MEDICAL IMAGING—PICTORIAL ESSAY

Magnetic resonance imaging of cervical ligamentous anatomy and traumatic ligamentous injuries

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Conflict of interest: No conflict of interest.

Submitted 5 November 2019; accepted 6 February 2020.

doi:10.1111/1754-9485.13016

Summary

Cervical spine trauma accounts for majority of spinal injuries, and approximately one-third involve the craniocervical junction (CCJ). Due to its high sensitivity, magnetic resonance imaging (MRI) has become the standard tool for imaging suspected ligamentous injuries in an unstable spine and in patients with neurological deficits having a normal CT. The ligamentous anatomy of the CCJ is complex, and thorough knowledge is a prerequisite for accurate interpretation of the MRI findings. This pictorial essay aims to familiarise radiologists with the ligamentous anatomy, mechanisms of injury and MRI appearances of injuries in the cervical spine, with emphasis on the CCJ.

Key words: alar ligament; cervical spine injury; craniocervical junction; tectorial membrane; transverse ligament.

Introduction

Cervical spine trauma accounts for majority of spinal injuries, and approximately one-third involve the craniocervical junction (CCJ). Although computed tomography (CT) is the initial imaging modality employed for suspected bony injuries, due to its high sensitivity and availability, magnetic resonance imaging (MRI) has become a standard tool for imaging suspected ligamentous and soft tissue injuries, especially in an unstable spine.[1–3] According to the latest American College of Radiology appropriateness criteria 2019,[4] MRI should be the primary modality for evaluating ligamentous injuries in acute trauma of the cervical spine. The ligamentous anatomy of the CCJ is complex, and thorough knowledge is a prerequisite for accurate interpretation of injuries. The aim of this pictorial essay was to familiarise radiologists with the ligamentous anatomy and MRI appearance of traumatic injuries to the cervical spine, with emphasis on the CCJ.

Indications for MRI in patients with neck trauma

The indications for MRI in patients with neck trauma are listed in Table 1.[2,5] Russin et al.[6] analysed 13 articles comprising 1322 patients and concluded that CT as stand-alone evaluation is insufficient for clearing the spine in unevaluable patients. An additional exam (MRI) was recommended to evaluate ligamentous instability.

Ligamentous anatomy and instability

Spinal instability occurs when spinal ligaments and bones lose their ability to maintain normal alignment under a physiological load. Ligamentous anatomy of the spine can be divided into two groups: the craniocervical junction (CCJ) and the rest of the cervical spine from C3 to C7 levels.

Table 1. Indications for MRI in patients with neck trauma

Patients with negative radiographs and CT having neurological symptoms or persistent neck pain, suspected ligamentous or cord injury
Patients who cannot be clinically evaluated for more than 48 hours due to altered level of consciousness
Findings on radiographs or CT indicating a ligamentous injury (facetal dislocations, disc or interspinous widening, fractures in the vicinity of ligaments and prevertebral swelling)
Patients with fracture or unstable neck injury on radiographs or CT, requiring MRI for pre-operative planning
Prior to attempting a closed facetal reduction, MRI is useful for detection of disc herniation or epidural haematoma

Journal of Medical Imaging and Radiation Oncology

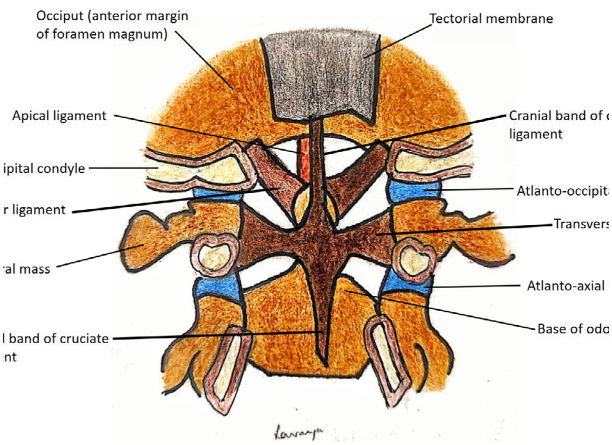

Fig. 1. 3-dimensional representation shows the CCJ ligaments – cruciate (transverse/cranial and caudal bands), odontoid (alar and apical) ligaments, the tectorial membrane and their attachments. Majority of these structures can be identified on the coronal plane. The transverse ligament is the strongest and largest ligament. The craniocaudal bands of the cruciate ligament and the apical ligament are very thin and considered vestigial structures.

