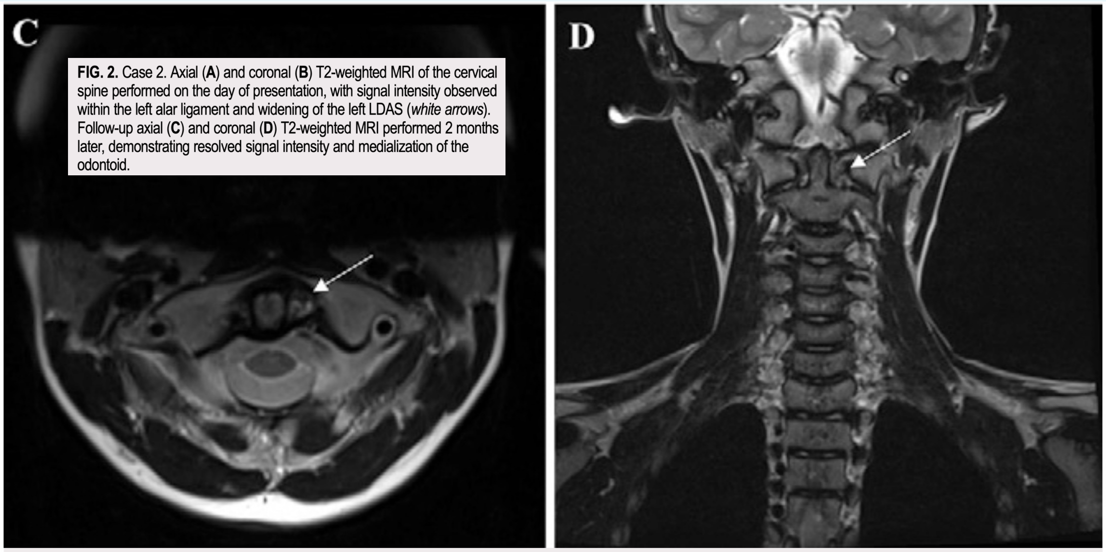


FIG. 2. Case 2. Axial (**A**) and coronal (**B**) T2-weighted MRI of the cervical spine performed on the day of presentation, with signal intensity observed within the left alar ligament and widening of the left LDAS (*white arrows*). Follow-up axial (**C**) and coronal (**D**) T2-weighted MRI performed 2 months later, demonstrating resolved signal intensity and medialization of the odontoid.

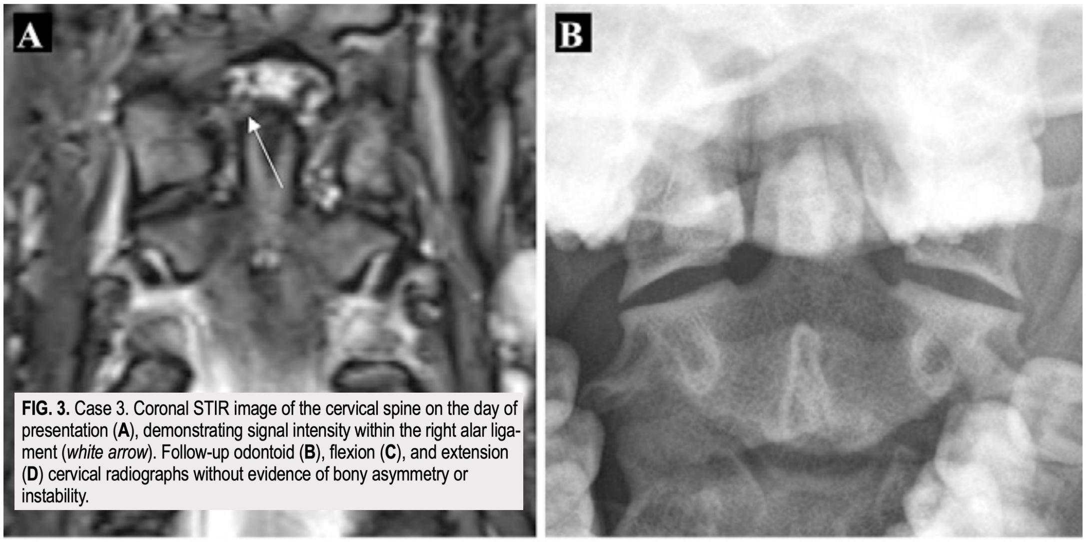
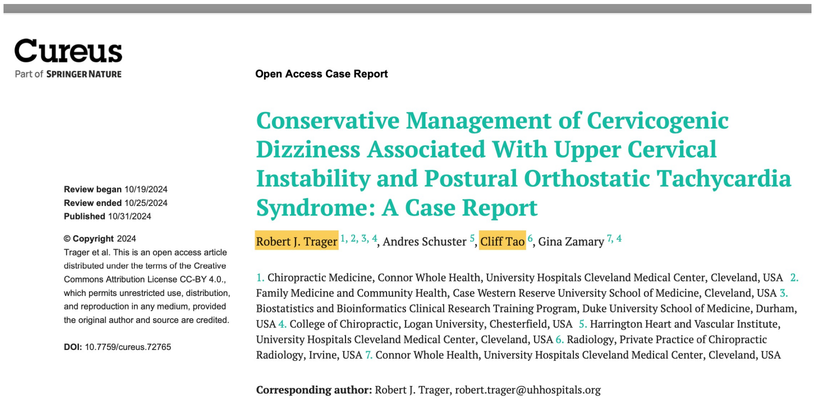


FIG. 3. Case 3. Coronal STIR image of the cervical spine on the day of presentation (**A**), demonstrating signal intensity within the right alar ligament (*white arrow*). Follow-up odontoid (**B**), flexion (**C**), and extension (**D**) cervical radiographs without evidence of bony asymmetry or instability.



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Open Access Case Report

Conservative Management of Cervicogenic Dizziness Associated With Upper Cervical Instability and Postural Orthostatic Tachycardia Syndrome: A Case Report

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- The present case highlights a 27-year-old woman with CGD and associated underlying lateral UCI and POTS whose dizziness improved with conservative care including manual therapy, exercises, and increased salt intake.

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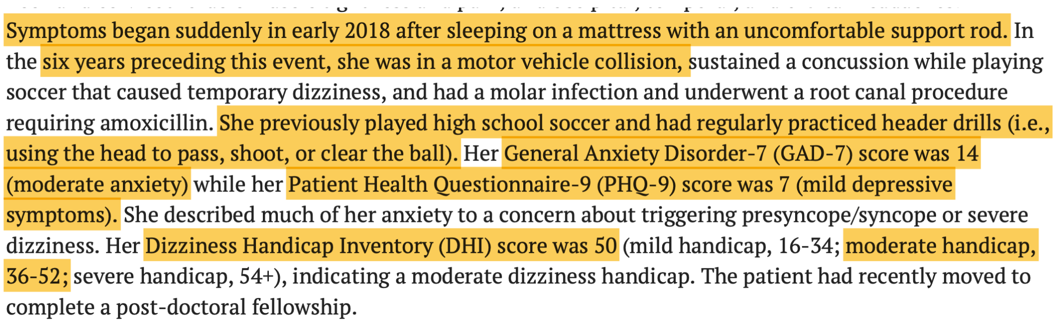

Symptoms began suddenly in early 2018 after sleeping on a mattress with an uncomfortable support rod. In the six years preceding this event, she was in a motor vehicle collision, sustained a concussion while playing soccer that caused temporary dizziness, and had a molar infection and underwent a root canal procedure requiring amoxicillin. She previously played high school soccer and had regularly practiced header drills (i.e., using the head to pass, shoot, or clear the ball). Her General Anxiety Disorder-7 (GAD-7) score was 14 (moderate anxiety) while her Patient Health Questionnaire-9 (PHQ-9) score was 7 (mild depressive symptoms). She described much of her anxiety to a concern about triggering presyncope/syncope or severe dizziness. Her Dizziness Handicap Inventory (DHI) score was 50 (mild handicap, 16-34; moderate handicap, 36-52; severe handicap, 54+), indicating a moderate dizziness handicap. The patient had recently moved to complete a post-doctoral fellowship.

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The patient described the dizziness as frequent lightheadedness with occasional near syncope, without distinct spinning. She reported long-lasting episodes once or twice per year where any movement would provoke dizziness to the degree that she would vomit and was bedridden. The neck pain was mild but constant, prompting the patient to massage her suboccipital regions regularly. Dizziness was worsened by hunger, walking down the supermarket aisles, quick head movements, and sometimes bending over. She reported that these symptoms substantially limited her quality of life. She avoided supermarkets and shopping alone, would only drive in the slow lane on highways in case she had to pull over, had difficulty cooking due to dizziness, and had difficulty eating due to nausea. She noted concerns of prolonged standing in lines due to the near syncope.

An examination by the chiropractor revealed a normal cervical range of motion with pain and hypertonic and tender suboccipital muscles, cervical erectors, upper trapezii, and temporomandibular muscles. There was a soft end feel in the upper cervical region during motion palpation and provocative ligamentous tests were therefore avoided. Cranial nerves 2 through 12 were intact, and the patient's coordination, motor strength, sensation, and muscle stretch reflexes were within normal limits. Romberg's test and Fukuda's stepping test were normal. Pathologic reflexes (including those of Hoffmann (via finger flick) and Rossolimo (via plantar tap)) were absent. During a bedside vestibular oculomotor screening test, tests for the horizontal and vertical vestibular-ocular reflex, in which the patient maintains a fixed gaze on a target while actively moving their head, exacerbated the patient's dizziness. Additionally, the visual motion sensitivity test, in which the patient fixes their gaze on their outstretched thumb while rotating their torso side to side, also provoked dizziness. No features within the Beighton scale were present (i.e., a nine-point scoring system to assess general hypermobility via physical tests including the thumbs, elbows, knees, and forward bending).

The chiropractor considered the possibility of cervical instability and post-concussion syndrome and ordered cervical spine radiographs including static and dynamic views. The lateral view demonstrated a straightening of the cervical lordosis (Figure *2*), while the anteroposterior open mouth (APOM) view illustrated abnormal lateral translation of C1 on C2 (Figure *3*), consistent with a diagnosis of UCI [9,10]. The chiropractor messaged these findings and proposed treatments to the referring cardiologist who concurred with a plan to recommend gentle exercises and manual therapies.

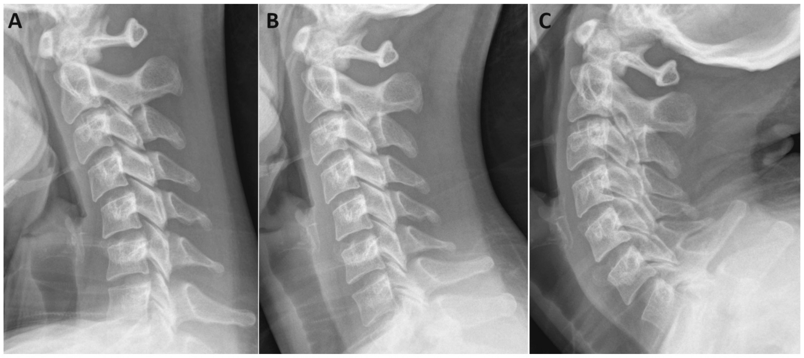


FIGURE 2: Lateral cervical radiographs taken in the standing position

These views illustrate flexion (A), neutral (B), and extension (C). No abnormal listheses or signs of instability or pathology are evident in these views. However, the cervical curve is relatively straight in the neutral position (B).

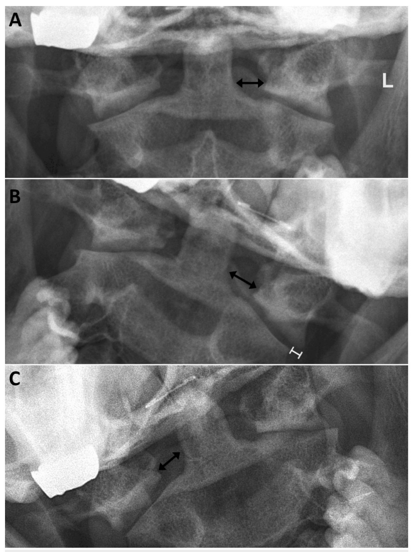
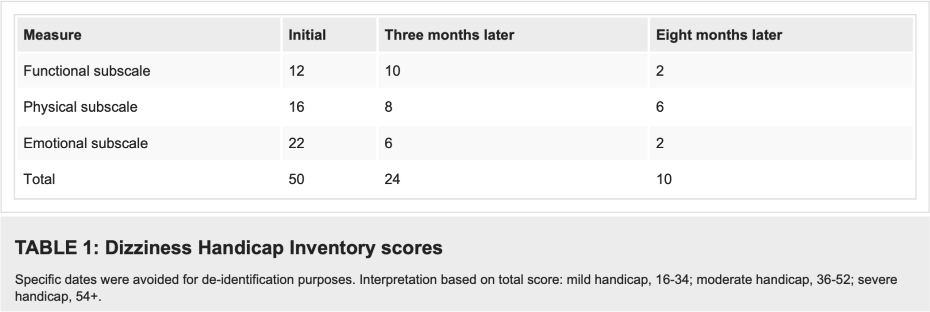


FIGURE 3: Anteroposterior open mouth lateral bending radiographs

The left (L) side marker is shown in the top image, which is consistent across each image (A, B, and C). The neutral image (A) depicts asymmetry of the odontoid-lateral mass interval (OLMI) (double-sided arrows) of 1.7 millimeters (mm) with OLMI measurement larger on the left (7.5 mm) than on the right (5.8 mm). The left lateral bending image (B) demonstrates an increase in OLMI asymmetry to 4.2 mm with OLMI larger on the left (8.0 mm) than on the right (3.8 mm). The right lateral bending image (C) demonstrates an asymmetrical OLMI, albeit smaller in magnitude (7.3 mm on the right, 5.8 mm on the left; asymmetry of 1.5 mm). A step-off is visible with left lateral bending (B), as the left lateral mass is displaced 2.4 mm to the left relative to the articular pillar of C2.

Given the patient’s history of neck pain and dizziness exacerbated by head movements, a targeted approach using manual therapy aimed at stabilizing the cervical spine was deemed appropriate. Upon follow-up with the chiropractor, the patient consented to care including manual therapies used to address the suboccipital and cervicothoracic muscular hypertonicity. These included a supine suboccipital release maneuver, myofascial release, dry needling, and stretches targeting the hypertonic upper trapezius and levator scapulae; posterior-anterior mid-cervical mobilization (Figure *4*); and thrust manipulation used in the thoracic spine. All manipulative techniques in the cervical spine were done gently without any thrust/impulse. The patient tolerated all procedures well and noted increasing relief within the days following each visit. The chiropractor demonstrated performing gentle isometric cervical lateral bending exercises (i.e., with opposing hand pressure; Figure *5*) and neutral-spine chin retractions (Figure *6*) to strengthen the deep cervical stabilizing musculature, to be performed for 10 seconds or repetitions each, respectively, three times per day. The patient was also advised to purchase an Apex® cervical orthosis (Core

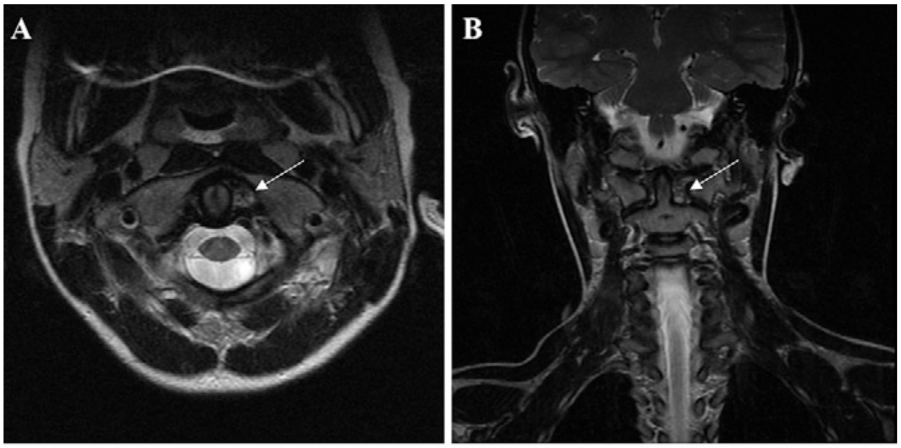
At eight months post-treatment, she only had occasional mild dizziness and no severe episodes of nausea and vomiting nor episodes of being bedridden. By this time, visits had been spaced apart to approximately one month and she had completed 13 chiropractic visits.



Measure	Initial	Three months later	Eight months later
Functional subscale	12	10	2
Physical subscale	16	8	6
Emotional subscale	22	6	2
Total	50	24	10

TABLE 1: Dizziness Handicap Inventory scores

Specific dates were avoided for de-identification purposes. Interpretation based on total score: mild handicap, 16-34; moderate handicap, 36-52; severe handicap, 54+.



Anatomy

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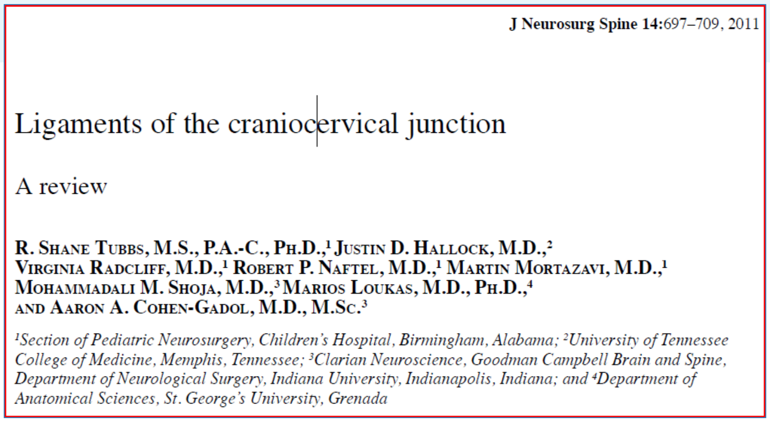

J Neurosurg Spine 14:697–709, 2011

Ligaments of the craniocervical junction

A review

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Virginia Radcliff, M.D.,[1] Robert P. Naftel, M.D.,[1] Martin Mortazavi, M.D.,[1]
Mohammadali M. Shoja, M.D.,[3] Marios Loukas, M.D., Ph.D.,[4]
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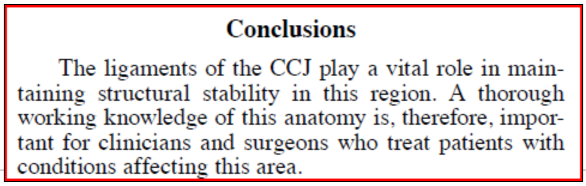

Conclusions

The ligaments of the CCJ play a vital role in maintaining structural stability in this region. A thorough working knowledge of this anatomy is, therefore, important for clinicians and surgeons who treat patients with conditions affecting this area.

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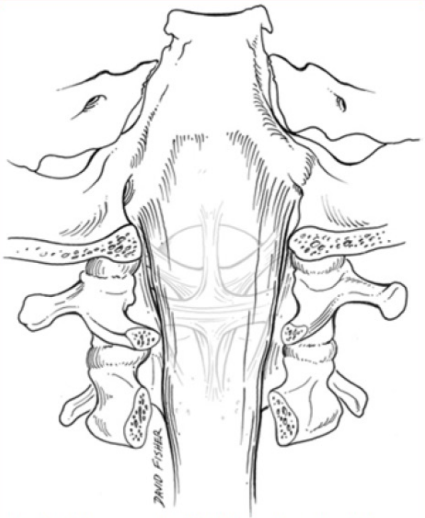

Fig. 8. Posterior view of the CCJ illustrating the relationship between the tectorial membrane *(shadowed)* and the more anterior-lying ligaments.

Craniocervical junction ligaments

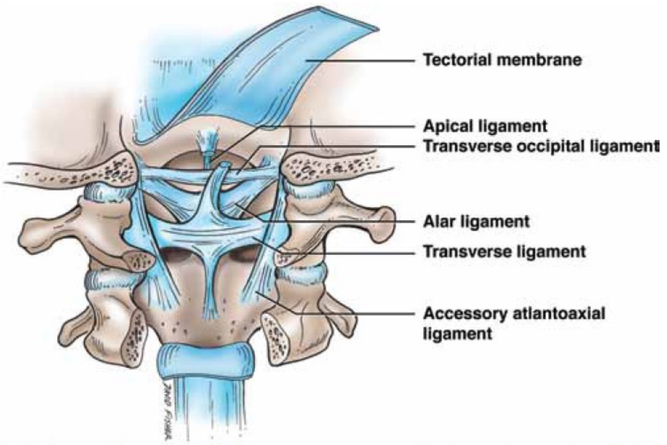

Fig. 1. Artist's drawing of the posterior CCJ illustrating its numerous specialized ligamentous structures. The tectorial membrane is reflected up and down in this drawing.

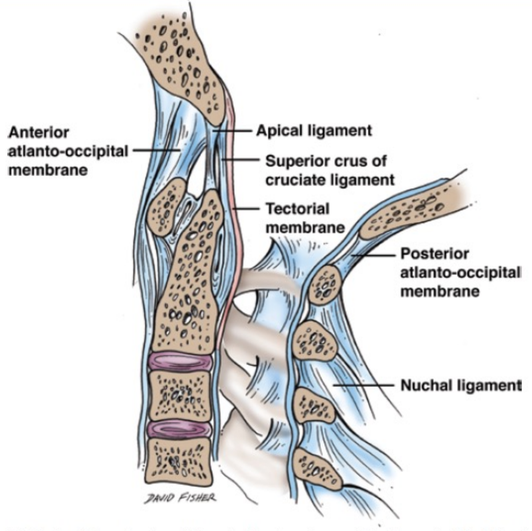

Fig. 9. Sagittal drawing of the neck and cranial base depicting the various specialized ligaments of the CCJ region.

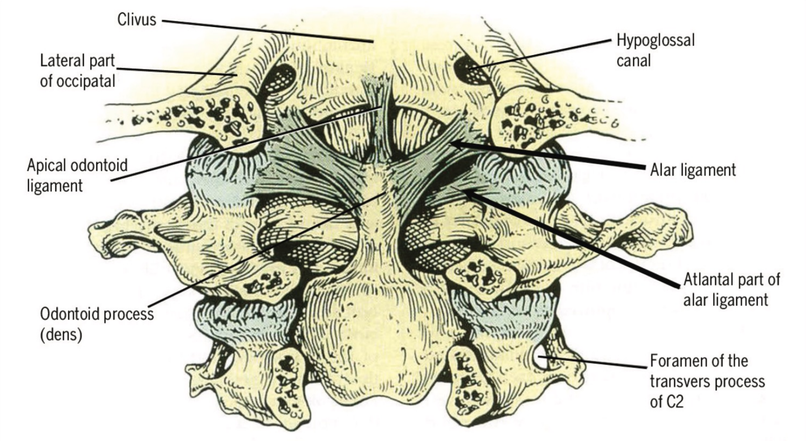

FIGURE 2. Posterior view with transverse ligament removed, showing the alar ligaments. Note that the atlantal part of the alar ligaments blends into an attachment with the C1-2 joint capsule. From Cramer GD, Darby SA. *Basic and Clinical Anatomy of the Spine, Spinal Cord, and ANS*. 2nd ed. 2005. St Louis, MO: Mosby; 2005. Used with permission from Elsevier Ltd.

JUNE 2011 | VOLUME 41 | NUMBER 6 | JOURNAL OF ORTHOPAEDIC & SPORTS PHYSICAL THERAPY

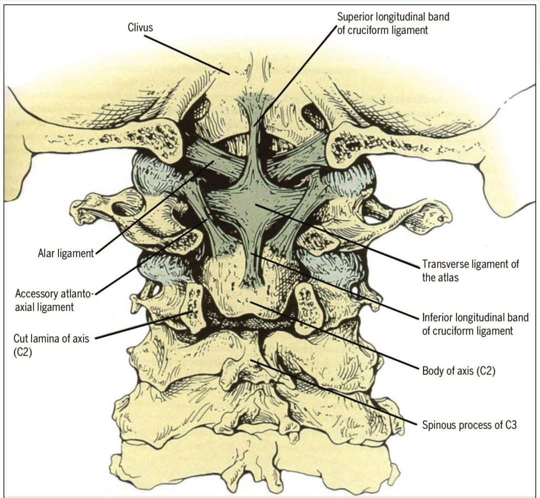

FIGURE 1. Posterior view of the upper cervical region depicting the anatomy of the transverse ligament. Also note the superior portion of the alar ligaments. From Cramer GD, Darby SA. *Basic and Clinical Anatomy of the Spine, Spinal Cord, and ANS.* 2nd ed. St Louis, MO: Mosby; 2005. Used with permission from Elsevier Ltd.

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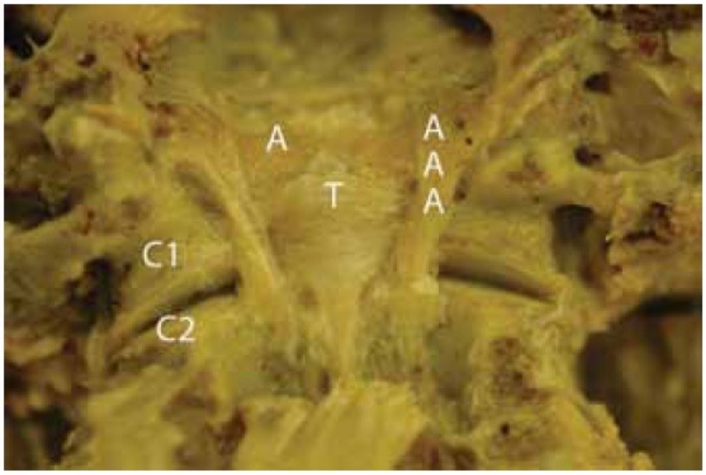


Fig. 2. Cadaveric dissection illustrating the view of Fig. 1. Note the transverse ligament (T), alar ligament (A), accessory atlantooccipital membrane (AAA), and the atlas (C1) and axis (C2).

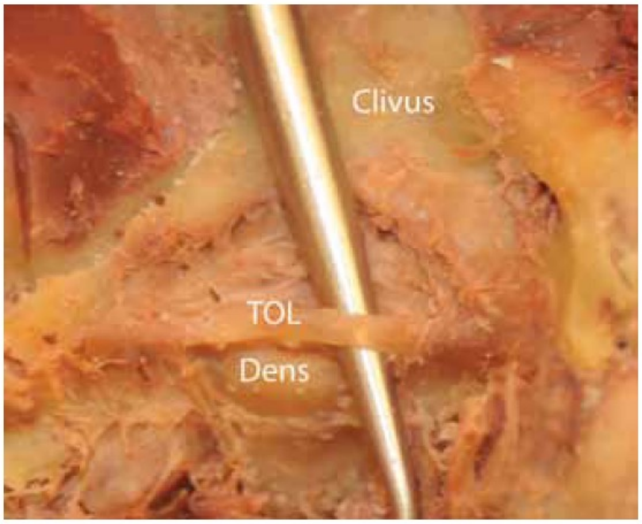


Fig. 3. Cadaveric dissection noting the transverse occipital ligament (TOL).

Craniocervical junction ligaments

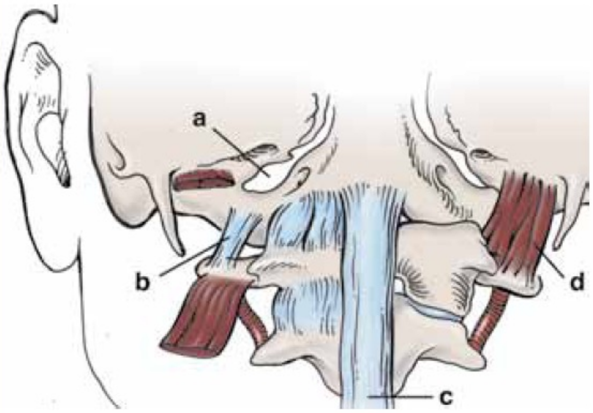


Fig. 4. Anterior drawing noting the jugular foramen **(a)** and its relationship to the lateral atlantooccipital ligament **(b)**. For reference, note the anterior longitudinal ligament **(c)** and the rectus capitis lateralis **(d)**.

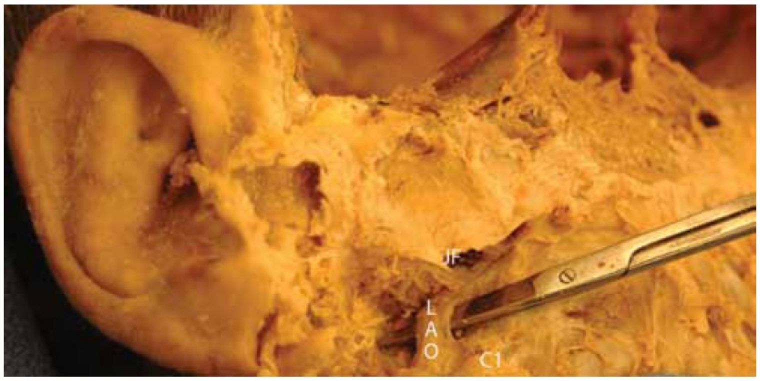
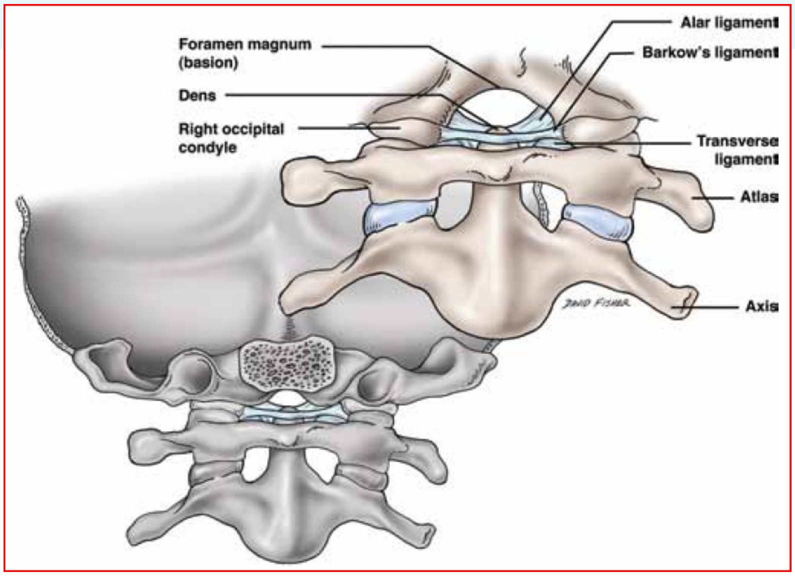


Fig. 5. Cadaveric dissection noting the right lateral atlantooccipital (LAO) ligament. Note the jugular foramen (JF) and atlas (C1).



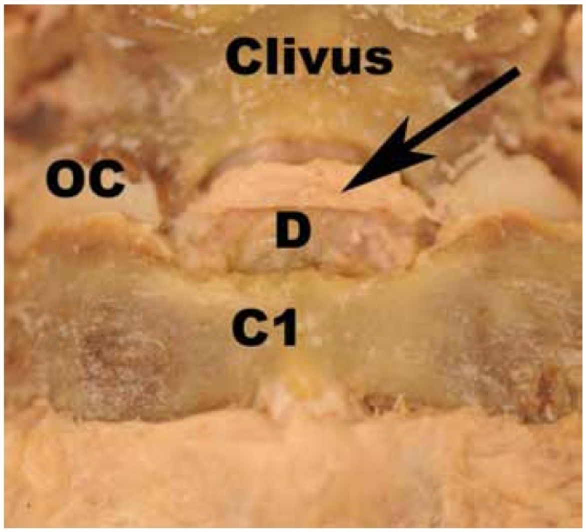
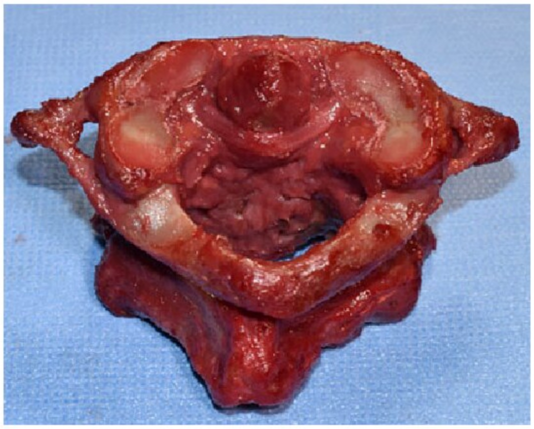


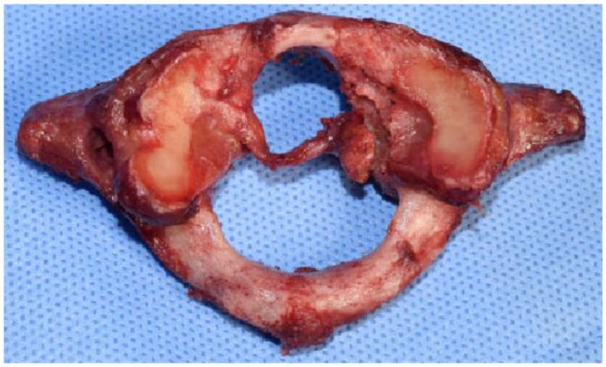
Fig. 7. Cadaveric dissection noting the Barkow ligament *(arrow)*. For reference, note the right occipital condyle (OC) and dens (D).



Figure

Caption

Figure 1. Harvested C1-2 specimen with posterior view of the transverse ligament.



Figure

Caption

Figure 4. Bony avulsion on the right side occurred in one male specimen at a failure force of 326 N.

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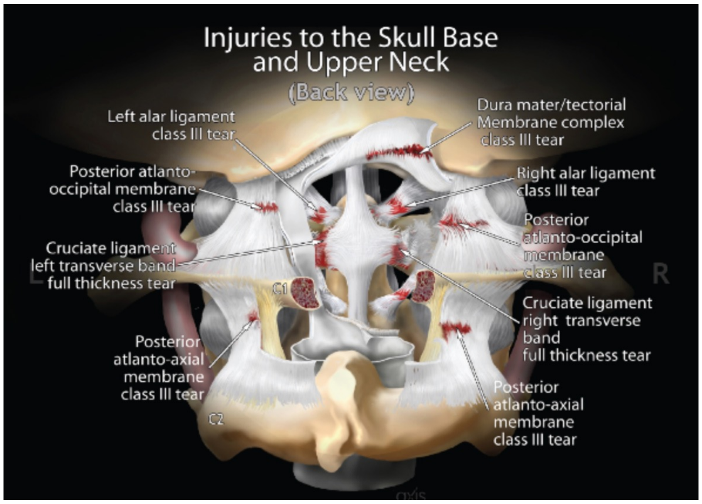
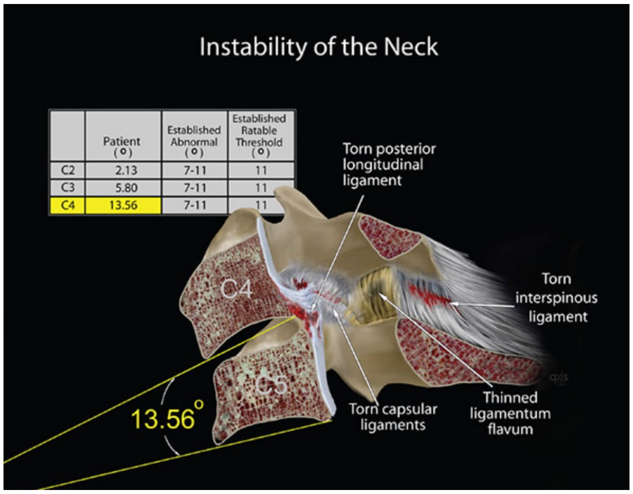
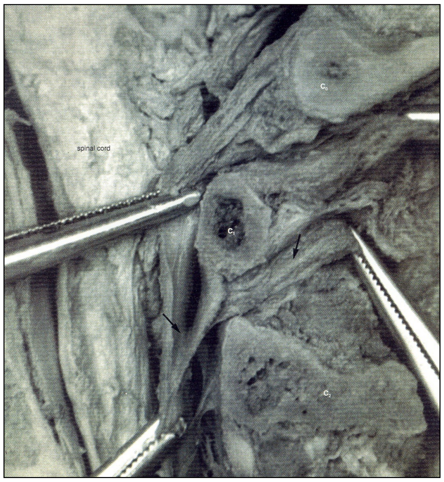




	Patient (°)	Established Abnormal (°)	Established Ratable Threshold (°)
C2	2.13	7-11	11
C3	5.80	7-11	11
C4	13.56	7-11	11

Myodural Bridge



Spine
ANATOMY
SPINE Volume 36, Number 25, pp E1612–E1614
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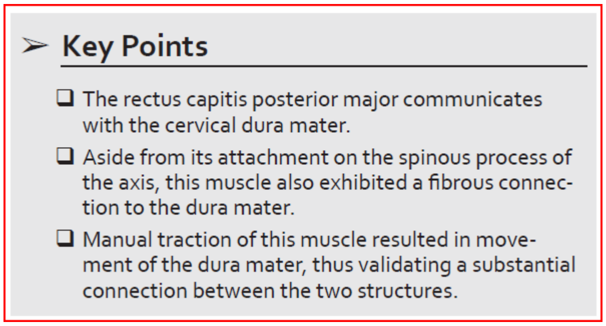
Anatomical Connection Between the Rectus Capitis Posterior Major and the Dura Mater

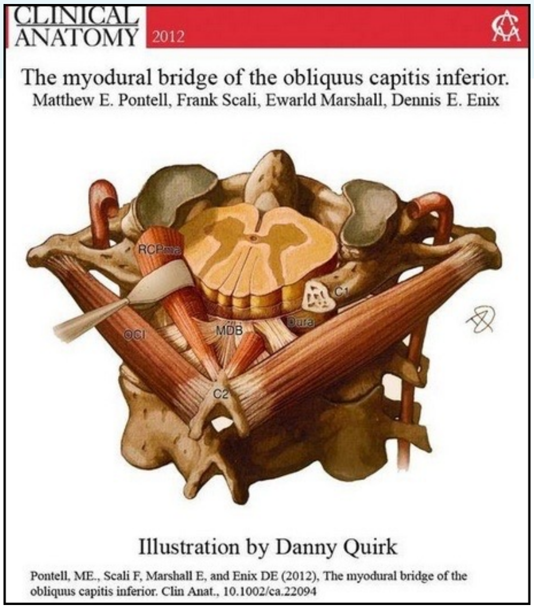
Frank Scali, DC,* Eric S. Marsili, DC,† and Matthew E. Pontell, BSc*



➢ Key Points

- ☐ The rectus capitis posterior major communicates with the cervical dura mater.
- ☐ Aside from its attachment on the spinous process of the axis, this muscle also exhibited a fibrous connection to the dura mater.
- ☐ Manual traction of this muscle resulted in movement of the dura mater, thus validating a substantial connection between the two structures.

Figure 2. Photograph of dural attachment between rectus capitis posterior major (RCPma) and cervical dura mater. (1) Attachment between RCPma and cervical dura mater; (2) RCPma; (3) cervical dura mater; (4) lamina of axis; (5) transverse process of atlas; (6) third cervical vertebra; (7) fourth cervical vertebra; (8) spinal cord; and (9) body of fourth cervical vertebra.

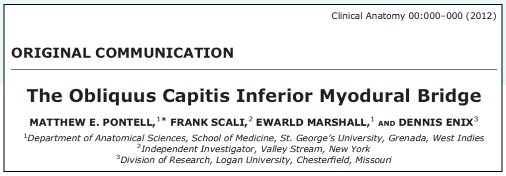


CLINICAL ANATOMY 2012

The myodural bridge of the obliquus capitis inferior.
Matthew E. Pontell, Frank Scali, Ewarld Marshall, Dennis E. Enix

Illustration by Danny Quirk

Pontell, ME., Scali F, Marshall E, and Enix DE (2012), The myodural bridge of the obliquus capitis inferior. Clin Anat., 10.1002/ca.22094



Clinical Anatomy 00:000–000 (2012)

ORIGINAL COMMUNICATION

The Obliquus Capitis Inferior Myodural Bridge

MATTHEW E. PONTELL,[1]* FRANK SCALI,[2] EWARLD MARSHALL,[1] AND DENNIS ENIX[3]
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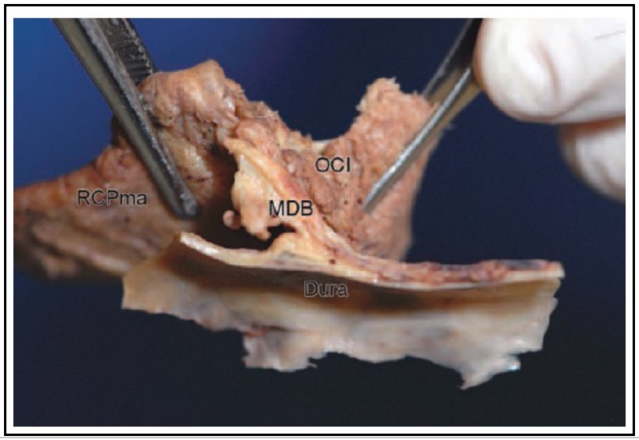
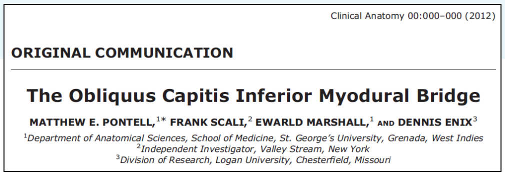
[2]*Independent Investigator, Valley Stream, New York*
[3]*Division of Research, Logan University, Chesterfield, Missouri*





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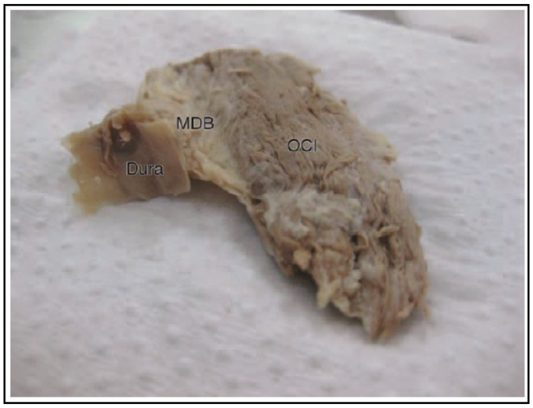

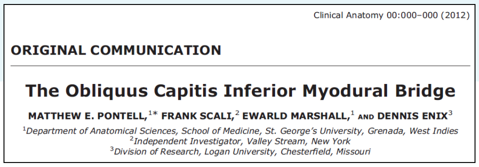

Clinical Anatomy 00:000–000 (2012)

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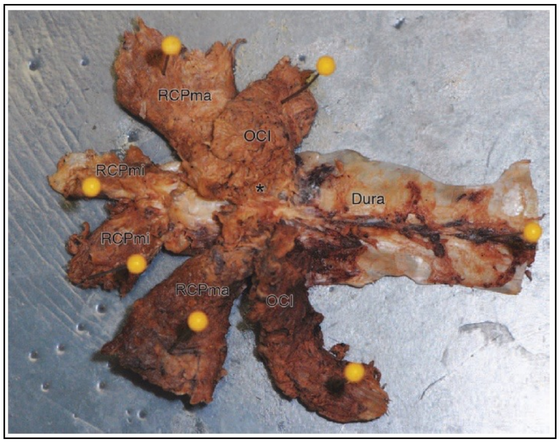

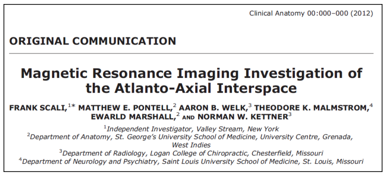

Clinical Anatomy 00:000–000 (2012)

ORIGINAL COMMUNICATION

Magnetic Resonance Imaging Investigation of the Atlanto-Axial Interspace

FRANK SCALI,[1]* MATTHEW E. PONTELL,[2] AARON B. WELK,[3] THEODORE K. MALMSTROM,[4] EWARLD MARSHALL,[2] AND NORMAN W. KETTNER[3]
[1]*Independent Investigator, Valley Stream, New York*
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[3]*Department of Radiology, Logan College of Chiropractic, Chesterfield, Missouri*
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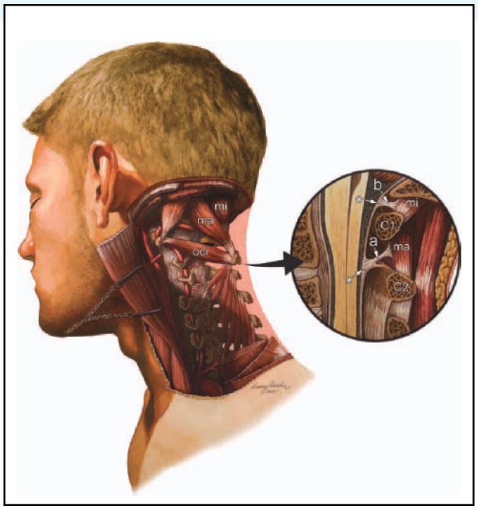