Ligamentous anatomy and stability of CCJ

The CCJ comprises three bones (atlas, axis and occiput) and two joints (atlanto-occipital and atlanto-axial). The ligamentous complex stabilising these joints is divided into intrinsic and extrinsic ligaments.

Intrinsic ligaments comprise three layers anterior to the dura mater: the odontoid ligaments, cruciate ligament and tectorial membrane[2] (Fig. 1). The odontoid ligaments include the apical and alar ligaments. The apical ligament extends from the apex of the odontoid peg to the anterior margin of the foramen magnum (Fig. 2a, b). The paired alar ligaments attach the apex of the odontoid peg to the ipsilateral medial occipital condyles[7–9] (Fig. 2c,d).

The cross-shaped cruciate ligament consists of the transverse ligament and craniocaudal bands. The transverse ligament is the strongest and thickest ligament arising from the tubercles on the lateral masses of the atlas and runs horizontally behind the posterior margin of the dens (Figs 1,3a,). The cranial and caudal bands are extremely thin and play no role in stability.[2,8,9]

The tectorial membrane is a broad ligamentous sheath located posterior to the cruciate ligament. It is a cranial extension of the posterior longitudinal ligament (PLL) and extends posterior to the dens, attaching to the anterior margin of the foramen magnum[2,9] (Figs 2b and 4).

Extrinsic ligaments are fibroelastic membranes that are cranial continuations of the anterior longitudinal ligament (ALL), ligamentum flava, interspinous and supraspinous ligaments. They are divided into anterior and posterior groups, and comprise the following:

The anterior atlanto-occipital membrane (AAOM) attaches from the anterior arch of the atlas to the anterior margin of the foramen magnum. The anterior atlanto-axial membrane (AAAM) attaches from the anterior body of the axis to the anterior arch of atlas (Figs 4, 5a, 6a).

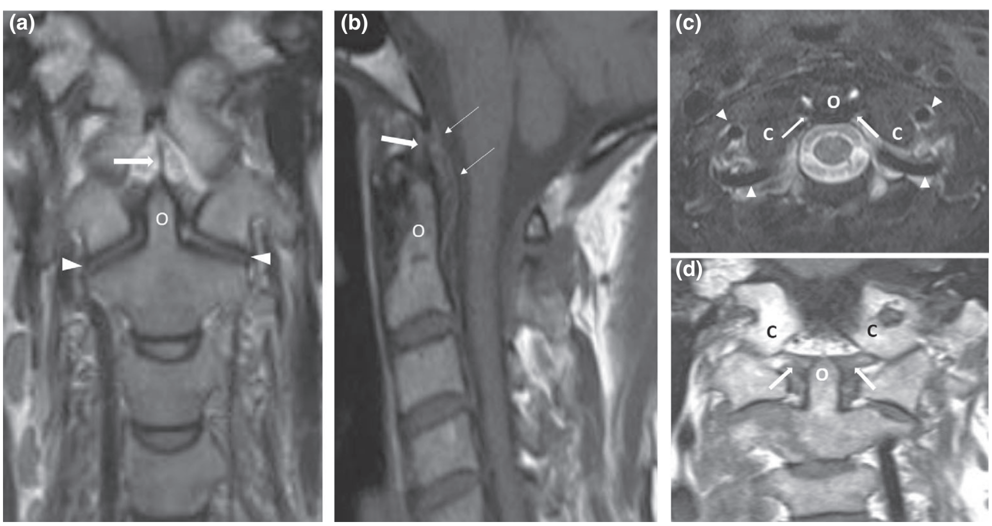

Fig. 2. (a) Coronal and (b) sagittal T1 MR-W images show the normal apical ligament (thick arrows) attaching the apex of the odontoid peg (O) to the anterior occipital margin of the foramen magnum. Sagittal image shows the tectorial membrane (thin arrows) extending along the posterior aspect of the odontoid, cranially up to the anterior margin of the foramen magnum. The lateral atlanto-axial joints (arrowheads) are also depicted. (c) Axial STIR and (d) coronal T1-W MR images show the normal paired alar ligaments (thick arrows), attaching the apex of the odontoid peg (O) to the ipsilateral medial occipital condyles (c) bilaterally. The alar ligaments are best seen on either axial or coronal planes. The coronal plane shows the whole length of the ligament and allows comparison between both sides. Alar ligamentous injury may result in excessive axial rotation and compression/ damage to the adjacent vertebral artery (arrowheads). The correlation can be appreciated by the closeness of these structures in the image.