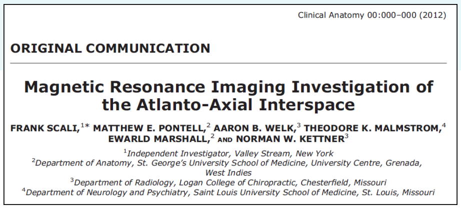

Clinical Anatomy 00:000–000 (2012)

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[3]*Department of Radiology, Logan College of Chiropractic, Chesterfield, Missouri*
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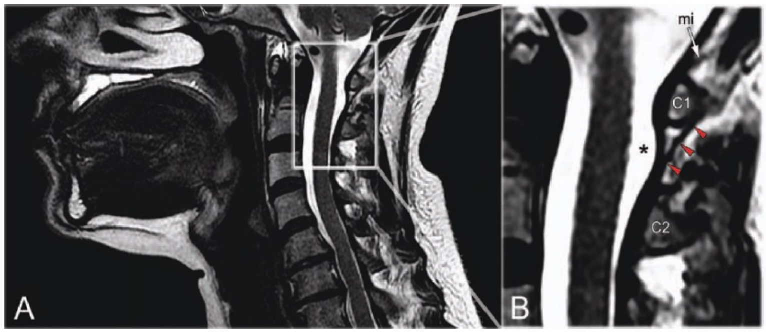
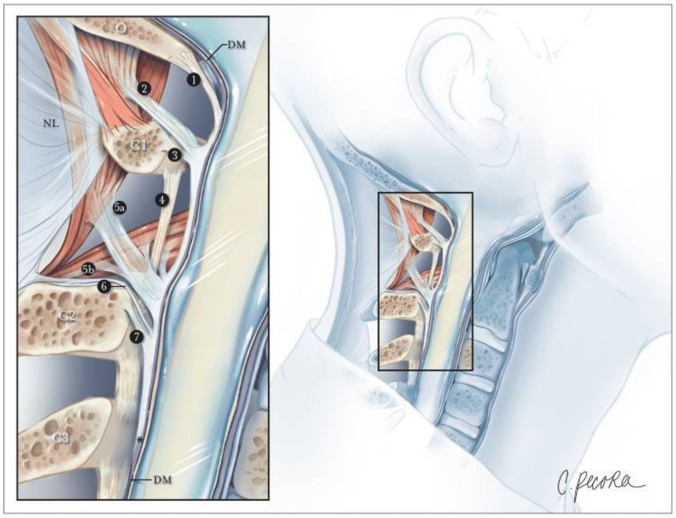
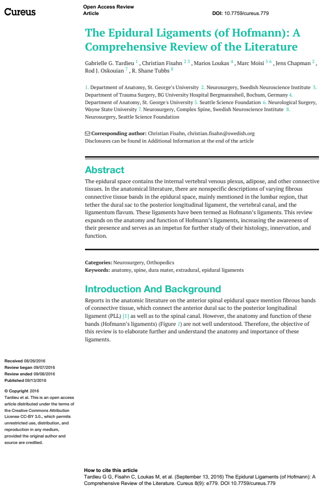
Scali et al.







Cureus
Open Access Review Article
DOI: 10.7759/cureus.779

The Epidural Ligaments (of Hofmann): A Comprehensive Review of the Literature

Gabrielle G. Tardieu [1] , Christian Fisahn [2, 3] , Marios Loukas [4] , Marc Moisi [5, 6] , Jens Chapman [2] , Rod J. Oskouian [7] , R. Shane Tubbs [8]

1. Department of Anatomy, St. George's University 2. Neurosurgery, Swedish Neuroscience Institute 3. Department of Trauma Surgery, BG University Hospital Bergmannsheil, Bochum, Germany 4. Department of Anatomy, St. George's University 5. Seattle Science Foundation 6. Neurological Surgery, Wayne State University 7. Neurosurgery, Complex Spine, Swedish Neuroscience Institute 8. Neurosurgery, Seattle Science Foundation

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Disclosures can be found in Additional Information at the end of the article

Abstract

The epidural space contains the internal vertebral venous plexus, adipose, and other connective tissues. In the anatomical literature, there are nonspecific descriptions of varying fibrous connective tissue bands in the epidural space, mainly mentioned in the lumbar region, that tether the dural sac to the posterior longitudinal ligament, the vertebral canal, and the ligamentum flavum. These ligaments have been termed as Hofmann's ligaments. This review expands on the anatomy and function of Hofmann's ligaments, increasing the awareness of their presence and serves as an impetus for further study of their histology, innervation, and function.

Categories: Neurosurgery, Orthopedics
Keywords: anatomy, spine, dura mater, extradural, epidural ligaments

Introduction And Background

Reports in the anatomic literature on the anterior spinal epidural space mention fibrous bands of connective tissue, which connect the anterior dural sac to the posterior longitudinal ligament (PLL) [1] as well as to the spinal canal. However, the anatomy and function of these bands (Hofmann's ligaments) (Figure 1) are not well understood. Therefore, the objective of this review is to elaborate further and understand the anatomy and importance of these ligaments.

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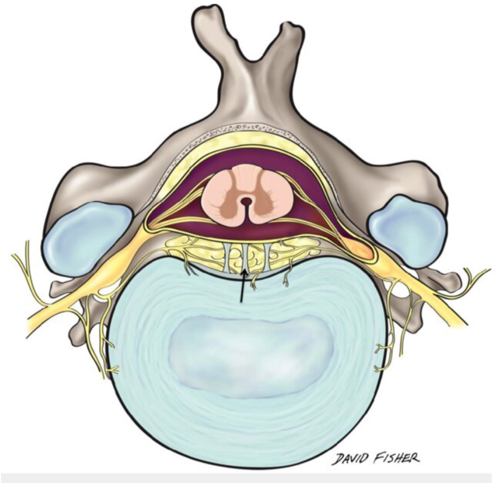
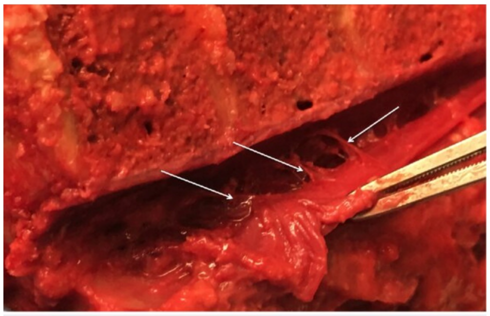
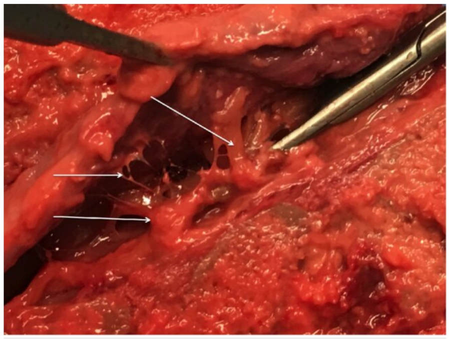




Figure

Caption

FIGURE 2: Fresh cadaveric dissections noting Hofmann's ligaments (arrows) here attaching anteriorly to the PLL.

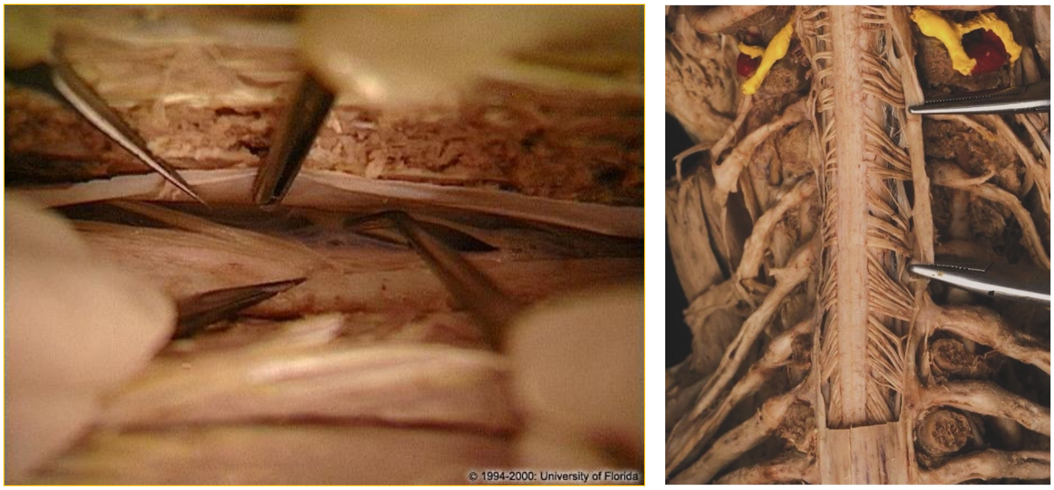


Figure

Caption

FIGURE 3: Fresh cadaveric specimen demonstrating varying sizes of Hofmann's ligaments (arrows).

Denticulate Ligaments



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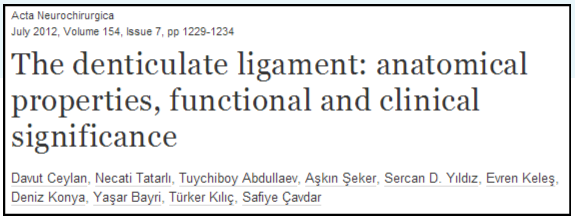
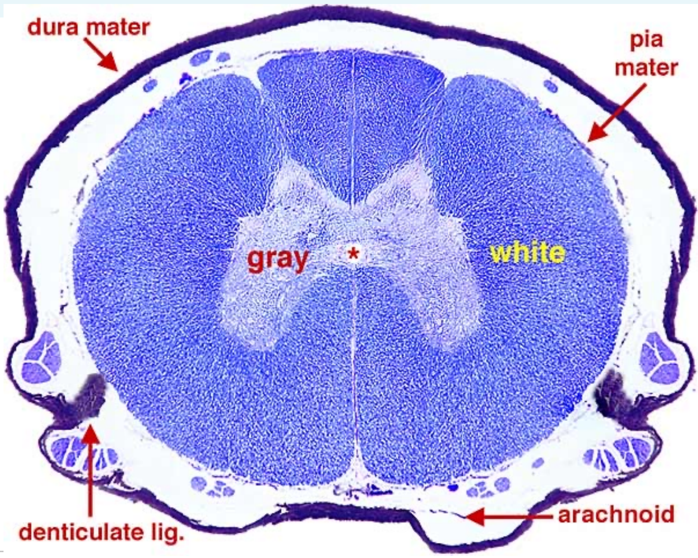


Acta Neurochirurgica
July 2012, Volume 154, Issue 7, pp 1229-1234

The denticulate ligament: anatomical properties, functional and clinical significance

Davut Ceylan, Necati Tatarlı, Tuychiboy Abdullaev, Aşkın Şeker, Sercan D. Yıldız, Evren Keleş, Deniz Konya, Yaşar Bayri, Türker Kılıç, Safiye Çavdar

- The main findings were:
  - (1) each DL is composed of a single narrow fibrous strip that extends from the craniovertebral junction to T12, and each also features 18–20 triangular extensions that attach to the dura at their apices;
  - (2) the triangular extensions are smaller and more numerous at the cervical levels, and are larger and less numerous at the thoracic levels;
  - (3) the apices of the extensions attach to the dura via fibrous bands at cervical levels (each band 3-5 mm long) and lower thoracic levels (21-26 mm long), whereas they attach directly to the dura at upper thoracic levels;
  - (4) the narrow fibrous strip of the DL features longitudinally oriented collagen fibers, whereas the triangular extensions are composed of transverse and obliquely oriented collagen fibers. The collagen fibers are thicker and more abundant at the cervical than at the thoracic levels.



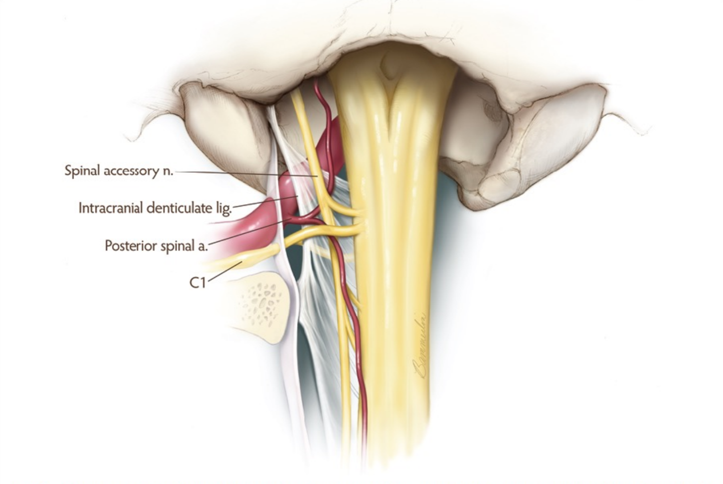


Fig. 1. Schematic drawing illustrating the relationships of the left intracranial denticulate ligament (lig). Note the relationship between the course of the vertebral artery and its branches and the spinal accessory nerve (n) and first cervical rootlets to this ligament. a = artery. Used with permission from Clarian Health.

J Neurosurg / Volume 114 / February 2011

NMR Biomed. 2012 July ; 25(7): 891–899.

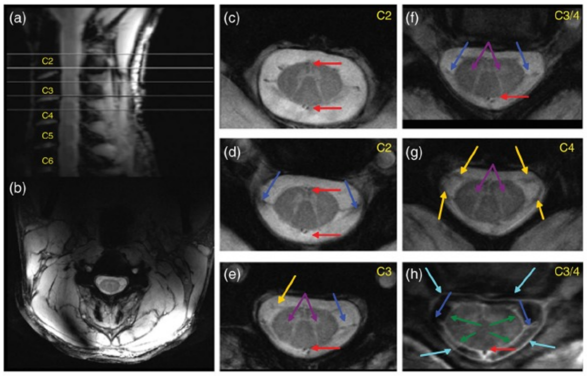


Figure 4.
Cervical spine T_2-weighted MRI at 7 T (four-channel array). (a) Sagittal localizer view showing slice and vertebra locations. (b) Full field of view axial gradient echo (GRE) image. Enlarged view of spinal cord area in GRE (c–g) and turbo spin echo (TSE) (h) sequences. Labeled structures: dorsal/ ventral nerve roots (yellow), gray matter anterior horn (purple), denticulate ligament (blue), dorsal/ventral blood vessels (red), dura mater (cyan), pia mater (green).

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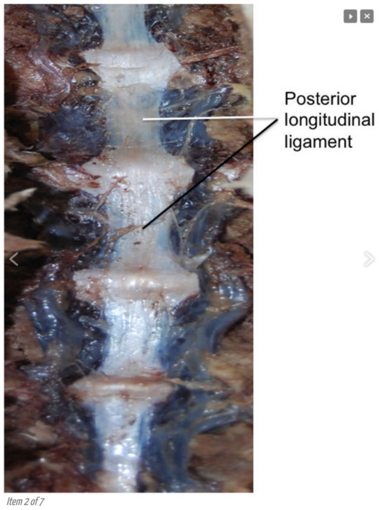

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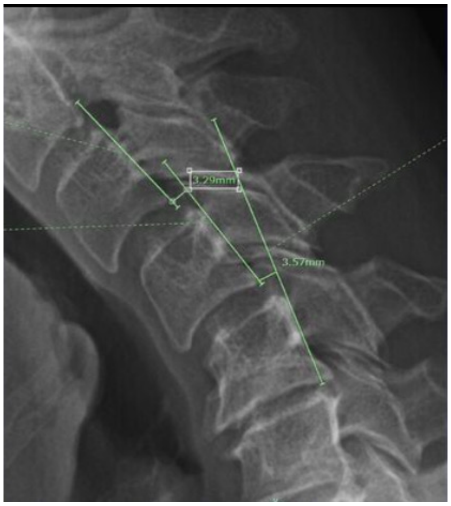
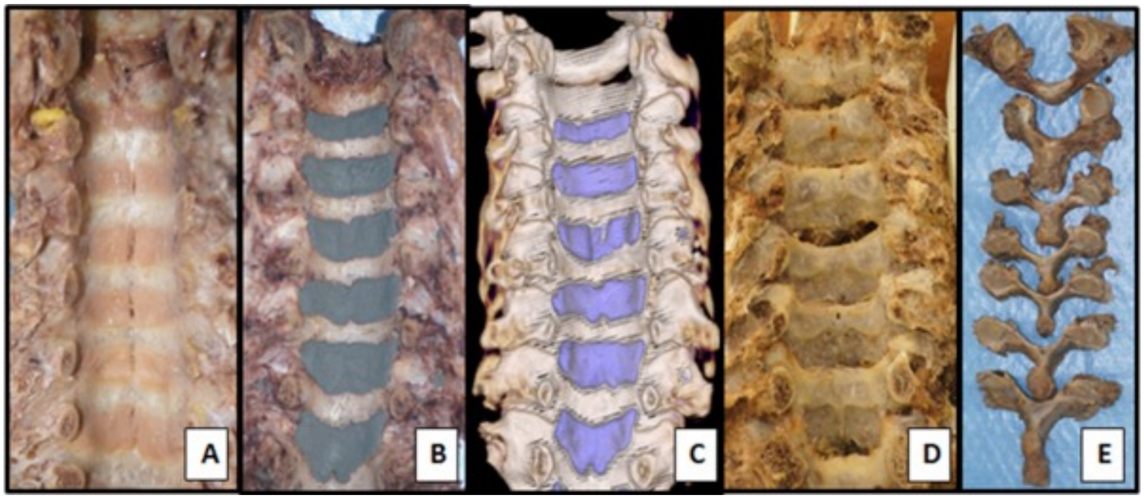

3.29mm
3.57mm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B
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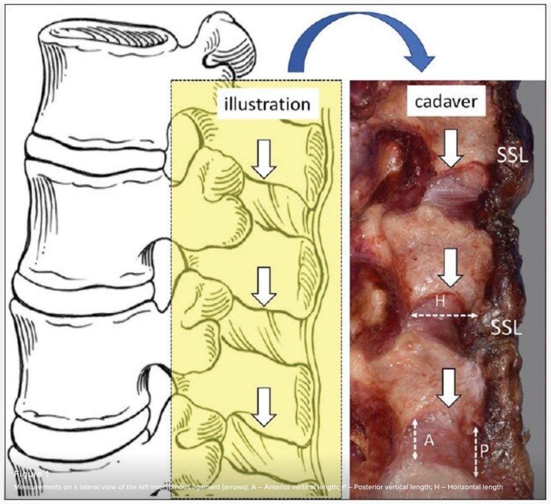

Figure 1

Measurements on a lateral view of the left interspinous ligament (arrows). A – Anterior vertical length; *P* – Posterior vertical length; H – Horizontal length

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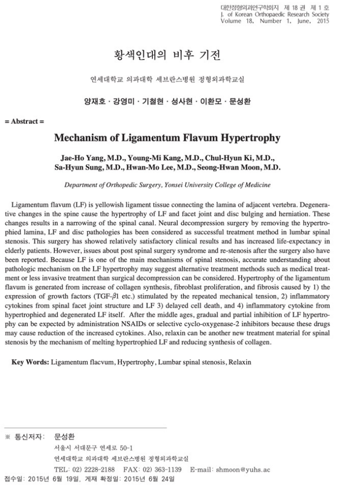

대한정형외과연구학회지 제 18 권 제 1 호
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Volume 18, Number 1, June, 2015

황색인대의 비후 기전

연세대학교 의과대학 세브란스병원 정형외과학교실

양재호 · 강영미 · 기철현 · 성사현 · 이환모 · 문성환

= Abstract =

Mechanism of Ligamentum Flavum Hypertrophy

**Jae-Ho Yang, M.D., Young-Mi Kang, M.D., Chul-Hyun Ki, M.D.,
Sa-Hyun Sung, M.D., Hwan-Mo Lee, M.D., Seong-Hwan Moon, M.D.**

Department of Orthopedic Surgery, Yonsei University College of Medicine

Ligamentum flavum (LF) is yellowish ligament tissue connecting the lamina of adjacent vertebra. Degenerative changes in the spine cause the hypertrophy of LF and facet joint and disc bulging and herniation. These changes results in a narrowing of the spinal canal. Neural decompression surgery by removing the hypertrophied lamina, LF and disc pathologies has been considered as successful treatment method in lumbar spinal stenosis. This surgery has showed relatively satisfactory clinical results and has increased life-expectancy in elderly patients. However, issues about post spinal surgery syndrome and re-stenosis after the surgery also have been reported. Because LF is one of the main mechanisms of spinal stenosis, accurate understanding about pathologic mechanism on the LF hypertrophy may suggest alternative treatment methods such as medical treatment or less invasive treatment than surgical decompression can be considered. Hypertrophy of the ligamentum flavum is generated from increase of collagen synthesis, fibroblast proliferation, and fibrosis caused by 1) the expression of growth factors (TGF-β1 etc.) stimulated by the repeated mechanical tension, 2) inflammatory cytokines from spinal facet joint structure and LF 3) delayed cell death, and 4) inflammatory cytokine from hypertrophied and degenerated LF itself. After the middle ages, gradual and partial inhibition of LF hypertrophy can be expected by administration NSAIDs or selective cyclo-oxygenase-2 inhibitors because these drugs may cause reduction of the increased cytokines. Also, relaxin can be another new treatment material for spinal stenosis by the mechanism of melting hypertrophied LF and reducing synthesis of collagen.

Key Words: Ligamentum flacvum, Hypertrophy, Lumbar spinal stenosis, Relaxin

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접수일: 2015년 6월 19일, 게재 확정일: 2015년 6월 24일

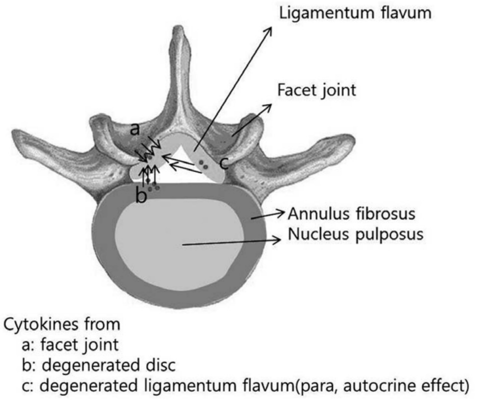

Fig. 2. Hypertrophy factors in ligamentum flavum.

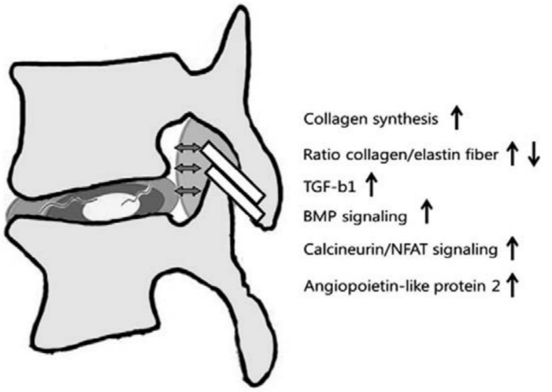

Fig. 1. Mechanism of the ligamentum flavum hypertrophy by mechanical stress.

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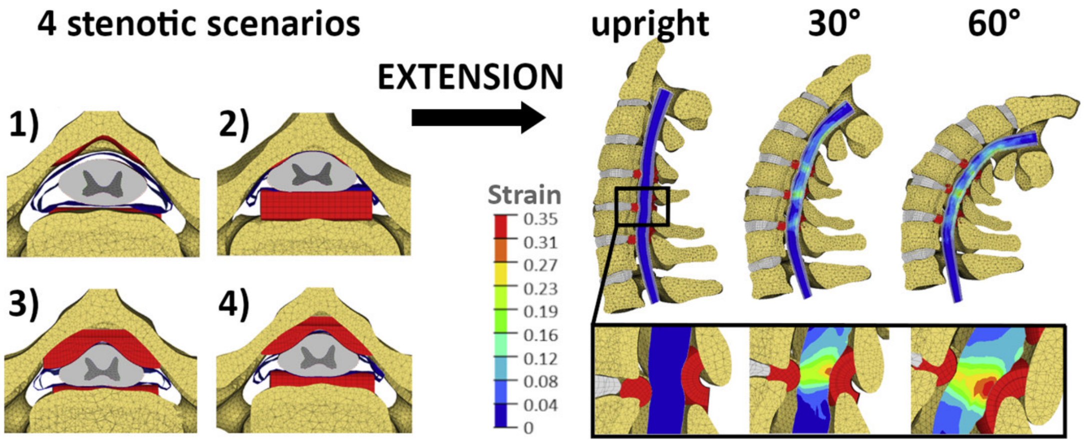

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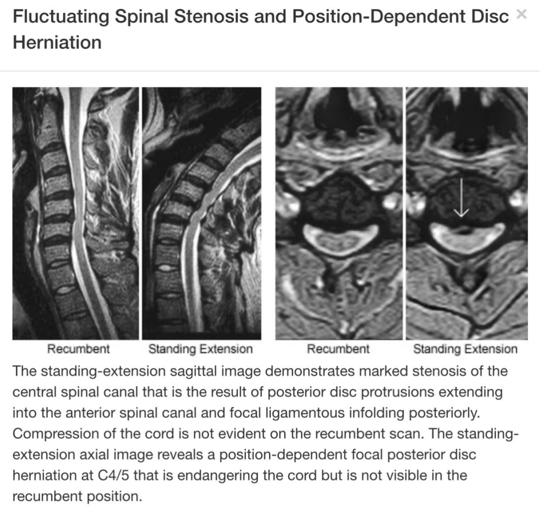
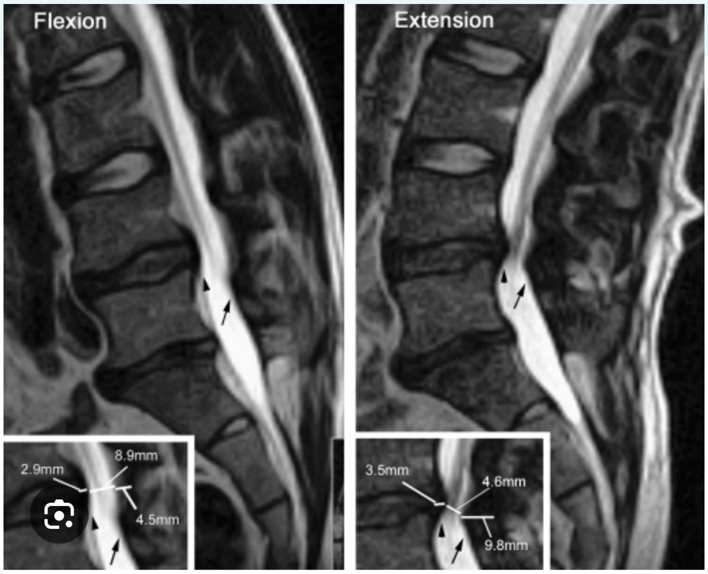
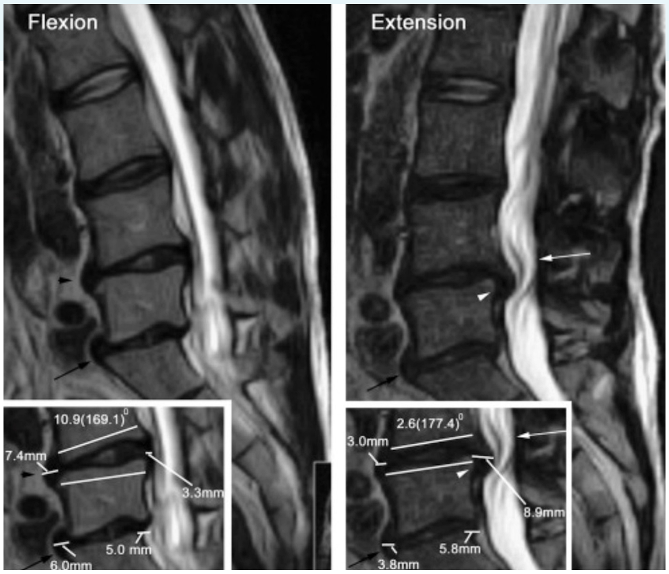
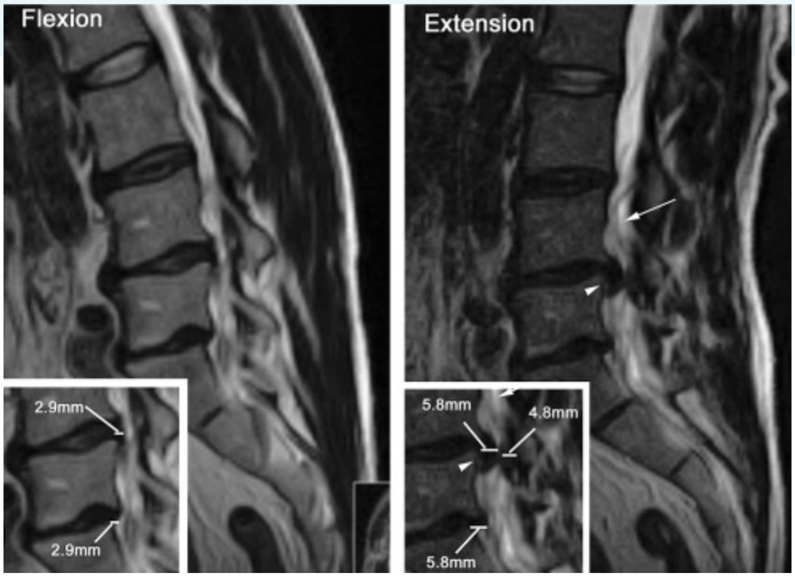


Fluctuating Spinal Stenosis and Position-Dependent Disc Herniation

The standing-extension sagittal image demonstrates marked stenosis of the central spinal canal that is the result of posterior disc protrusions extending into the anterior spinal canal and focal ligamentous infolding posteriorly. Compression of the cord is not evident on the recumbent scan. The standing-extension axial image reveals a position-dependent focal posterior disc herniation at C4/5 that is endangering the cord but is not visible in the recumbent position.


Flexion
Extension
2.9mm
8.9mm
4.5mm
3.5mm
4.6mm
9.8mm


Flexion
Extension
10.9(169.1)^0
7.4mm
3.3mm
5.0 mm
6.0mm
2.6(177.4)^0
3.0mm
8.9mm
5.8mm
3.8mm


Flexion
2.9mm
2.9mm
Extension
5.8mm
4.8mm
5.8mm

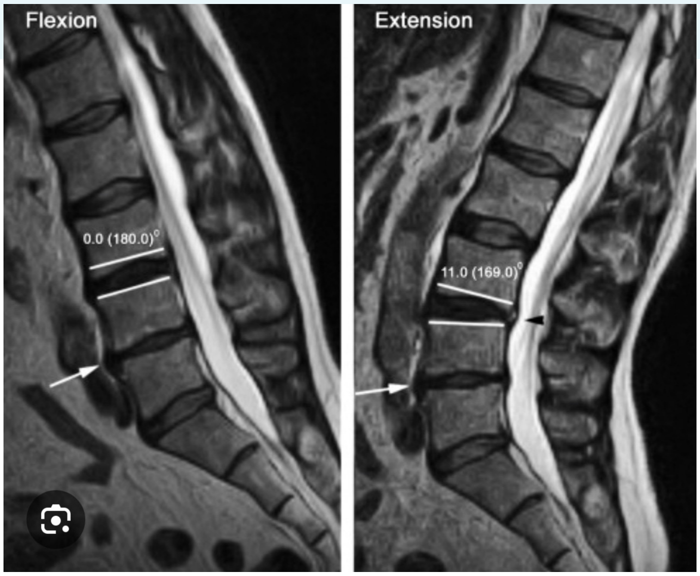
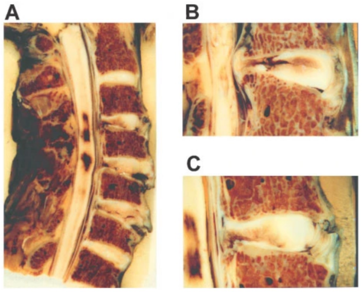

Flexion
0.0 (180.0)°
Extension
11.0 (169.0)°

Figure 1

From: Retropulsion of intervertebral discs associated with traumatic hyperextension of the cervical spine and absence of vertebral fracture: an uncommon mechanism of spinal cord injury



(**A**) Midsagittal section of cervical spine (left side hemisection) showing rupture of anterior longitudinal ligament, disc disruption at C$_{3-4}$, C$_{4-5}$, C$_{5-6}$, including herniation of C$_{4-5}$, and discrete foci of central cord hemorrhage. (**B**) C$_{3-4}$ disc (right hemisection) protrusion causing extradural cord compression. (**C**) C$_{3-4}$ disc (left hemisection) herniation causing extradural cord compression and central cord hemorrhage

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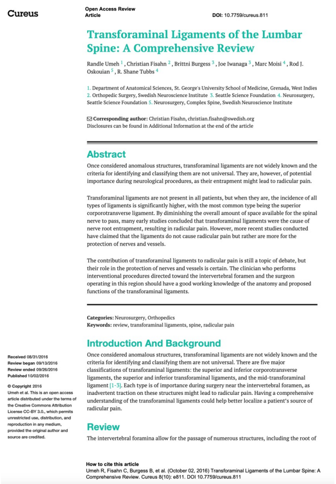

Cureus
Open Access Review Article
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Transforaminal Ligaments of the Lumbar Spine: A Comprehensive Review

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Disclosures can be found in Additional Information at the end of the article

Abstract

Once considered anomalous structures, transforaminal ligaments are not widely known and the criteria for identifying and classifying them are not universal. They are, however, of potential importance during neurological procedures, as their entrapment might lead to radicular pain.

Transforaminal ligaments are not present in all patients, but when they are, the incidence of all types of ligaments is significantly higher, with the most common type being the superior corporotransverse ligament. By diminishing the overall amount of space available for the spinal nerve to pass, many early studies concluded that transforaminal ligaments were the cause of nerve root entrapment, resulting in radicular pain. However, more recent studies conducted have claimed that the ligaments do not cause radicular pain but rather are more for the protection of nerves and vessels.

The contribution of transforaminal ligaments to radicular pain is still a topic of debate, but their role in the protection of nerves and vessels is certain. The clinician who performs interventional procedures directed toward the intervertebral foramen and the surgeon operating in this region should have a good working knowledge of the anatomy and proposed functions of the transforaminal ligaments.

Categories: Neurosurgery, Orthopedics
Keywords: review, transforaminal ligaments, spine, radicular pain

Introduction And Background

Once considered anomalous structures, transforaminal ligaments are not widely known and the criteria for identifying and classifying them are not universal. There are five major classifications of transforaminal ligaments: the superior and inferior corporotransverse ligaments, the superior and inferior transforaminal ligaments, and the mid-transforaminal ligament [1-3]. Each type is of importance during surgery near the intervertebral foramen, as inadvertent traction on these structures might lead to radicular pain. Having a comprehensive understanding of the transforaminal ligaments could help better localize a patient's source of radicular pain.

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Review

The intervertebral foramina allow for the passage of numerous structures, including the root of

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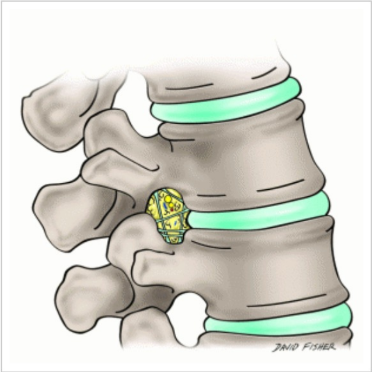


FIGURE 2-6. The transforaminal ligaments and relationship to the intervertebral foramina. (Courtesy of David Fisher.)

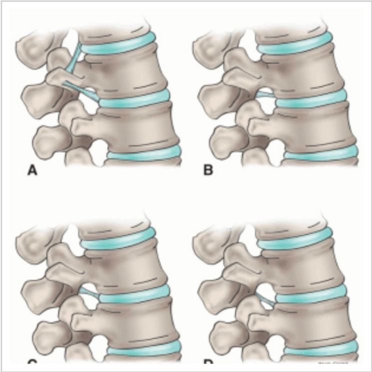
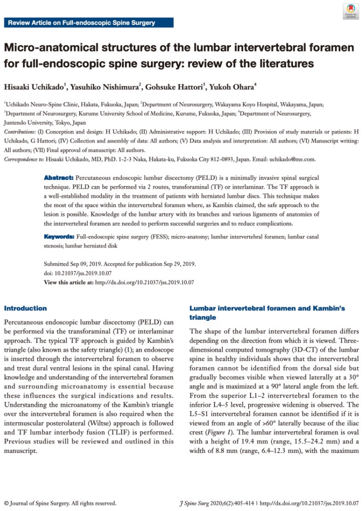


FIGURE 2-7. The transforaminal ligaments and relationship to the intervertebral foramina. (Courtesy of David Fisher.)



Review Article on Full-endoscopic Spine Surgery

Micro-anatomical structures of the lumbar intervertebral foramen for full-endoscopic spine surgery: review of the literatures

Hisaaki Uchikado[1], Yasuhiko Nishimura[2], Gohsuke Hattori[3], Yukoh Ohara[4]

[1]Uchikado Neuro-Spine Clinic, Hakata, Fukuoka, Japan; [2]Department of Neurosurgery, Wakayama Koyo Hospital, Wakayama, Japan; [3]Department of Neurosurgery, Kurume University School of Medicine, Kurume, Fukuoka, Japan; [4]Department of Neurosurgery, Juntendo University, Tokyo, Japan

Contributions: (I) Conception and design: H Uchikado; (II) Administrative support: H Uchikado; (III) Provision of study materials or patients: H Uchikado, G Hattori; (IV) Collection and assembly of data: All authors; (V) Data analysis and interpretation: All authors; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Hisaaki Uchikado, MD, PhD. 1-2-3 Naka, Hakata-ku, Fukuoka City 812-0893, Japan. Email: uchikado@me.com.

Abstract: Percutaneous endoscopic lumbar discectomy (PELD) is a minimally invasive spinal surgical technique. PELD can be performed via 2 routes, transforaminal (TF) or interlaminar. The TF approach is a well-established modality in the treatment of patients with herniated lumbar discs. This technique makes the most of the space within the intervertebral foramen where, as Kambin claimed, the safe approach to the lesion is possible. Knowledge of the lumbar artery with its branches and various ligaments of anatomies of the intervertebral foramen are needed to perform successful surgeries and to reduce complications.

Keywords: Full-endoscopic spine surgery (FESS); micro-anatomy; lumbar intervertebral foramen; lumbar canal stenosis; lumbar herniated disk

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Introduction

Percutaneous endoscopic lumbar discectomy (PELD) can be performed via the transforaminal (TF) or interlaminar approach. The typical TF approach is guided by Kambin's triangle (also known as the safety triangle) (1); an endoscope is inserted through the intervertebral foramen to observe and treat dural ventral lesions in the spinal canal. Having knowledge and understanding of the intervertebral foramen and surrounding microanatomy is essential because these influences the surgical indications and results. Understanding the microanatomy of the Kambin's triangle over the intervertebral foramen is also required when the intermuscular posterolateral (Wiltse) approach is followed and TF lumbar interbody fusion (TLIF) is performed. Previous studies will be reviewed and outlined in this manuscript.

Lumbar intervertebral foramen and Kambin's triangle

The shape of the lumbar intervertebral foramen differs depending on the direction from which it is viewed. Three-dimensional computed tomography (3D-CT) of the lumbar spine in healthy individuals shows that the intervertebral foramen cannot be identified from the dorsal side but gradually becomes visible when viewed laterally at a 30° angle and is maximized at a 90° lateral angle from the left. From the superior L1–2 intervertebral foramen to the inferior L4–5 level, progressive widening is observed. The L5–S1 intervertebral foramen cannot be identified if it is viewed from an angle of >60° laterally because of the iliac crest (*Figure 1*). The lumbar intervertebral foramen is oval with a height of 19.4 mm (range, 15.5–24.2 mm) and a width of 8.8 mm (range, 6.4–12.3 mm), with the maximum

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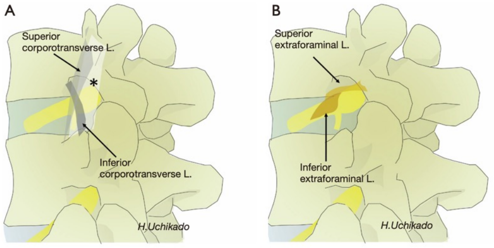
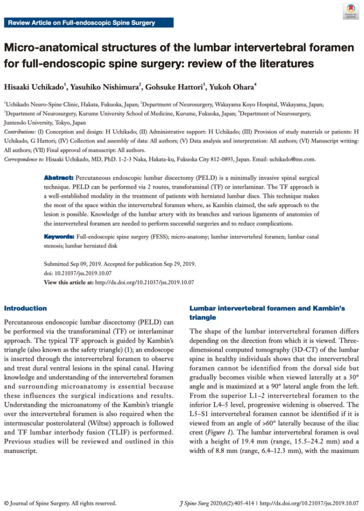


Figure 3 Schematic drawings of external ligaments of the intervertebral foramen. (A) Superior and inferior corporotransverse ligament (L), inter-transverse ligament (asterisk). (B) Superior and inferior extraforaminal ligament (L).



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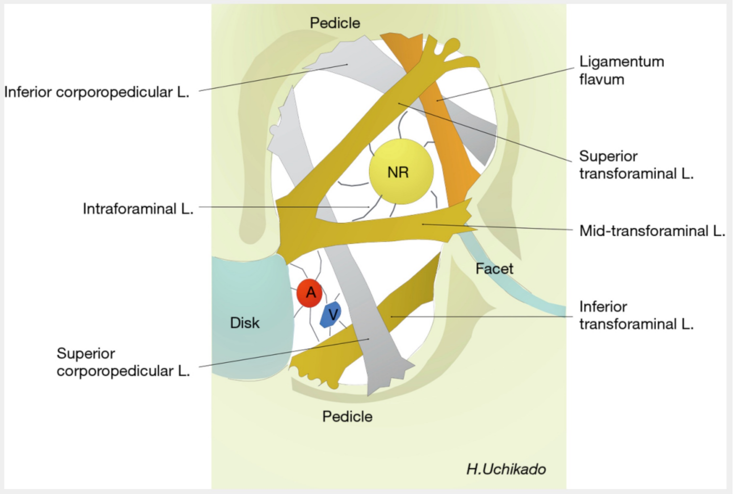

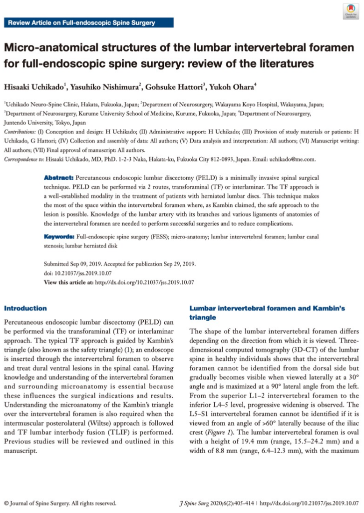

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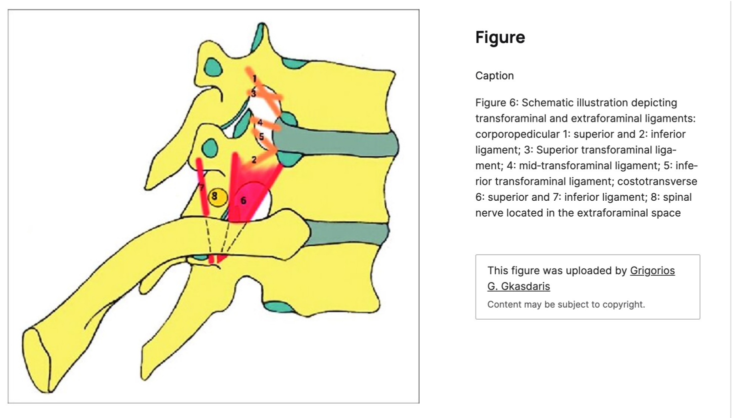

Figure

Caption

Figure 6: Schematic illustration depicting transforaminal and extraforaminal ligaments: corporopedicular 1: superior and 2: inferior ligament; 3: Superior transforaminal ligament; 4: mid-transforaminal ligament; 5: inferior transforaminal ligament; costotransverse 6: superior and 7: inferior ligament; 8: spinal nerve located in the extraforaminal space

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https://doi.org/10.1007/s00586-022-07153-7

ORIGINAL ARTICLE

In vivo detection of the lumbar intraforaminal ligaments by MRI

Jeanette Henkelmann[1] · Dina Wiersbicki[2] · Hanno Steinke[2] · Timm Denecke[1] · Christoph-Eckhard Heyde[3] · Anna Voelker[3]

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Abstract

Purpose Intraforaminal ligaments (IFL) are of great interest to anatomists and clinicians to fully understand the detailed anatomy of the neuroforamina and to diagnose unclear radicular symptoms. Studies published until now have described radiological imaging of the IFLs using magnetic resonance imaging (MRI) on donor bodies. In the present study, we investigated the detectability of lumbar IFLs in vivo in adults using the high spatial resolution of the constructive interference in steady state (CISS) sequence.