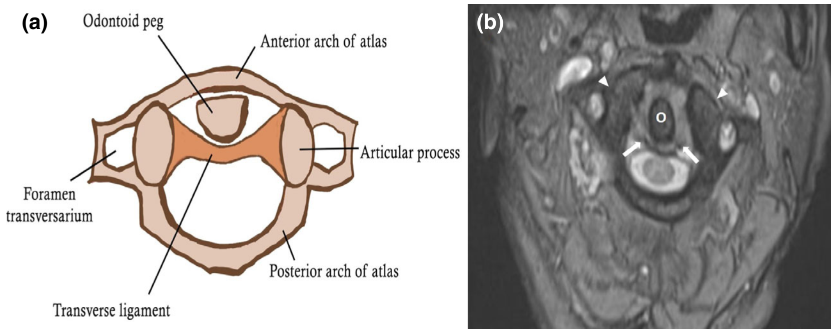

Fig. 3. (a) Axial diagrammatic representation shows the transverse ligament attaching to both the lateral masses of the atlas. It is the thickest and strongest ligament of the CCJ and divides the ring of the atlas into anteroposterior compartments. It has a key role in stabilizing the odontoid peg and holds the peg in place against the anterior arch of the atlas preventing posterior dislocation and cord compression. (b) Axial GRE MR image shows the normal transverse ligament (arrows) arising from the tubercles of the lateral masses of the atlas (arrowheads) bilaterally and traversing posterior to the odontoid process (O). It is best seen on the axial plane.

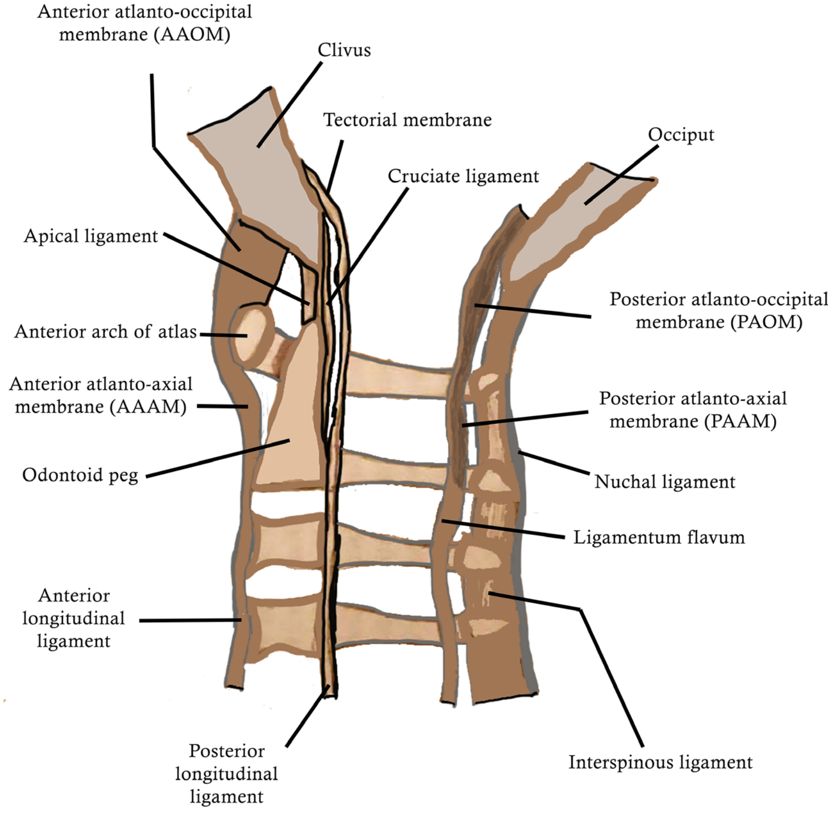

Fig. 4. Sagittal diagrammatic representation shows some of the extrinsic CCJ ligaments and tectorial membrane, in relation to the mid to low cervical ligaments that are best seen in the mid-sagittal plane. Also seen is the sagittal view of the intrinsic ligaments including the apical and cruciate ligaments. The tectorial membrane is depicted as the cranial continuation of the PLL. It covers the posterior surface of the dens but does not adhere to it. The AAOM and AAAM are depicted as cranial continuations of the ALL and the PAOM and PAAM as cranial continuations of the ligamentum flavum. Nuchal ligament is depicted as the cranial extension of the interspinous/supraspinous ligaments.

The posterior atlanto-occipital membrane (PAOM) extends from the posterior arch of the atlas to the posterior margin of the foramen magnum, and the posterior atlanto-axial membrane (PAAM) extends from the posterior margin of the body of the axis onto the atlas[9] (Figs 4, 5b, 6b,). These membranes merge caudally with the ligamentum flavum.

The nuchal ligament is the cephalic extension of the interspinous and supraspinous ligaments, extending

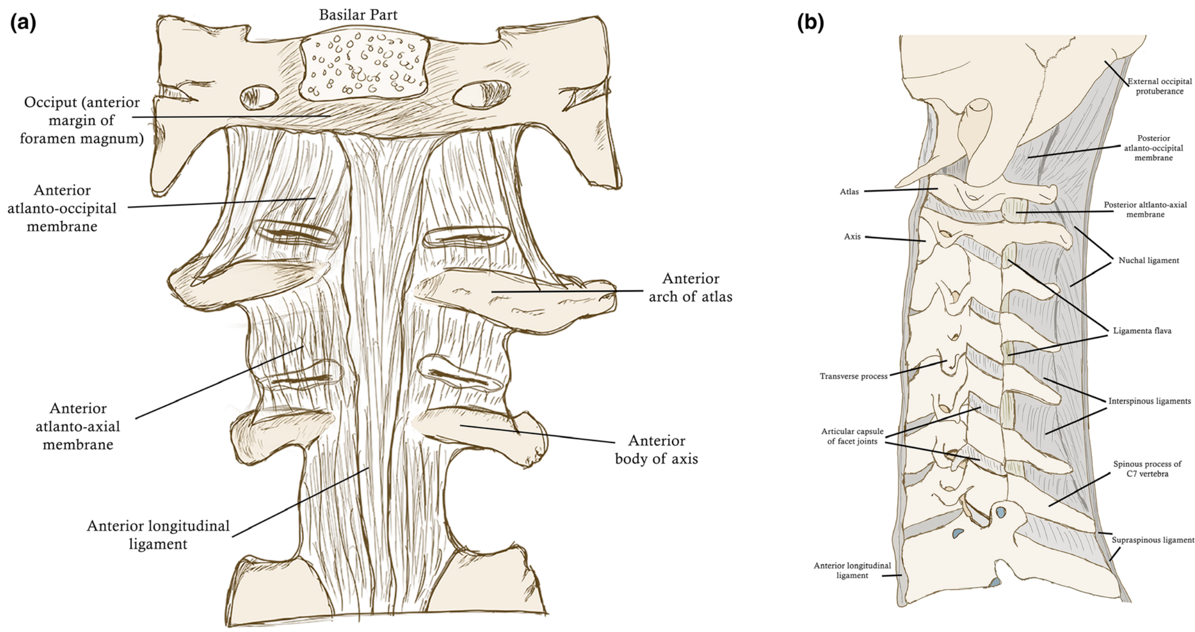

Fig. 5. (a) 3-dimensional coronal diagrammatic representation shows the anterior extrinsic ligaments of the CCJ and upper cervical spine: the anterior atlanto-occipital (AAOM), atlanto-axial (AAAM) and the anterior longitudinal ligament (ALL). The AAOM and AAAM have lateral extensions covering the atlanto-occipital and atlanto-axial articulations and merge anteriorly with the anterior longitudinal ligament. (b) 3-dimensional oblique sagittal diagrammatic representation depicts the various cervical ligaments as seen from the oblique view – the ALL, facet joint capsules, ligamentum flavum, interspinous and supraspinous and nuchal ligaments.