Methods A total of 14 patients were studied using a 1.5 T MRI scanner. The lumbar spine was imaged using the parasagittal CISS sequence, and the detectability of the IFLs was assessed for each lumbar level. All image datasets were analyzed by a radiologist, an orthopedic surgeon, and an anatomist. Interrater reliability was expressed as Fleiss' Kappa. Using a single data set, a three-dimensional (3D) model was created to map the location of the IFLs within the intervertebral foramen (IF) and the immediate surrounding vessels.

Results Overall, the radiologist was able to detect IFLs in 60% of all imaged IFs, the orthopedic surgeon in 62%, and the anatomist in 66%. Fleiss' Kappa for the various segments varies from 0.71 for L4/5 up to 0.90 for L3/4.

Conclusion Lumbar IFLs were successfully detected in vivo in every patient. The detection frequency varied from 42–86% per IF. We demonstrated reproducible imaging of the IFLs on MRI, with good interrater reliability. The present study was a launching point for further clinical studies investigating the potential impact of altered IFLs on radicular pain.

Keywords Clinical imaging · Magnetic resonance imaging · Lumbar spine · Intraforaminal ligaments · Radicular pain

Introduction

Symptoms in the area of the lumbar spine, such as low back pain and radicular pain, are among the most frequent reasons for consulting with patients in the clinical practice of orthopedics. To improve patient care, a comprehensive examination and thorough knowledge of the anatomical region is necessary. In most cases, radicular pain syndromes can be adequately explained by specific pathologies in the lumbar spine, such as disc herniation and neuroforaminal stenosis. However, patients frequently present with leg pain without a clear explanation in terms of etiology. In addition to spinal nerves, the intervertebral foramen (IF) contains blood vessels, lymphatic vessels, and the intraforaminal ligaments (IFLs). The IFLs divide the neuroforamen into different compartments [1] and function to protect the spinal nerves and connect and attach the spinal nerve to the bone of the IF via the surrounding connective tissue [2]. Hypothetically, thickening of the IFLs can lead to an affection of the spinal nerve in the IF, causing radicular leg pain.

In a previous study, we focused on the anatomy of the lumbar IFLs and their close topographical relationship to the lumbar spinal nerves [3]. According to Lee et al. [4], the IF can be divided into an entrance zone (medial side of the pedicle and superior articular process), a mid-zone (below the pedicle and the pars articular is of the lamina), and an exit zone (surrounding the IF). The IFLs were then

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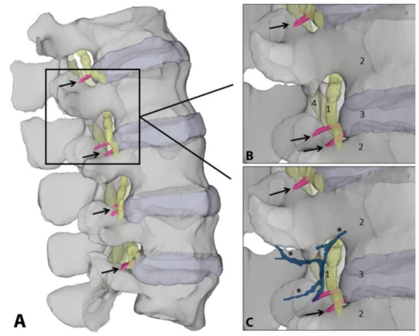
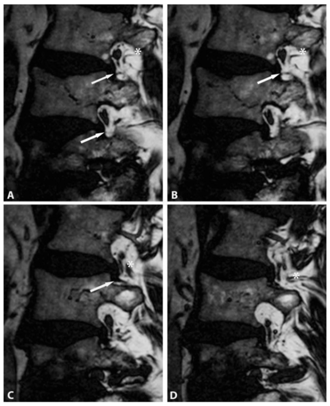
Fig. 3

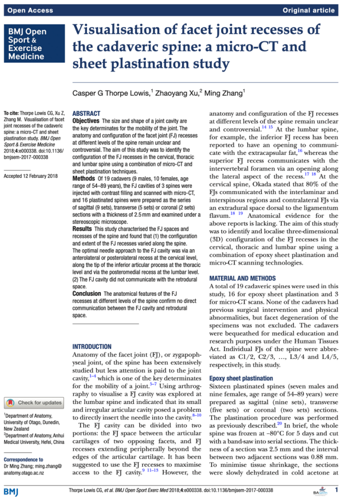


Three-dimensional (3D) reconstruction of the lumbar spine using the magnetic resonance imaging (MRI) data from the three-dimensional (3D) constructive interference in steady state (CISS) sequence of a 66-year-old male proband, illustrating the anatomical course of the detected intraforaminal ligaments (black arrow) inside the intervertebral foramina: 1—spinal nerve root, 2—vertebral body, 3—intervertebral disc, 4—ligamenta flava; **a** shows a semitransparent overview, in a right lateral view; **b** is a semitransparent lateral close-up of the intervertebral foramina at L2/3; **c** is **a** with additional reconstruction of the small vessels

Fig. 2



Sagittal magnetic resonance imaging (MRI) three-dimensional (3D) constructive interference in steady state (CISS) sequence of a 66 year-old male proband: the lumbar spine is seen from the vertebral body L1 to L3; **a** and **b**, as well as **c** and **d**, are consecutive slices; the inferior intervertebral ligament is highlighted with an arrow, and the small vessels are marked with white stars



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Methods Of 19 cadavers (9 males, 10 females, age range of 54–89 years), the FJ cavities of 3 spines were injected with contrast filling and scanned with micro-CT, and 16 plastinated spines were prepared as the series of sagittal (9 sets), transverse (5 sets) or coronal (2 sets) sections with a thickness of 2.5 mm and examined under a stereoscopic microscope.

Results This study characterised the FJ spaces and recesses of the spine and found that (1) the configuration and extent of the FJ recesses varied along the spine. The optimal needle approach to the FJ cavity was via an anterolateral or posterolateral recess at the cervical level, along the tip of the inferior articular process at the thoracic level and via the posteromedial recess at the lumbar level. (2) The FJ cavity did not communicate with the retrodural space.

Conclusion The anatomical features of the FJ recesses at different levels of the spine confirm no direct communication between the FJ cavity and retrodural space.

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The FJ cavity can be divided into two portions: the FJ space between the articular cartilages of two opposing facets, and FJ recesses extending peripherally beyond the edges of the articular cartilage. It has been suggested to use the FJ recesses to maximise access to the FJ cavity.[9 11–13] However, the anatomy and configuration of the FJ recesses at different levels of the spine remain unclear and controversial.[14 15] At the lumbar spine, for example, the inferior FJ recess has been reported to have an opening to communicate with the extracapsular fat,[16] whereas the superior FJ recess communicates with the intervertebral foramen via an opening along the lateral aspect of the recess.[17 18] At the cervical spine, Okada stated that 80% of the FJs communicated with the interlaminar and interspinous regions and contralateral FJs via an extradural space dorsal to the ligamentum flavum.[18 19] Anatomical evidence for the above reports is lacking. The aim of this study was to identify and localise three-dimensional (3D) configuration of the FJ recesses in the cervical, thoracic and lumbar spine using a combination of epoxy sheet plastination and micro-CT scanning technologies.

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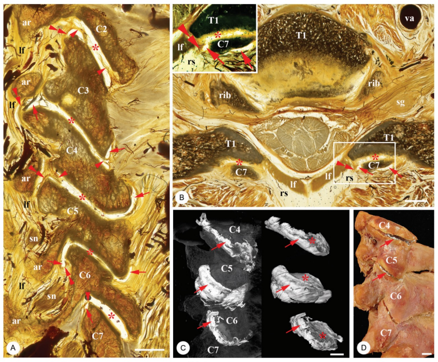
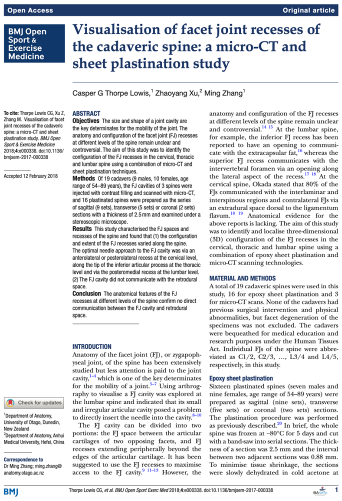


Figure 1 The facet joint (FJ) recesses at C2–C7 levels. (A) Sagittal view of the FJ spaces (asterisks) and recesses (arrows) of the C2–C7 FJ cavities. Arrowheads point to the synovial folds. Double arrowheads point to the synovial capsule dorsal to the lf which attaches to the vertebral ar. (B) Transverse view of the spaces (asterisks) and recesses (arrows) of the inferior part of the C7/T1 FJ cavity. The inset is a phase-contrast view of the line box in (B), showing that the FJ capsule (double arrowheads) separates the FJ recess (arrows; a real space) from the rs (an adipose potential space) which lies dorsal to the lf. (C) Lateral views of the three-dimensional reconstruction model of the recesses (arrows) and spaces (asterisks) of the C4–C7 FJ cavities with and without vertebrae. (D) Lateral view of a cadaveric specimen showing the partially opened C4–C7 FJ cavities (arrows) with the contrast filling after micro-CT scanning (C). ar, arch; C2–T1, the order of the vertebrae; lf, ligamentum flavum; rs, retrodural space; sg, spinal ganglion; sn, spinal nerve; va, vertebral artery. Bars, 5 mm.



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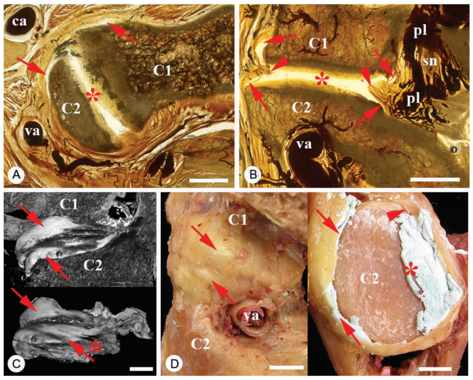
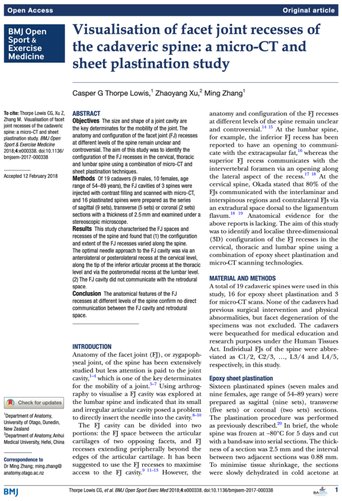


Figure 2 The C1/C2 facet joint (FJ) recesses. (A) Transverse view of the space (asterisk) and recesses (arrows) of a left C1/C2 FJ cavity. (B) Sagittal view of the space (asterisk) and recesses (arrows) of the C1/C2 FJ cavity. Arrowheads point to the synovial folds. Note the pl and sn posterior to the FJ cavity. (C) Lateral views of the three-dimensional reconstruction model of the recesses (arrows) and space (asterisk) of a C1/C2 FJ cavity with and without the vertebrae after micro-CT scanning. (D) The intact and opened C1/C2 FJ specimen after a contrast filling injection and micro-CT scanning (C). Arrows point to the FJ recesses and asterisk indicates the FJ space. C1–C2, the first and second cervical vertebrae; ca, carotid artery; pl, vascular plexus; sn, spinal nerve; va, vertebral artery. Bars, 5 mm.



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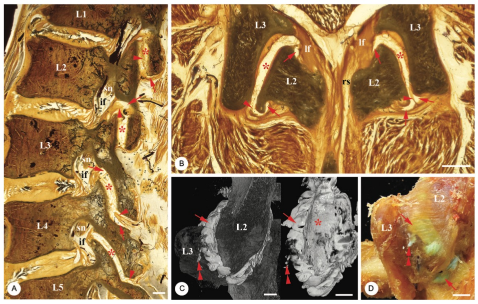

Figure 3 The facet joint (FJ) recesses at L1–L5 levels. (A) Sagittal view of the spaces (asterisks) and recesses (arrows) of the L1–L5 FJ cavities. Arrowheads point to the synovial folds. The spinal nerve (sn) is anterior and superior to the FJ and in the intervertebral foramen (if). (B) Transverse view of the spaces (asterisks) and recesses (arrows) of the L2/L3 FJ cavity. Arrowheads point to the synovial folds. Retrodural space (rs) is posterior to the ligamentum flavum (lf). (C) Posterior views of the three-dimensional reconstruction model of the space (asterisk) and recesses (arrows) of the L2/L3 FJ cavity in D with and without the vertebrae. Double arrowheads point to the contrast filling injection site. (D) Posterior view of the L2/L3 FJ specimen after contrast filling injection (double arrowheads). Arrows point to the recesses. L1–L5, the order of the vertebrae. Bars, 5 mm.

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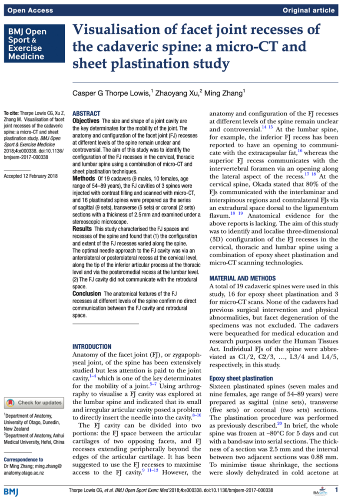

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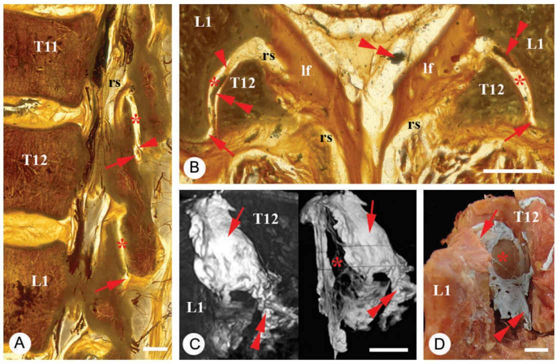

Figure 4 The facet joint (FJ) recesses at T11–L1 levels. (A) Sagittal view of the spaces (asterisks) and recesses (arrows) of the T11–L1 FJ cavities. (B) Transverse view of the spaces (asterisks) and recesses (arrows) of the T12/L1 FJ cavities. Arrowhead points to the synovial fold. Retrodural space (rs) is posterior to the ligamentum flavum (lf). Double arrowheads point to the saw dust. (C) Posterior views of the three-dimensional reconstruction model of the space (asterisk) and recesses (arrows) of the T12/L1 FJ cavity with and without the vertebrae. Double arrowheads point to the injection site. (D) Posterior view of the space (asterisk) and recess (arrow) of the opened T12/L1 FJ (C) after contrast filling injection (double arrowheads) and micro-CT scanning. T11–L1, the order of the vertebrae; Bars, 5 mm.

The Utility of MRI

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Role of magnetic resonance imaging in acute spinal trauma: a pictorial review

Yogesh Kumar[1] and Daichi Hayashi[1,2*]

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According to American College of Radiology (ACR) appropriateness criteria, MRI of spine combined with

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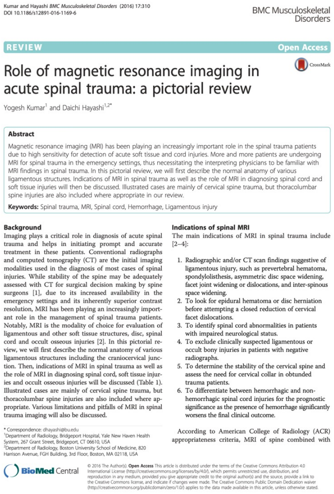
- **According to American College of Radiology (ACR) appropriateness criteria,** MRI of spine combined with CT scan is appropriate in the setting of acute spinal trauma if [5]:
  - National Emergency X-Radiography Utilization Study (NEXUS) or Canadian Cervical-Spine Rule (CCR) criteria are met and there are clinical findings of myelopathy.
  - NEXUS or CCR criteria are met and there are clinical or imaging findings to suggest ligamentous injury.
  - NEXUS or CCR criteria indicate imaging and the mechanically unstable spine is anticipated.



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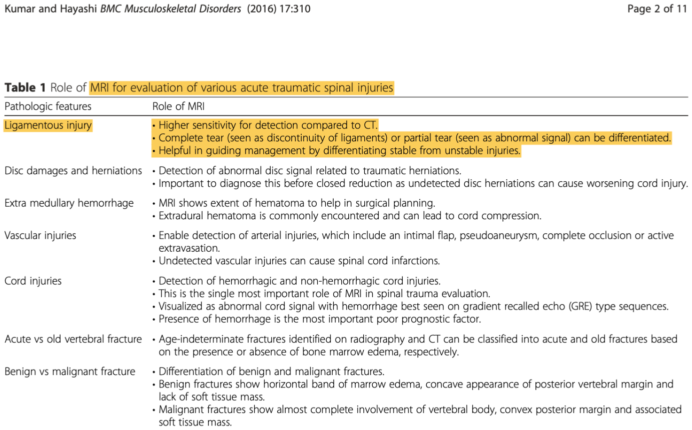

Table 1 Role of MRI for evaluation of various acute traumatic spinal injuries

Pathologic features	Role of MRI
Ligamentous injury	• Higher sensitivity for detection compared to CT. • Complete tear (seen as discontinuity of ligaments) or partial tear (seen as abnormal signal) can be differentiated. • Helpful in guiding management by differentiating stable from unstable injuries.
Disc damages and herniations	• Detection of abnormal disc signal related to traumatic herniations. • Important to diagnose this before closed reduction as undetected disc herniations can cause worsening cord injury.
Extra medullary hemorrhage	• MRI shows extent of hematoma to help in surgical planning. • Extradural hematoma is commonly encountered and can lead to cord compression.
Vascular injuries	• Enable detection of arterial injuries, which include an intimal flap, pseudoaneurysm, complete occlusion or active extravasation. • Undetected vascular injuries can cause spinal cord infarctions.
Cord injuries	• Detection of hemorrhagic and non-hemorrhagic cord injuries. • This is the single most important role of MRI in spinal trauma evaluation. • Visualized as abnormal cord signal with hemorrhage best seen on gradient recalled echo (GRE) type sequences. • Presence of hemorrhage is the most important poor prognostic factor.
Acute vs old vertebral fracture	• Age-indeterminate fractures identified on radiography and CT can be classified into acute and old fractures based on the presence or absence of bone marrow edema, respectively.
Benign vs malignant fracture	• Differentiation of benign and malignant fractures. • Benign fractures show horizontal band of marrow edema, concave appearance of posterior vertebral margin and lack of soft tissue mass. • Malignant fractures show almost complete involvement of vertebral body, convex posterior margin and associated soft tissue mass.

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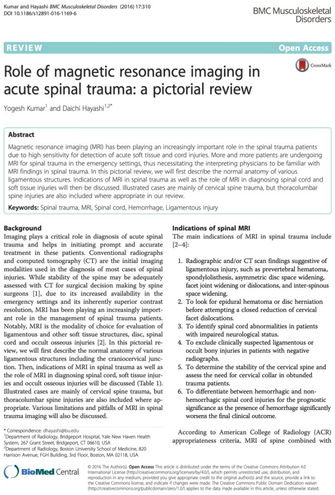
- **Technical Considerations for MRI**
  - The typical MRI protocol for spinal injury includes:
    - sagittal T1 weighted (T1W) and T2 weighted (T2W) spin echo sequences,
    - and T2* weighted (T2*W) gradient recalled echo (GRE) sequence,
    - and sagittal short tau inversion recovery (STIR) sequences,
    - as well as axial T2W and T2*W GRE sequences.
    - T1W images are mainly used for depiction of anatomy and osseous fractures.



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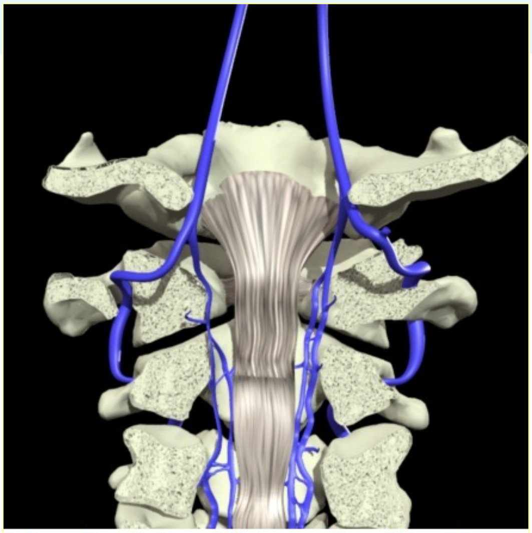
- **Technical Considerations for MRI**
  - STIR images are very sensitive for detection of edema and is helpful in diagnosing the soft tissue and ligamentous injuries, particularly of the interspinous or supraspinous ligaments.
  - Although fat-suppressed T2W images can also be used for detection of edema, STIR images provide more uniform fat suppression.
  - T2W images are very good in detecting the cord edema, and T2*W GRE images are used to detect the hemorrhage in and around the cord [6].
  - Recently, diffusion tensor imaging (DTI) has been used to detect trauma related changes in the spinal cord which are not seen on conventional MRI technique [7, 8].
  - Ideally MRI should be performed within 72 hours of injury as the T2 hyperintensity produced by edema improves the conspicuity of the ligaments which are seen as low signal intensity in normal state [9].
  - Later on, resolution of the edema and hemorrhage reduces sensitivity of MRI to detect ligamentous injuries.

Clinical Anatomy – MRI of Injured Ligaments

Magnetic Resonance Imaging Assessment of Craniovertebral Ligaments and Membranes After Whiplash Trauma

Krakenes, Jostein MD, PhD*; Kaale, Bertel R. MT *Spine*. Volume 31(24), 15 November 2006, pp 2820-2826

- By use of high-resolution MRI, it is possible to assess ligaments and membranes in the craniovertebral junction with reasonable reliability.
- Significantly more high-grade lesions in a whiplash injured than in a noninjured population.
- There is association between high-grade changes in the alar ligaments and clinical impairment.
- There is association between specific lesions and specific trauma mechanisms.