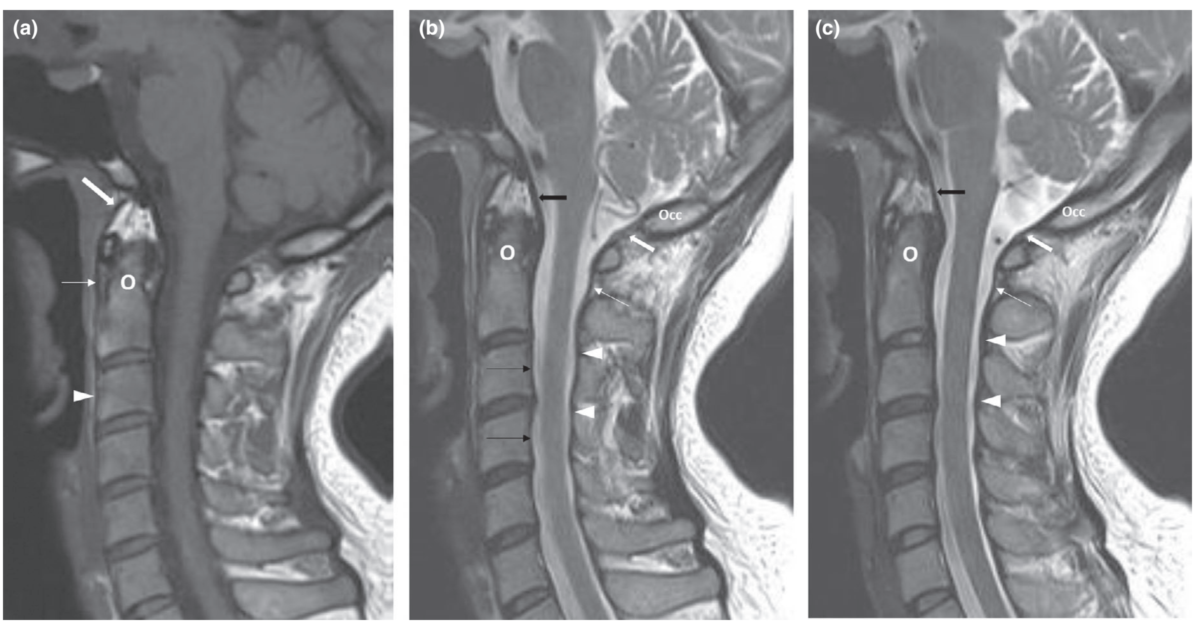

Fig. 6. (a) Mid-sagittal T1W MR image shows the normal anterior atlanto-occipital membrane (AAOM – thick arrow), anterior atlanto-axial membrane (AAAM – thin arrow) and the anterior longitudinal ligament (ALLarrowhead), best seen on the sagittal plane. These membranes are normally hypointense on T1 and T2W images and are not separately discernible from the adjacent bony cortex or intervertebral disc. (b) and (c) Contiguous mid-sagittal T2-W MR images show the normal posterior atlanto-occipital membrane (PAOM- thick white arrow), posterior atlanto-axial membrane (PAAM- thin white arrow), and the ligamentum flavum (arrowheads), all best seen on sagittal plane. These membranes are normally hypointense on T1 and T2W images. The tectorial membrane (thick black arrow) and PLL are depicted (thin black arrows). The normal PLL is not separately discernible from the adjacent bony cortex or the disc. The odontoid peg (O) and posterior occiput (Occ) are also depicted.