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A, Normal anatomy. The tectorial membrane (arrows) is fused with the dura mater and extends from the C2 body to the clivus. The posterior atlanto-occipital membrane (arrowheads), also fused with the dura mater, extends from the posterior arch of the atlas to the occipital bone.

From: **Krakenes: Spine, Volume 31(24).November 15, 2006. 2820-2826**

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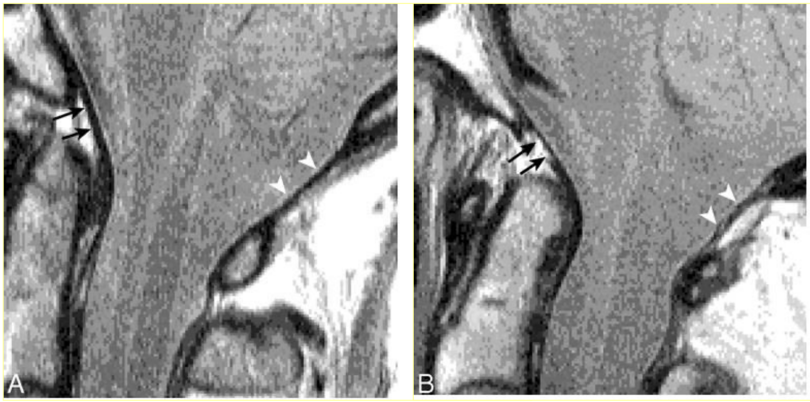
B, A 40-year-old woman sustaining frontal collision 4 years previously. Upper part of the tectorial membrane (arrows) is absent; only the dura is shown.

From: **Krakenes: Spine, Volume 31(24).November 15, 2006. 2820-2826**



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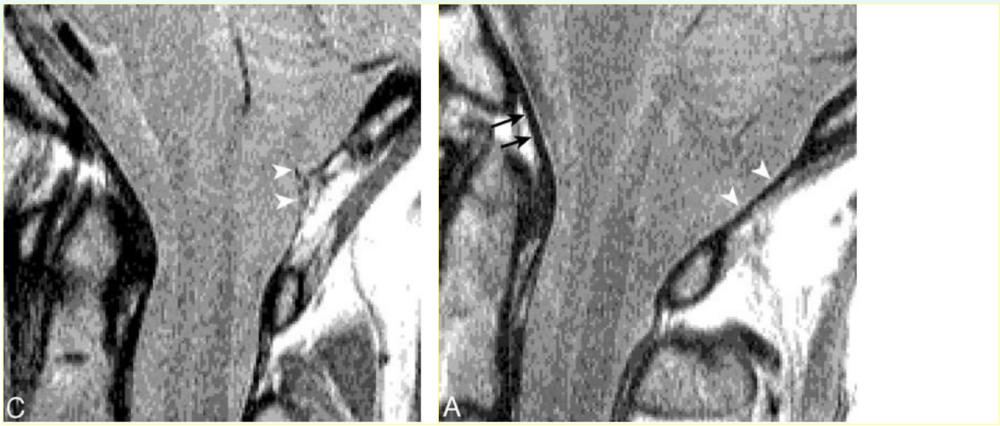

C, A 46-year-old woman sustaining rear-end collision 11 years previously. The flap combined with thinning of the atlanto-occipital membrane/dura complex was classified as Grade 3 (arrowheads).

From: **Krakenes: Spine, Volume 31(24).November 15, 2006. 2820-2826**

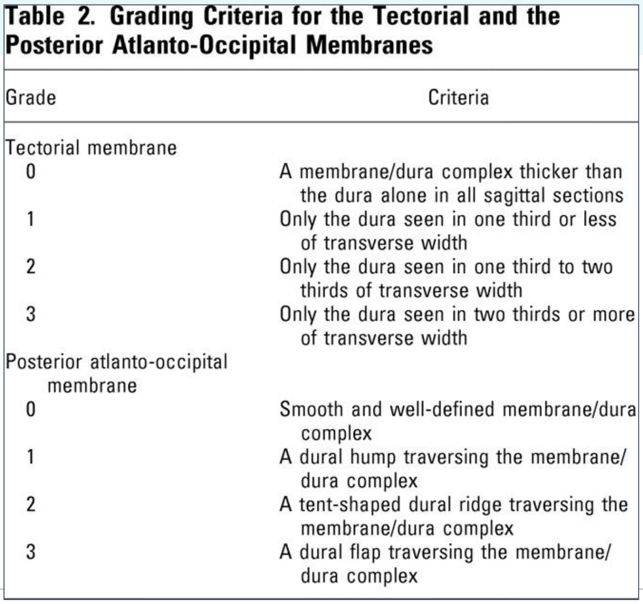

Table 2. Grading Criteria for the Tectorial and the Posterior Atlanto-Occipital Membranes

Grade	Criteria
Tectorial membrane	
0	A membrane/dura complex thicker than the dura alone in all sagittal sections
1	Only the dura seen in one third or less of transverse width
2	Only the dura seen in one third to two thirds of transverse width
3	Only the dura seen in two thirds or more of transverse width
Posterior atlanto-occipital membrane	
0	Smooth and well-defined membrane/dura complex
1	A dural hump traversing the membrane/dura complex
2	A tent-shaped dural ridge traversing the membrane/dura complex
3	A dural flap traversing the membrane/dura complex

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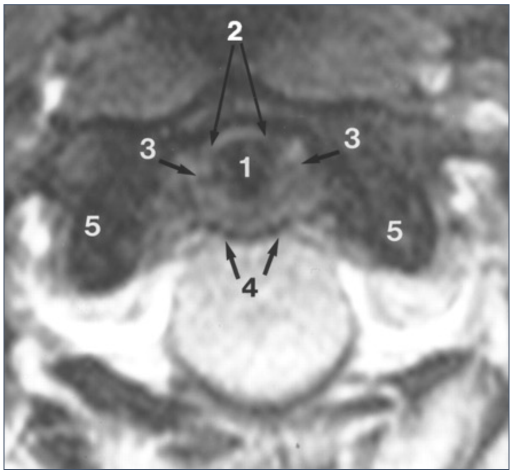
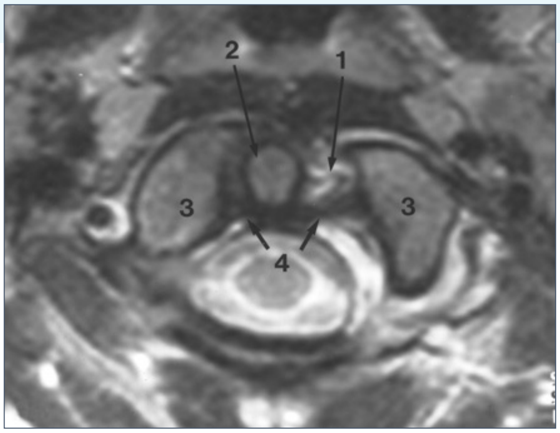


Dens (1), presumed anterior atlantodental ligaments (2), alar ligaments (3), transverse ligament (4), and lateral masses of C1 (5).

MR Imaging Findings in Spinal Ligamentous Injury
Benedetti et al. ***AJR 2000; 175:661-665***



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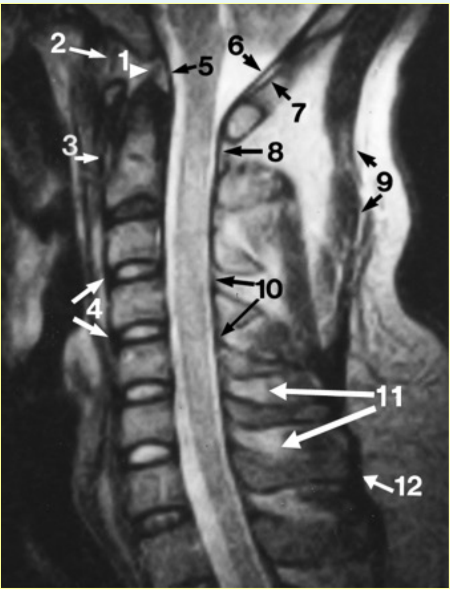
Left alar ligament tear in 19-year-old woman with severe neck pain after fall on her head while snowboarding. Fixed deviation of dens to right was seen on radiograph (not shown):

- C1-2 rotatory subluxation was suspected.
- Isolated tear of left alar ligament (1) and deviation of dens (2) toward right with respect to lateral masses of C2 (3).
- Transverse ligament (4) is intact.

Sagittal images (not shown) depict normal alignment of occipital condyles with C2, thus no rotatory subluxation is present.

CT performed before MR imaging was negative for fracture and fixed rotatory subluxation.



Normal apical ligament (1), anterior occipitoatlantal membrane (2), anterior atlantoaxial membrane (3), anterior longitudinal ligament (4), tectorial membrane (5), dural reflection (6), posterior occipitoatlantal membrane (7), posterior atlantoaxial membrane (8), nuchal ligament (9), flaval ligaments (10), area of interspinous ligaments (11), and supraspinous ligament (12).

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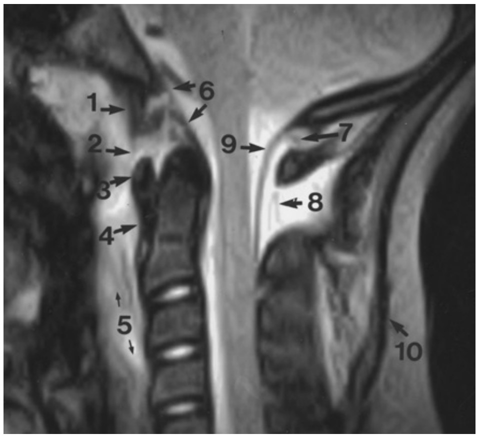

Occipitoatlantal dislocation in 11-year-old boy who was neurologically intact after motor vehicle crash. Intact (1) and torn (2) portions of anterior occipitoatlantal membrane, anterior arch of C1 (3), intact anterior atlantoaxial membrane (4), prevertebral edema or hemorrhage (5), torn tectorial membrane (6), torn posterior occipitoatlantal membrane (7), torn posterior atlantoaxial membrane (8), intact dural reflection (9), and intact nuchal ligament (10). Before MR imaging, full extent of injury and degree of instability were not appreciated either clinically or from results of radiographs or CT scans. Patient underwent surgical fusion shortly thereafter.

MR Imaging Findings in Spinal Ligamentous Injury
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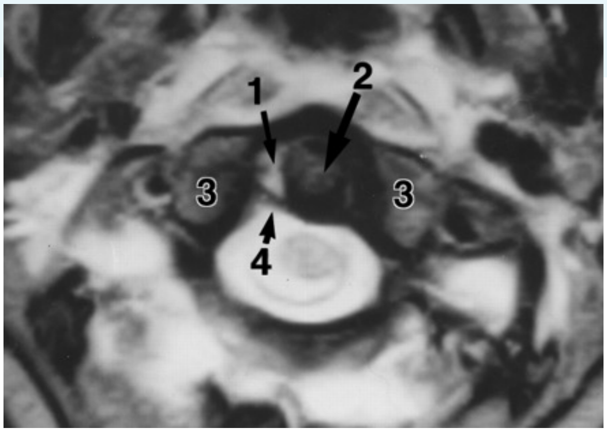

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MR Imaging Findings in Spinal Ligamentous Injury
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Fig. 10.—Hyperextension injury in 71-year-old man who fell from bicycle and presented with central cord syndrome. Sagittal T2-weighted MR image (TR/TE, 4500/117) obtained on 0.3-T MR scanner shows flaval ligament hypertrophy (1), C5–6 posterior disk protrusion (2), anterior longitudinal ligament tear, and partial disruption of C5–6 intervertebral disk (3).

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Fig. 11.—6-year-old boy with cervical spine hyperextension injury during motor vehicle crash. Sagittal fast spin-echo inversion-recovery MR image (TR/TE, 3000/51; inversion time, 140 msec) obtained on 1.5-T MR scanner shows horizontal fracture through inferior endplate of C6 (1), posterior longitudinal ligament tear (2), cord contusion (3), anterior longitudinal ligament tear (4), prevertebral hemorrhage or edema (5), and extradural hemorrhage (6). MR imaging findings guided therapy resulting in anterior surgical fusion.

Teardrop fracture of C7 in 27-year-old man involved in motor vehicle crash. Extensive posterior paravertebral edema or hemorrhage and probable tearing of interspinous ligaments (1), partial tear of nuchal ligament (2), flaval ligament tear (3), partial tear of posterior longitudinal ligament (4), anterior superior corner fracture of C7 vertebral body (5), stripping of anterior longitudinal ligament from anterior surface of C7 vertebral body (6), and prevertebral edema or hemorrhage (7).

MR Imaging Findings in Spinal Ligamentous Injury
Benedetti et al. *AJR 2000; 175:661-665*

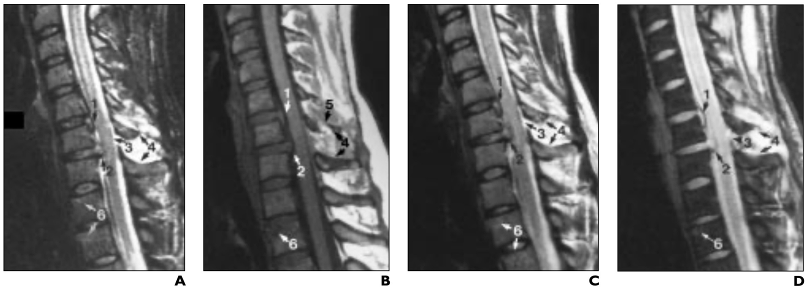

Fig. 9.—35-year old woman involved in head-on motor vehicle collision who presented with severe neck pain, right arm pain, and numbness. Radiographs and CT scans (not shown) showed negative findings. Four pulse sequences from a 1.0-T MR scanner at midsagittal level are provided to allow reader to compare and contrast abnormalities. Findings include disk extrusion and inferior stripping of posterior longitudinal ligament at C5–6 (1); disk extrusion and tear of posterior longitudinal ligament and annulus fibrosus at C6–7 (2); flaval ligament tear at C6–7 (3); splaying of dorsal spines and interspinous ligament tear at C6–7 (4); fracture of C6 spinous process (5); and mild superior endplate impaction fractures of T1, T2, and T3 vertebral bodies (6). Solely on basis of results of MR images, the following day patient was started in traction and taken to surgery where anterior diskectomy and fusion at C5–6 and C6–7 were performed. Patient experienced immediate marked improvement in symptoms after surgery.

A, Fast spin-echo inversion-recovery sagittal MR image (TR/TE, 4000/60; inversion time, 140 msec) best shows bone marrow edema caused by fracture or trabecular contusion, spinal cord injury, and soft-tissue edema.

B, T1-weighted MR image (500/15) is helpful in showing anatomic detail and alignment and in detecting fracture.

C, T2-weighted fast spin-echo MR images (3500/90), like this one, are often best for showing ligaments, blood in spinal cord, bone marrow edema, and soft-tissue edema.

D, Gradient-echo MR images (500/18; flip angle, 30°), like this one, are often best for showing ligaments and blood in spinal cord.

AJR:175, September 2000 663

Kumar and Hayashi *BMC Musculoskeletal Disorders* (2016) 17:310

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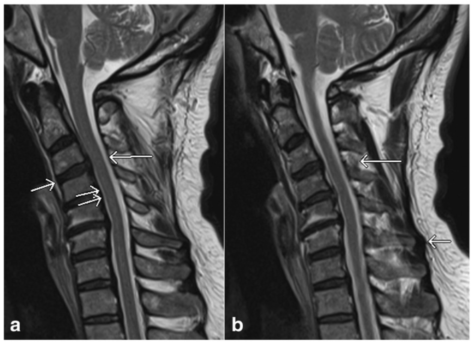


Fig. 2 Sagittal T2 weighted image (**a**) shows normal anterior longitudinal ligament (*short single arrow*), posterior longitudinal ligament (*short double arrows*) and ligamentum flavum (*long arrow*). Sagittal T2 weighted image (**b**) shows normal wavy supraspinous ligament (*short arrow*), and normal striated interspinous ligament (*long arrow*)

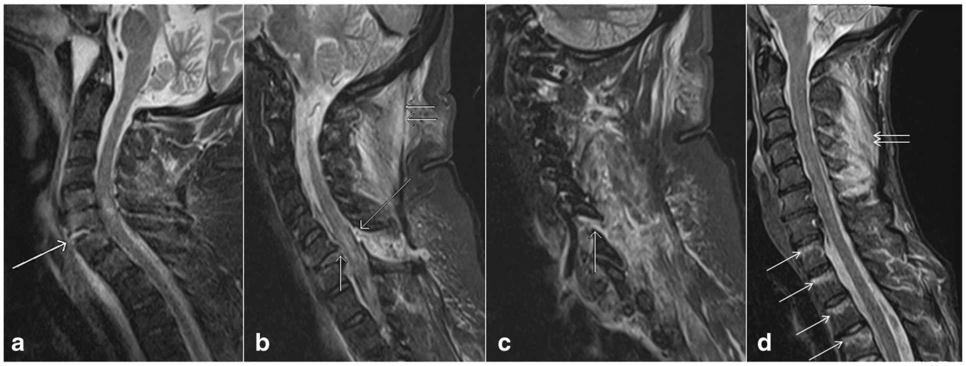
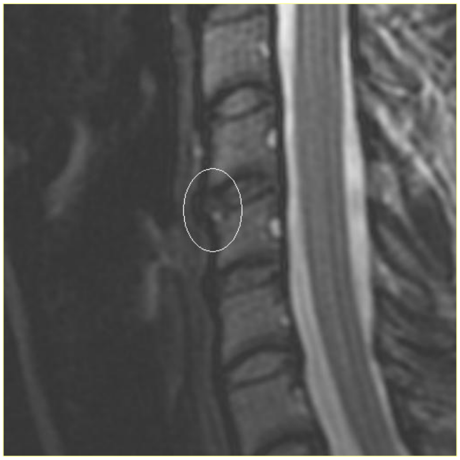


Fig. 3 Sagittal short tau inversion recovery (STIR) images show complete anterior longitudinal ligament tear (*arrow*, **a**), complete posterior longitudinal ligament tear (*short single arrow*, **b**) and ligamentum flavum tear (*long arrow*, **b**), ligamentum nuchae tear (*short double arrows*, **b**), facet capsular injury (*arrow*, **c**), and interspinous ligament injury (*short double arrows*, **d**). Also note the presence of thoracic vertebrae contusions (*arrows*, **d**)

Instructive Case…



A 30 year old female was involved in a MVC. Despite 6-months of chiropractic care, she reports persistent symptoms.

The MRI was interpreted as normal.

What do you see that refutes that reading?

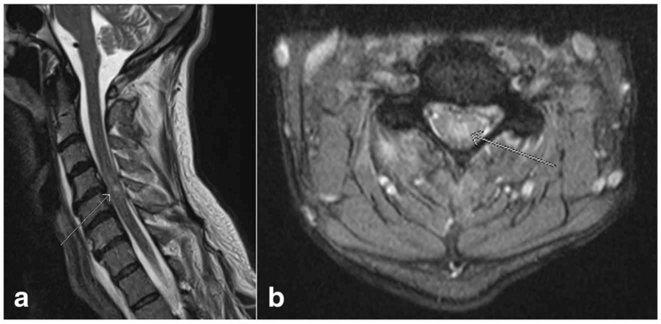


Fig. 7 Sagittal T2 weighted image (**a**) and axial gradient recalled echo (GRE) image (**b**) show the presence of nonhemorrhagic contusion in the spinal cord (*arrows*)

Kumar and Hayashi *BMC Musculoskeletal Disorders* (2016) 17:310 Page 7 of 11

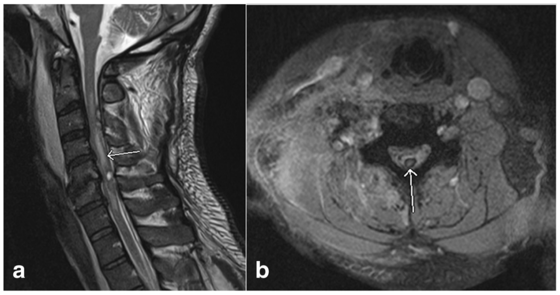
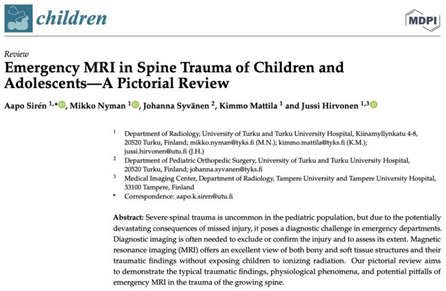


Fig. 8 Sagittal T2 weighted image (**a**) and axial gradient recalled echo (GRE) image (**b**) show the presence of hemorrhagic contusion (*arrow*, **a**) in the spinal cord characterized by susceptibility artifact on GRE image (*arrow*, **b**)

Fig. 9 Sagittal CT image in the bone window (**a**) did not show any CT evidence for a fracture in this trauma patient. However, sagittal short tau inversion recovery (STIR) image (**b**) shows bone marrow edema in the superior aspect of multiple vertebrae (*arrows*) suggesting bone contusions

Fig. 10 Sagittal short tau inversion recovery image shows prevertebral edema/hemorrhage (*short arrow*) and paraspinal muscle edema suggesting muscle injuries (*long arrow*)



children
MDPI

Review

Emergency MRI in Spine Trauma of Children and Adolescents—A Pictorial Review

Aapo Sirén [1,*], Mikko Nyman [1], Johanna Syvänen [2], Kimmo Mattila [1] and Jussi Hirvonen [1,3]

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Abstract: Severe spinal trauma is uncommon in the pediatric population, but due to the potentially devastating consequences of missed injury, it poses a diagnostic challenge in emergency departments. Diagnostic imaging is often needed to exclude or confirm the injury and to assess its extent. Magnetic resonance imaging (MRI) offers an excellent view of both bony and soft tissue structures and their traumatic findings without exposing children to ionizing radiation. Our pictorial review aims to demonstrate the typical traumatic findings, physiological phenomena, and potential pitfalls of emergency MRI in the trauma of the growing spine.

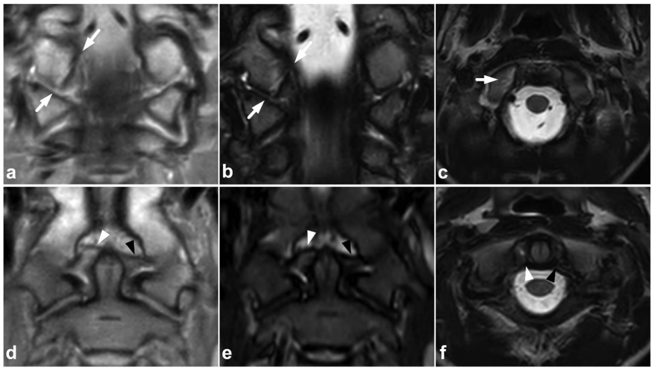
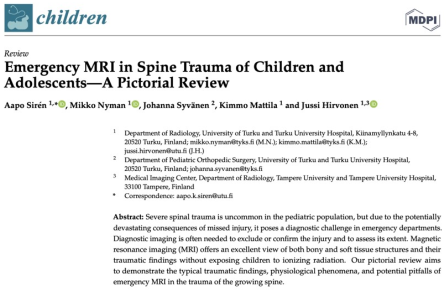


Figure 4. (**a**) Coronal PD-weighted. (**b**) Coronal T2-weighted. (**c**) Axial T2-weighted. (**d**) Coronal PD-weighted. (**e**) Coronal STIR. (**f**) Axial T2-weighted. A 13-year-old male, motor vehicle accident. Avulsion fracture (arrows) of the right alar ligament origo in the occipital condyle, minor dislocation. The right alar ligament (white arrowheads) is swollen and loose but not completely torn. An intact left alar ligament is marked with black arrowheads.



children

Review

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Abstract: Severe spinal trauma is uncommon in the pediatric population, but due to the potentially devastating consequences of missed injury, it poses a diagnostic challenge in emergency departments. Diagnostic imaging is often needed to exclude or confirm the injury and to assess its extent. Magnetic resonance imaging (MRI) offers an excellent view of both bony and soft tissue structures and their traumatic findings without exposing children to ionizing radiation. Our pictorial review aims to demonstrate the typical traumatic findings, physiological phenomena, and potential pitfalls of emergency MRI in the trauma of the growing spine.

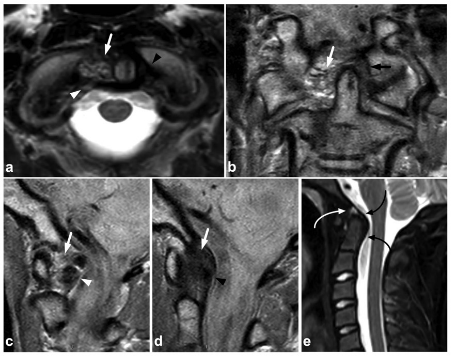
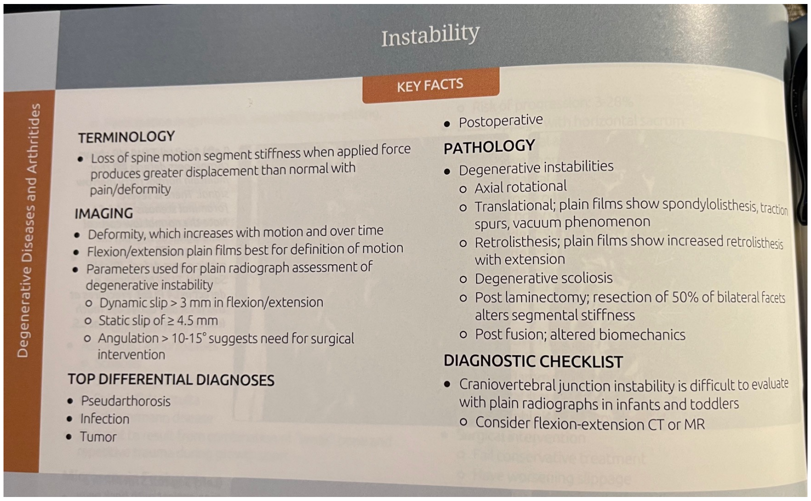


Figure 8. (**a**) Axial T2-weighted. (**b**) Coronal PD-weighted. (**c**) Right-sided off-midline sagittal PD-weighted. (**d**) Sagittal PD-weighted. (**e**) Sagittal STIR. A 12-year-old male, football injury. The right alar ligament (white arrows) is torn. The right side of the transversal ligament is thickened and heterogenous, suggesting a partial distension injury (white arrowheads). The left alar ligament (black arrows) and the central and left-sided portions of the transversal ligament (black arrowheads) are intact. The tectorial membrane is unharmed (curved black arrows), but the apical ligament of the dens is poorly visible, probably torn (curved white arrow). Apparent asymmetry of the lateral atlantodental intervals is seen, but there are no signs of occipitocervical or atlantoaxial joint capsule disruption.

Instability

Ross and Moore – Diagnostic Imaging Spine



Degenerative Diseases and Arthritides

Instability

KEY FACTS

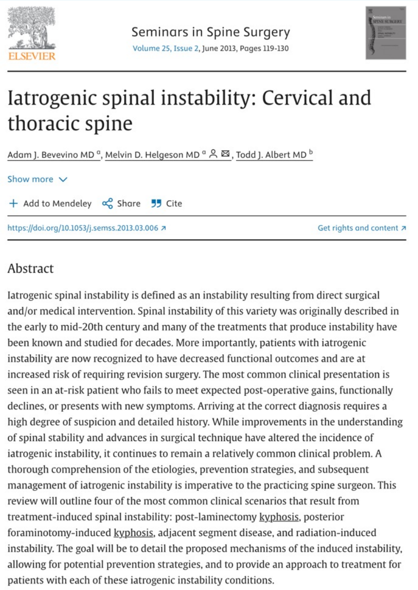
TERMINOLOGY
- Loss of spine motion segment stiffness when applied force produces greater displacement than normal with pain/deformity

IMAGING
- Deformity, which increases with motion and over time
- Flexion/extension plain films best for definition of motion
- Parameters used for plain radiograph assessment of degenerative instability
  - Dynamic slip > 3 mm in flexion/extension
  - Static slip of ≥ 4.5 mm
  - Angulation > 10-15° suggests need for surgical intervention

TOP DIFFERENTIAL DIAGNOSES
- Pseudarthorosis
- Infection
- Tumor
- Postoperative

PATHOLOGY
- Degenerative instabilities
  - Axial rotational
  - Translational; plain films show spondylolisthesis, traction spurs, vacuum phenomenon
  - Retrolisthesis; plain films show increased retrolisthesis with extension
  - Degenerative scoliosis
  - Post laminectomy; resection of 50% of bilateral facets alters segmental stiffness
  - Post fusion; altered biomechanics

DIAGNOSTIC CHECKLIST
- Craniovertebral junction instability is difficult to evaluate with plain radiographs in infants and toddlers
  - Consider flexion-extension CT or MR



Seminars in Spine Surgery
Volume 25, Issue 2, June 2013, Pages 119-130

Iatrogenic spinal instability: Cervical and thoracic spine

Adam J. Bevevino MD [a], Melvin D. Helgeson MD [a], Todd J. Albert MD [b]

https://doi.org/10.1053/j.semss.2013.03.006

Abstract

Iatrogenic spinal instability is defined as an instability resulting from direct surgical and/or medical intervention. Spinal instability of this variety was originally described in the early to mid-20th century and many of the treatments that produce instability have been known and studied for decades. More importantly, patients with iatrogenic instability are now recognized to have decreased functional outcomes and are at increased risk of requiring revision surgery. The most common clinical presentation is seen in an at-risk patient who fails to meet expected post-operative gains, functionally declines, or presents with new symptoms. Arriving at the correct diagnosis requires a high degree of suspicion and detailed history. While improvements in the understanding of spinal stability and advances in surgical technique have altered the incidence of iatrogenic instability, it continues to remain a relatively common clinical problem. A thorough comprehension of the etiologies, prevention strategies, and subsequent management of iatrogenic instability is imperative to the practicing spine surgeon. This review will outline four of the most common clinical scenarios that result from treatment-induced spinal instability: post-laminectomy kyphosis, posterior foraminotomy-induced kyphosis, adjacent segment disease, and radiation-induced instability. The goal will be to detail the proposed mechanisms of the induced instability, allowing for potential prevention strategies, and to provide an approach to treatment for patients with each of these iatrogenic instability conditions.

Vij N, Tolson H, Kiernan H, Agusala V, Viswanath O, Urits I. Pathoanatomy, biomechanics, and treatment of upper cervical ligamentous instability: A literature review. *Orthopedic Reviews*. 2022;14(3). doi:10.52965/001c.37099

Reviews

Pathoanatomy, biomechanics, and treatment of upper cervical ligamentous instability: A literature review

Neeraj Vij[1] [a], Hannah Tolson[1], Hayley Kiernan[1], Veena Agusala[2], Omar Viswanath[3], Ivan Urits[4]

[1] University of Arizona College of Medicine - Phoenix, [2] Texas Tech University Health Science Center School of Medicine, [3] Department of Anesthesiology, Louisiana State University Health Shreveport, [4] Department of Anesthesia, Critical Care, and Pain Medicine, Beth Israel Deaconess Medical Center

Keywords: Cervical spine injuries, finite element analysis, 3D reconstruction, minimally invasive, spine surgery

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Orthopedic Reviews

Vol. 14, Issue 3, 2022

Table 2. A summary of the recent finite element model analyses regarding the pathoanatomy of cervical spine instability.

Lead Author	Title	Year	Journal	Institution	Level of Evidence	Pathology Studied	Results	Conclusions
M. Beauséjour,	Contribution of injured posterior ligamentous complex and intervertebral disc on post-traumatic instability at the cervical spine	2020	Computer Methods in Biomechanics and Biomedical Engineering		Non-clinical study (Finite Element Analysis)	Traumatic UCSI	Posterior ligamentous complex (PLC)removal had little impact at C2-C3 but increased local range of motion (ROM) at the injured level by 77.2% and 190.7% at C4-C5 and C6-C7, respectively. Complete IVD rupture had the largest impact on C2-C3, increasing C2-C3 ROM by 181% and creating a large antero-posterior displacement of the C2-C3 segment.	The PLC may not play as critical of a role in stabilized the posterior upper cervical spine, and the IVD plays a larger role. Finite element analysis is an apt tool by which to understand the pathomechanics of the cervical spine.
Ivancic P	Cervical spine instability following axial compression injury: A biomechanical study	2014	*Orthopaedics and Traumatology: Surgery and Research*		IV	Traumatic UCSI	The sagittal instability parameters indicated extension-compression injuries at the upper and middle cervical spine and flexion-compression injuries at the lower cervical spine. Increases in extension RoM were 14.9° at the upper cervical spine and 24.9° (P< 0.05) at the middle cervical spine and in flexion RoM at C7/T1 were 25.6° RoM and NZ increases in axial rotation and lateral bending were nearly symmetric among left and right.	Head-first collisions may result in biomechanical instability by different mechanisms in the upper cervical spine as compared to the middle cervical spine.
Wang X Feng M Hu Y	Establishment and Finite Element Analysis of a Three-dimensional Dynamic Model of Upper Cervical Spine Instability	*2019*	*Orthopaedic Surgery*		Non-clinical study (Finite Element Analysis)	Traumatic UCSI	After the upper cervical spine instability, the pressure of the alar ligament during the upper cervical spine extension was increased from 2.85 to 8.12 MPa. The pressure of the flavum ligament was increased during the upper-cervical spine flexion, from 0.90 to 1.21 MPa. The pressure of the odontoid ligament was reduced during the upper cervical spine flexion and extension, from 10.46 to 6.67 MPa and 25.66 to 16.35 MPa, respectively. The pressure of the anterior longitudinal ligament and cruciate ligament was increased. The pressure of the anterior longitudinal ligament was increased during flexion and extension, from 7.70 to 10.10 MPa and 10.45	Finite-element analysis has the capacity to increase our understanding regarding ligament stress in upper cervical spinal instability.

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Vij N, Tolson H, Kiernan H, Agusala V, Viswanath O, Urits I. Pathoanatomy, biomechanics, and treatment of upper cervical ligamentous instability: A literature review. *Orthopedic Reviews*. 2022;14(3). doi:10.52965/001c.37099

Reviews

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Orthopedic Reviews

Vol. 14, Issue 3, 2022

Lead Author	Title	Year	Journal	Institution	Level of Evidence	Pathology Studied	Results	Conclusions
							to 13.75 MPa, respectively. The pressure of the cruciate ligament was increased during flexion and extension, from 2.29 to 4.34 MPa and 2.32 to 4.40 MPa, respectively. During upper cervical spine flexion, the angle of the atlanto-occipital joint was increased from 3.49° to 5.51°, and the angle of the atlanto-axial joint was increased from 8.84° to 13.70°. During upper cervical spine extension, the angle of the atlanto-occipital joint was increased from 11.16° to 12.96°, and the angle of the atlanto-axial joint was increased from 14.20° to 17.20°.	
Liang L	Establishment and evaluation of a cadaveric model of chronic strain-induced upper cervical spine instability based on fascia-bone theory	*2020*	*Chinese Journal of Tissue Engineering Research*			Chronic Patholaxity UCSI	(1) During anterior flexion, the range of motion of the atlantoaxial joint (C1-2) and the entire upper cervical vertebra (C0-2) of the specimens after modeling was significantly larger than that before modeling ($P < 0.05$). During posterior extension, the range of motion of the atlantooccipital joint (C0-1) and the entire upper cervical vertebra (C0-2) of the specimens after modeling was significantly larger than that before modeling ($P < 0.05$). During both flexion and extension, the range of motion of the atlantoaxial joint (C1-2) and the entire upper cervical vertebra (C0-2) of the specimens after modeling was significantly larger than that of the pre-modeling specimen ($P < 0.05$). (2) During lateral flexion, the range of motion of the atlantooccipital joint (C0-1), the atlantoaxial joint (C1-2), and the entire upper cervical vertebra (C0-2) of the specimens after modeling was increased compared with that before modeling. However, there was no significant difference ($P > 0.05$). (3) During right rotation, the range of motion of the whole upper cervical spine (C0-2) of the specimens after modeling was significantly increased compared with that before modeling ($P < 0.05$). During both left and right rotation, the range of motion of the atlantoaxial joint (C1-2) and the whole upper cervical spine (C0-2) of the specimens was significantly larger than that of the specimens before modeling ($P < 0.05$).	

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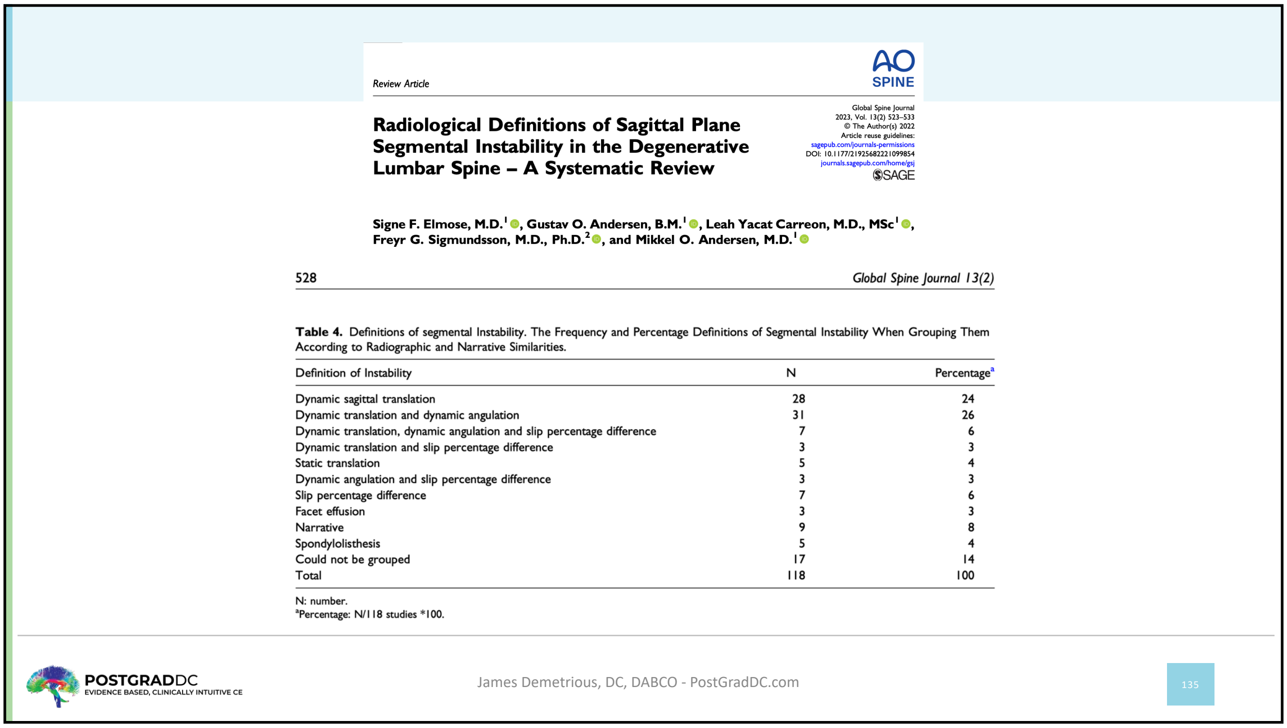

Review Article

AO SPINE

Radiological Definitions of Sagittal Plane Segmental Instability in the Degenerative Lumbar Spine – A Systematic Review

Global Spine Journal
2023, Vol. 13(2) 523–533
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Signe F. Elmose, M.D.[1], Gustav O. Andersen, B.M.[1], Leah Yacat Carreon, M.D., MSc[1], Freyr G. Sigmundsson, M.D., Ph.D.[2], and Mikkel O. Andersen, M.D.[1]

Table 4. Definitions of segmental Instability. The Frequency and Percentage Definitions of Segmental Instability When Grouping Them According to Radiographic and Narrative Similarities.

Definition of Instability	N	Percentage[a]
Dynamic sagittal translation	28	24
Dynamic translation and dynamic angulation	31	26
Dynamic translation, dynamic angulation and slip percentage difference	7	6
Dynamic translation and slip percentage difference	3	3
Static translation	5	4
Dynamic angulation and slip percentage difference	3	3
Slip percentage difference	7	6
Facet effusion	3	3
Narrative	9	8
Spondylolisthesis	5	4
Could not be grouped	17	14
Total	118	100

N: number.
[a] Percentage: N/118 studies *100.

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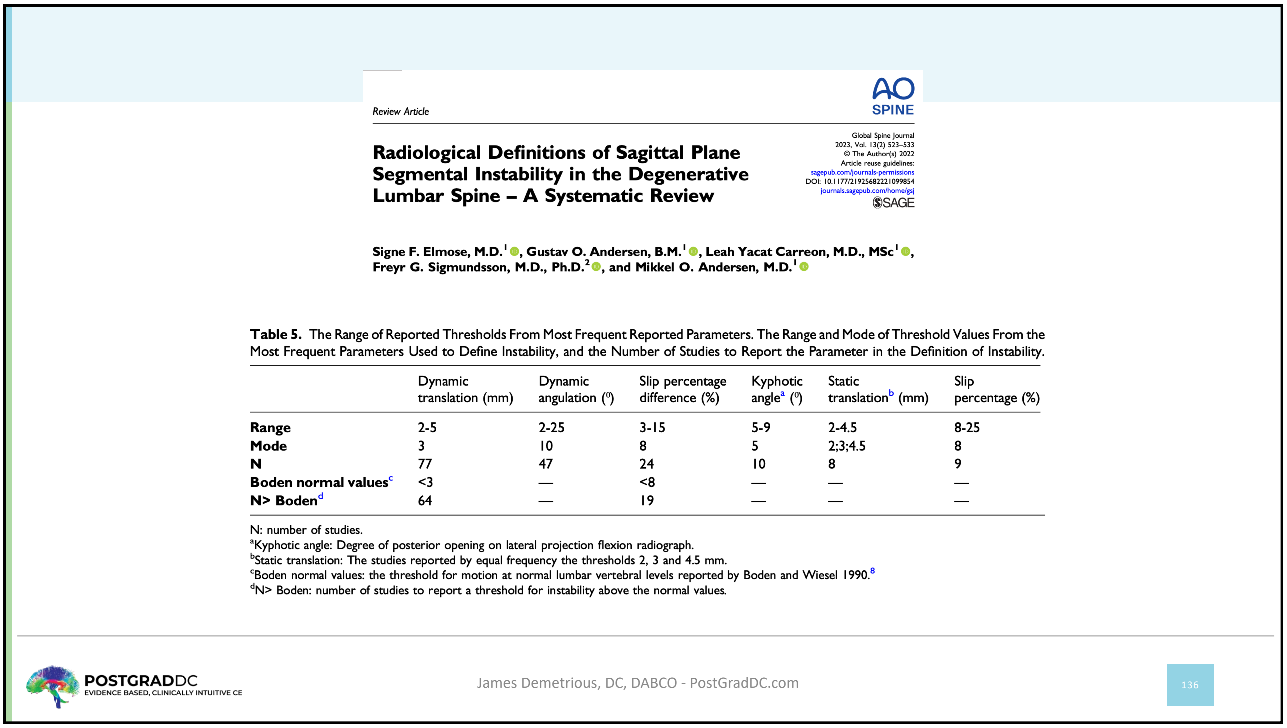

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Table 5. The Range of Reported Thresholds From Most Frequent Reported Parameters. The Range and Mode of Threshold Values From the Most Frequent Parameters Used to Define Instability, and the Number of Studies to Report the Parameter in the Definition of Instability.

	Dynamic translation (mm)	Dynamic angulation (°)	Slip percentage difference (%)	Kyphotic angle[a] (°)	Static translation[b] (mm)	Slip percentage (%)
Range	2-5	2-25	3-15	5-9	2-4.5	8-25
Mode	3	10	8	5	2;3;4.5	8
N	77	47	24	10	8	9
Boden normal values[c]	<3	—	<8	—	—	—
N> Boden[d]	64	—	19	—	—	—

N: number of studies.
[a] Kyphotic angle: Degree of posterior opening on lateral projection flexion radiograph.
[b] Static translation: The studies reported by equal frequency the thresholds 2, 3 and 4.5 mm.
[c] Boden normal values: the threshold for motion at normal lumbar vertebral levels reported by Boden and Wiesel 1990.[8]
[d] N> Boden: number of studies to report a threshold for instability above the normal values.