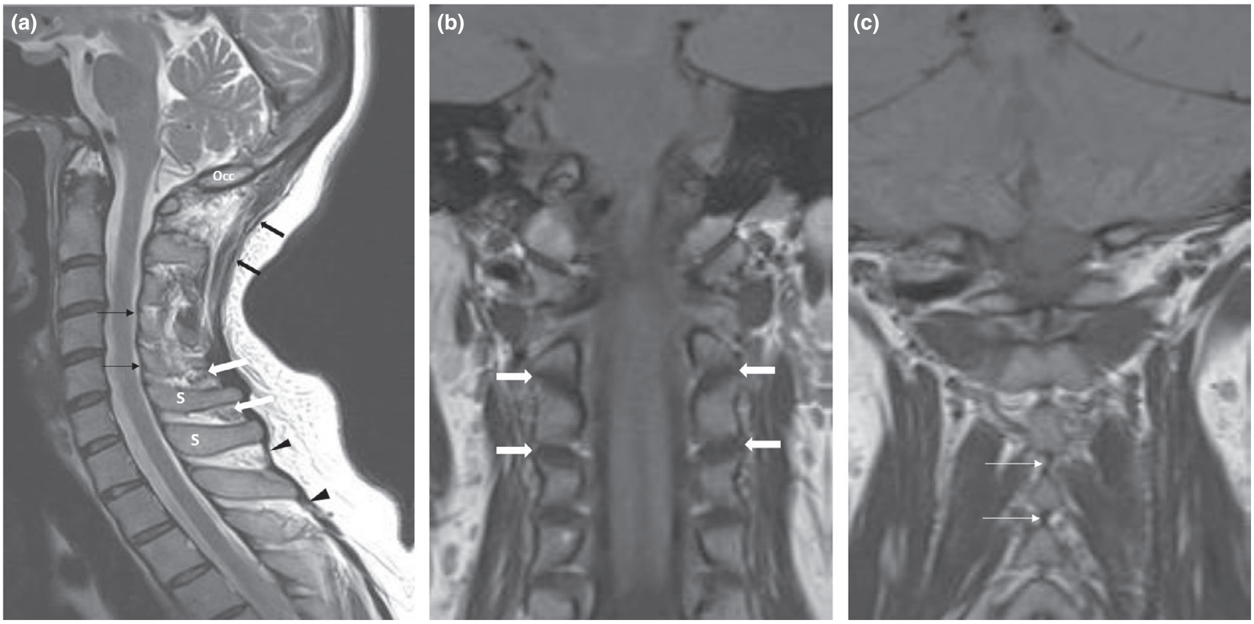

Fig. 7. (a) Mid-sagittal T2-W MR image shows the normal nuchal ligament (thick black arrows), ligamentum flavum (thin black arrows), interspinous ligaments (thick white arrows) and supraspinous ligaments (black arrowheads). These ligaments are best seen in the sagittal plane and are normally hypointense on the T1 and T2W images. Ligamentum flavum is seen bridging the lamina of the adjacent vertebrae. The nuchal ligament is depicted as the cranial extension of the supra and interspinous ligaments. The spinous processes (S) and posterior occiput (Occ) are labelled. (b) and (c) coronal T1-W MR images show the normal appearance of facetal capsules (thick arrows) and interspinous ligaments (thin arrows).

Table 2. Individual role of the CCJ ligaments in maintaining stability

Ligament	Function	Pattern of injury
Transverse ligament	Core stabiliser. Prevents anterior subluxation of atlas over axis and permits axial rotation. Disruption results in posterior odontoid peg dislocation and cord compression	Axial loading causing burst and lateral mass fractures of atlas
Alar ligaments	Limit axial rotation and contralateral lateral bending. Damage results in excessive axial rotation with compression of and/or damage to spinal accessory nerve or vertebral artery	Extreme hyperextension +/- lateral flexion/rotation High speed, whiplash injuries. Condylar avulsion fractures
Apical ligament	Vestigial	-
Tectorial membrane	Prevents impingement of odontoid process on the cervical canal	Extreme hyperextension ± lateral flexion/rotation
AAOM	Limits atlanto-occipital extension	Hyperextension
Nuchal ligament	Restricts hyperflexion of spine	Hyperflexion

from the C7 spinous process to the external occipital protuberance[2,9] (Figs 5b, 7a).

In summary, the 3 main stabilisers of the CCJ are the transverse ligament, alar ligaments and the tectorial membrane. Their individual functions are listed in Table 2.[2,9]

Ligamentous anatomy and stability of C3-C7 segments

The anterior and posterior longitudinal ligaments extend along the anterior and posterior margins of the vertebral bodies from the skull base to the sacrum. They are responsible for vertebral body alignment and spinal flexibility[1] (Figs 4, 5a,b, 4–6).