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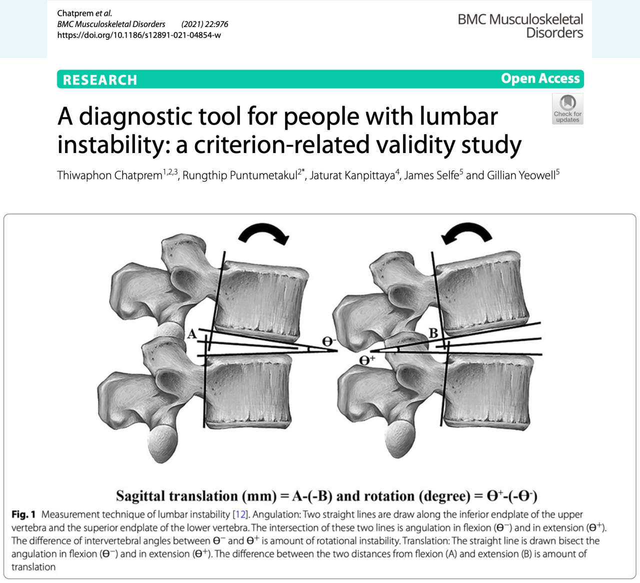

Chatprem *et al.*
BMC Musculoskeletal Disorders (2021) 22:976
https://doi.org/10.1186/s12891-021-04854-w

BMC Musculoskeletal
Disorders

RESEARCH Open Access

A diagnostic tool for people with lumbar instability: a criterion-related validity study

Thiwaphon Chatprem[1,2,3], Rungthip Puntumetakul[2*], Jaturat Kanpittaya[4], James Selfe[5] and Gillian Yeowell[5]

Sagittal translation (mm) = A-(-B) and rotation (degree) = Θ^+-(-Θ^-)

Fig. 1 Measurement technique of lumbar instability [12]. Angulation: Two straight lines are draw along the inferior endplate of the upper vertebra and the superior endplate of the lower vertebra. The intersection of these two lines is angulation in flexion (Θ^-) and in extension (Θ^+). The difference of intervertebral angles between Θ^- and Θ^+ is amount of rotational instability. Translation: The straight line is drawn bisect the angulation in flexion (Θ^-) and in extension (Θ^+). The difference between the two distances from flexion (A) and extension (B) is amount of translation

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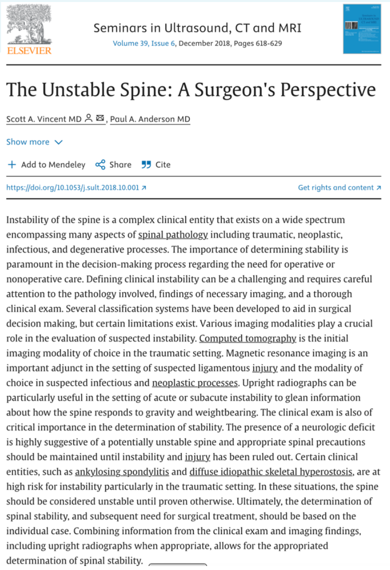

Seminars in Ultrasound, CT and MRI
Volume 39, Issue 6, December 2018, Pages 618-629

The Unstable Spine: A Surgeon's Perspective

Scott A. Vincent MD, Paul A. Anderson MD

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Instability of the spine is a complex clinical entity that exists on a wide spectrum encompassing many aspects of spinal pathology including traumatic, neoplastic, infectious, and degenerative processes. The importance of determining stability is paramount in the decision-making process regarding the need for operative or nonoperative care. Defining clinical instability can be a challenging and requires careful attention to the pathology involved, findings of necessary imaging, and a thorough clinical exam. Several classification systems have been developed to aid in surgical decision making, but certain limitations exist. Various imaging modalities play a crucial role in the evaluation of suspected instability. Computed tomography is the initial imaging modality of choice in the traumatic setting. Magnetic resonance imaging is an important adjunct in the setting of suspected ligamentous injury and the modality of choice in suspected infectious and neoplastic processes. Upright radiographs can be particularly useful in the setting of acute or subacute instability to glean information about how the spine responds to gravity and weightbearing. The clinical exam is also of critical importance in the determination of stability. The presence of a neurologic deficit is highly suggestive of a potentially unstable spine and appropriate spinal precautions should be maintained until instability and injury has been ruled out. Certain clinical entities, such as ankylosing spondylitis and diffuse idiopathic skeletal hyperostosis, are at high risk for instability particularly in the traumatic setting. In these situations, the spine should be considered unstable until proven otherwise. Ultimately, the determination of spinal stability, and subsequent need for surgical treatment, should be based on the individual case. Combining information from the clinical exam and imaging findings, including upright radiographs when appropriate, allows for the appropriated determination of spinal stability.

Chiropractic?

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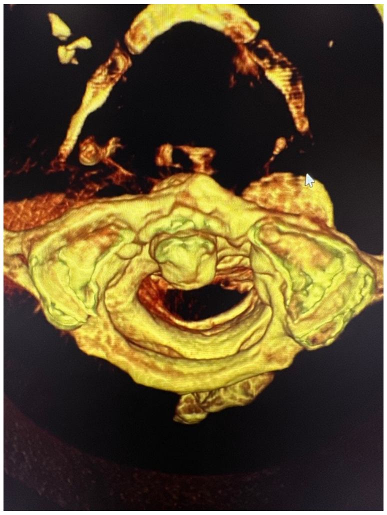

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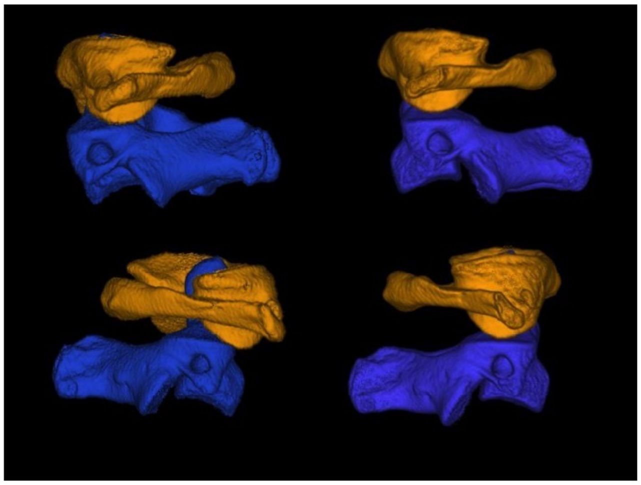
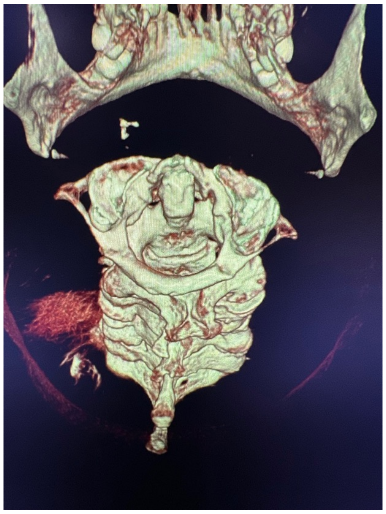
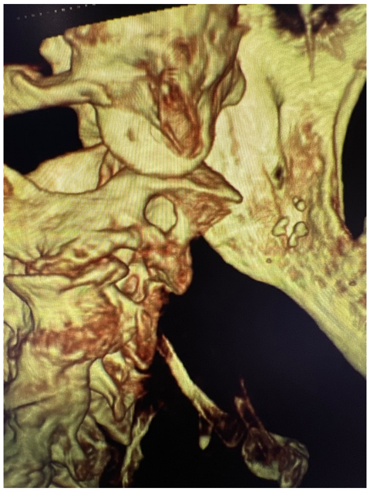
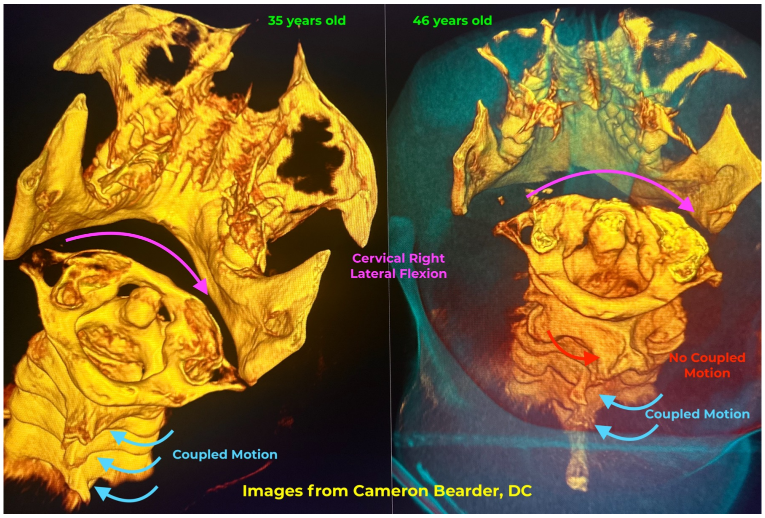
Image Courtesy of
Cameron Bearder, DC





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46 years old
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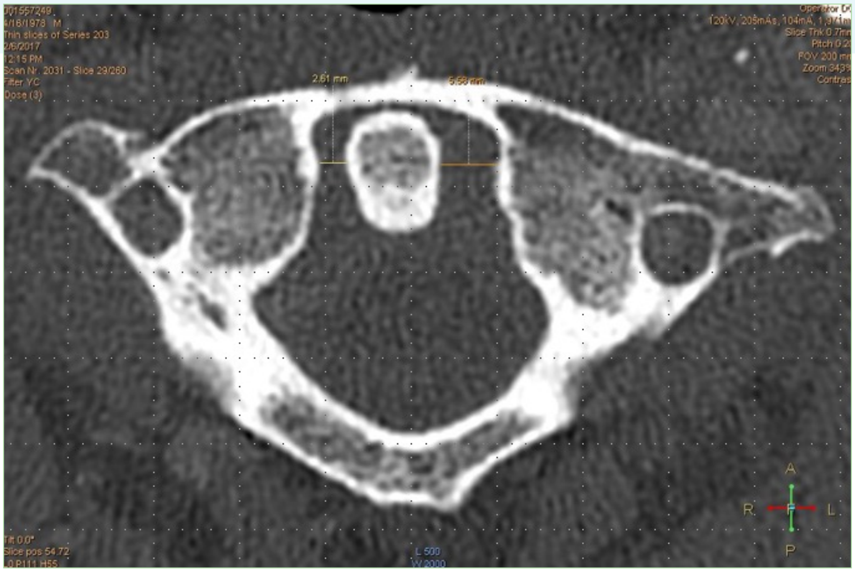
Lateral Flexion
No Coupled
Motion
Coupled Motion
Coupled Motion
Images from Cameron Bearder, DC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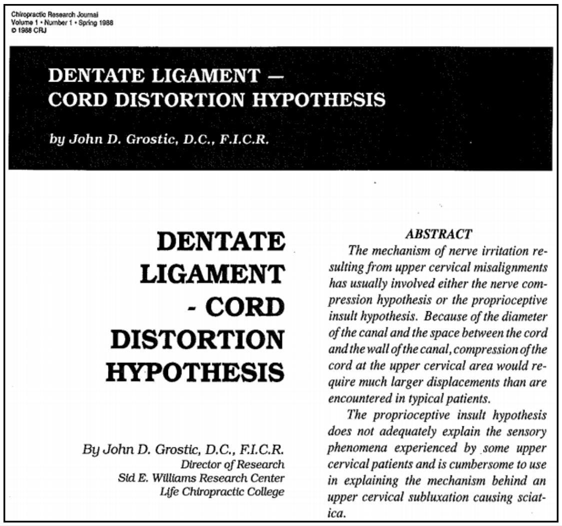
John Grostic, DC, FICR



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**DENTATE LIGAMENT —
CORD DISTORTION HYPOTHESIS**

by John D. Grostic, D.C., F.I.C.R.

**DENTATE
LIGAMENT
- CORD
DISTORTION
HYPOTHESIS**

By John D. Grostic, D.C., F.I.C.R.
Director of Research
Sid E. Williams Research Center
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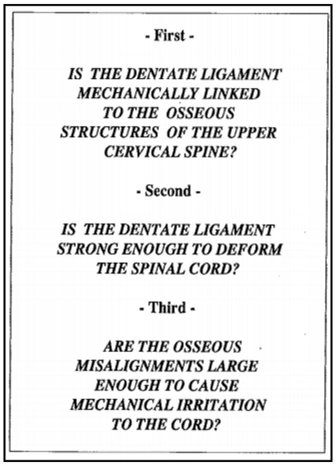
ABSTRACT

The mechanism of nerve irritation resulting from upper cervical misalignments has usually involved either the nerve compression hypothesis or the proprioceptive insult hypothesis. Because of the diameter of the canal and the space between the cord and the wall of the canal, compression of the cord at the upper cervical area would require much larger displacements than are encountered in typical patients.

The proprioceptive insult hypothesis does not adequately explain the sensory phenomena experienced by some upper cervical patients and is cumbersome to use in explaining the mechanism behind an upper cervical subluxation causing sciatica.



- First -

IS THE DENTATE LIGAMENT MECHANICALLY LINKED TO THE OSSEOUS STRUCTURES OF THE UPPER CERVICAL SPINE?

- Second -

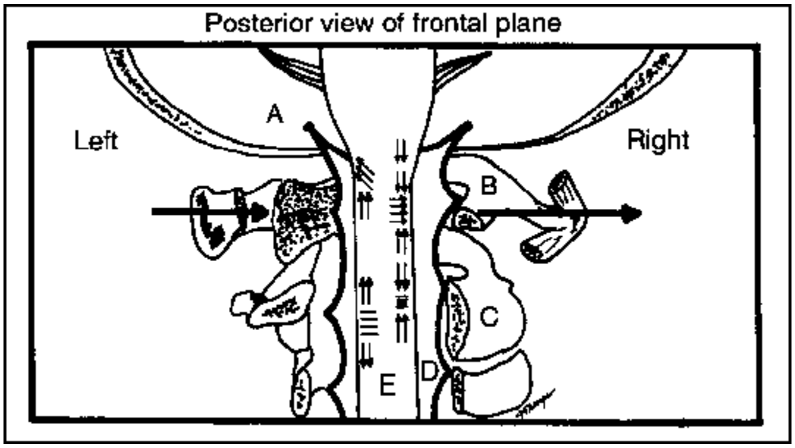
IS THE DENTATE LIGAMENT STRONG ENOUGH TO DEFORM THE SPINAL CORD?

- Third -

ARE THE OSSEOUS MISALIGNMENTS LARGE ENOUGH TO CAUSE MECHANICAL IRRITATION TO THE CORD?

John Grostic, DC, FICR

- The significance of Grostic's findings is that any subluxation of the atlas, by virtue of dural attachment, could transfer the forces of eccentric motion into the cord via the stronger cervical denticulate ligaments.



[RESIDENT'S CASE PROBLEM]

K. SEAN MATHERS, DC, CSCS[1] • **MICHAEL SCHNEIDER**, DC, PhD[2] • **MICHAEL TIMKO**, PT, MS, FAAOMPT[3]

Occult Hypermobility of the Craniocervical Junction: A Case Report and Review

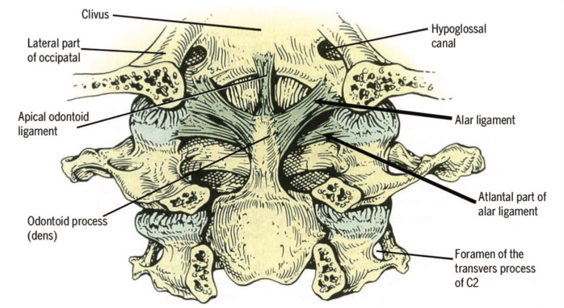


FIGURE 2. Posterior view with transverse ligament removed, showing the alar ligaments. Note that the atlantal part of the alar ligaments blends into an attachment with the C1-2 joint capsule. From Cramer GD, Darby SA. *Basic and Clinical Anatomy of the Spine, Spinal Cord, and ANS.* 2nd ed. 2005. St Louis, MO: Mosby; 2005. Used with permission from Elsevier Ltd.

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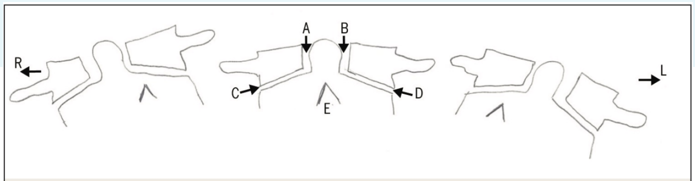

FIGURE 3. Normal. The CCJ is coupled with rotation. In neutral (the center figure), during neutral the C2 spinous process (E) is in midline and the spaces between the dens and the lateral masses (A and B) are symmetrical. During lateral flexion, counterrotation of the C2 spinous process occurs due to the posterior insertion of the alar ligaments on the odontoid and occiput and the symmetry of the lateral masses (C and D) over the body of C2 is maintained. Compare to actual radiographic images in **FIGURES 5** and **7**.

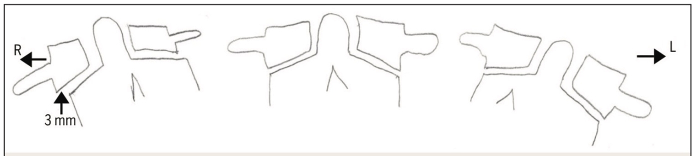

FIGURE 4. Abnormal lateral flexion mechanics of the CCJ. The normal biomechanics are disrupted. In this example, during right lateral flexion, there is no counterrotation of the C2 spinous process, and note the right translation of the right lateral mass over the body of C2, due to the failure of the left alar ligament. Compare to radiographic image in **FIGURE 6**.

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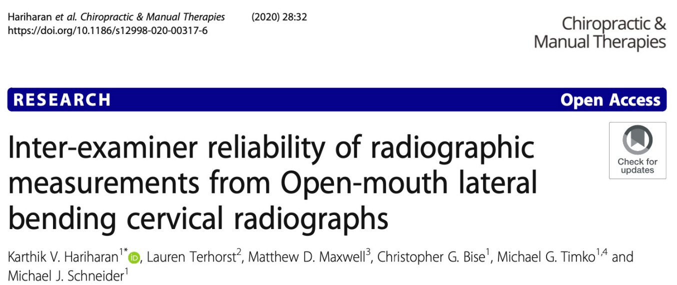

Hariharan *et al. Chiropractic & Manual Therapies* (2020) 28:32
https://doi.org/10.1186/s12998-020-00317-6

Chiropractic &
Manual Therapies

RESEARCH **Open Access**

Inter-examiner reliability of radiographic measurements from Open-mouth lateral bending cervical radiographs

Karthik V. Hariharan[1*], Lauren Terhorst[2], Matthew D. Maxwell[3], Christopher G. Bise[1], Michael G. Timko[1,4] and Michael J. Schneider[1]

- This study demonstrated good to excellent interrater reliability of both qualitative and quantitative measurements obtained using this imaging technique.
- Its use as a valid instrument in the clinical assessment of CCJ injury remains to be established.
- It does, however, offer potential promise as a relatively inexpensive and minimally invasive screening test for CCJ injury.

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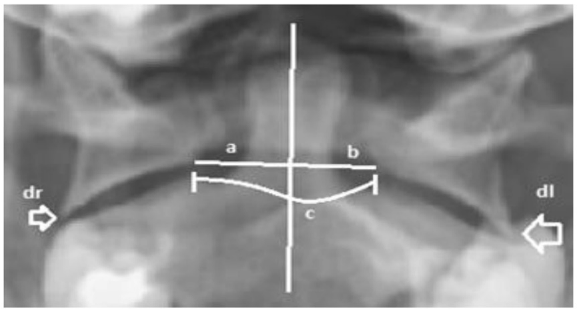
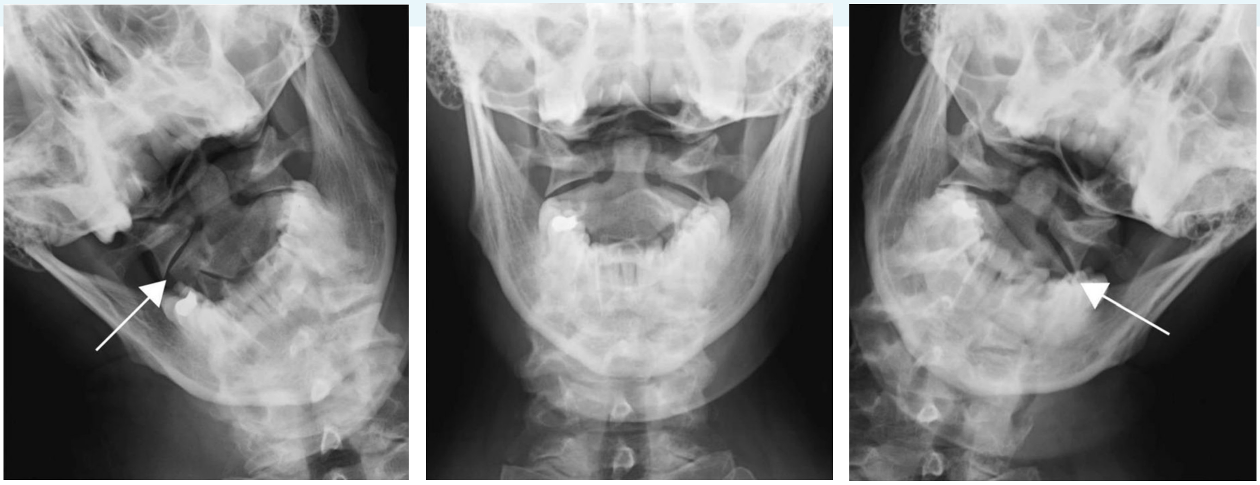


Fig. 2 Open Mouth Lateral bending cervical spine radiographs with measures recorded. **a** midline of Dens to right lateral mass; **b** midline of Dens to left lateral mass; **c** width between lateral mass; dr: Right lateral mass step-off; dl: left lateral mass step-off



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DOI: 10.4172/2165-7939.1000364
Mini Review
OMICS International

Diagnosis of Atlantoaxial Instability Requires Clinical Suspicion to Drive the Radiological Investigation

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[1]*Doctors Community Hospital, Lanham, MD, USA*
[2]*The Metropolitan Neurosurgery Group, LLC, Chevy Chase, MD, USA*
[3]*Medical University of South Carolina, Charleston, SC, USA*

Figure 4: AP open-mouth radiograph of the C1-C2 levels showing pathological loss of overlap.

Figure 5: (a) Sagittal model of atlanto-axial rotary sub-luxation; (b) Treatment of AAI.

Thank you!

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