The posterior ligamentous complex of Holdsworth includes the ligaments posterior to the spinal cord, namely ligamentum flavum, interspinous and supraspinous ligaments and facet joint capsules (Figs 5b, 7a–c). The ligamentum flavum bridges the adjacent lamina, and the interspinous and supraspinous ligaments bridge the spinous processes and their tips, respectively.[1,10]

The principles of the three-column concept devised by Francis Denis[11] are applicable to the cervical spine from C3-C7 levels.[1] Spinal injury is classified as unstable when two contiguous columns are affected. The columns and their components are illustrated in Fig. 8. The radiological signs suggesting an unstable spine are listed in Table 3.[5] Flexion, extension, axial loading and rotational

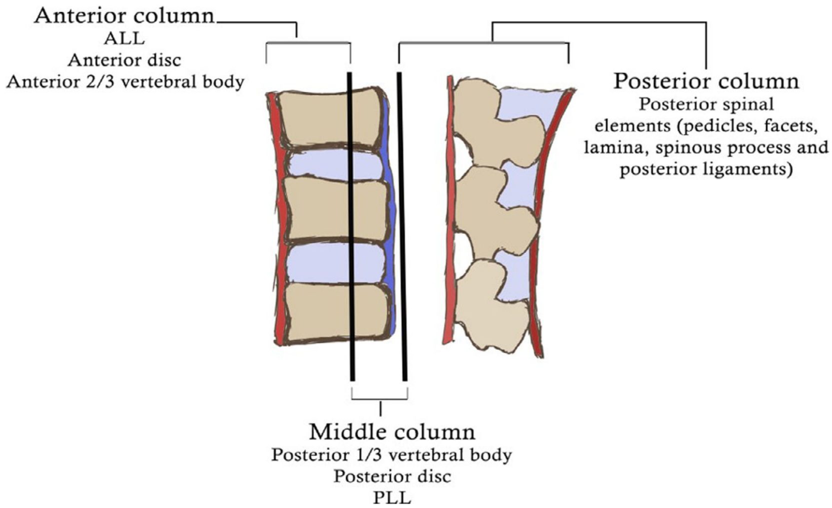

Fig. 8. Sagittal diagrammatic representation shows the Denis' 3 column concept of spinal stability and the components of the 3 columns. This was originally devised for the thoracolumbar spine but is now applicable to C3-7 segments. Involvement of any 2 contiguous columns results in spinal instability, with the middle column being involved. Anterior/ anterior+middle columns are disrupted due to hyperextension injuries, posterior/ posterior+middle columns due to hyperflexion injuries and all 3 columns are affected due to axial and rotational forces causing burst fractures, bilateral facetal injuries and teardrop fractures.

injuries are the four basic mechanisms of injury, a combination of which results in spinal instability.[2,3,9,10]

MRI appearances of ligamentous injuries

Ligaments are normally T1 and T2 hypointense on MRI, and acute injuries are easily identified by increased T2/ STIR signal due to oedema or haemorrhage. This signal intensity decreases with time, making identification of acute injuries challenging after 72 hours, which is therefore the optimal time between injury and obtaining an MRI.[12,13] An ideal MRI protocol comprises sagittal T1- and T2-weighted, GRE, STIR, axial GRE or T2-weighted and optional coronal T1-weighted or GRE images for evaluating the CCJ. GRE and T2-weighted sequences are best for evaluating ligaments and STIR most sensitive for soft tissue injury.[3]

Injury to the ALL, PLL and the tectorial membrane presents as linear T2/ STIR hyperintensity, stripping of the ligaments from the underlying bone by fluid or discontinuity (Fig. 9a,b). ALL injury may be associated with vertebral end-plate avulsion fractures[1,12] (Fig. 9c,d). Disc injuries may present as STIR hyperintense oedema with either widening, narrowing or herniation of the disc.

Table 3. Radiological findings indicative of an unstable spine

Involvement of two adjacent columns, with the middle column involved
>2 mm translation indicates ligamentous injury
Facet joint and interspinous space widening
Disruption of the posterior vertebral body line
>50% loss of vertebral body height/ >20 degrees kyphosis

Ligamentum flavum injuries manifest as T2/STIR oedema, discontinuity or buckling on sagittal MR images. They are mostly associated with fractures of the posterior elements.[1,5,13] Interspinous and supraspinous ligament injuries are best appreciated on mid-sagittal STIR images as areas of hyperintensity between and at the tips of the spinous processes (Fig. 10a). Partial tear or sprain is more common than complete tears. Fractures of the spinous processes and interspinous space widening are useful indicators for more severe tears (Fig. 10b). Facet joint capsular injuries are best seen on axial or sagittal images and present as STIR hyperintensity and> 2mm widening or dislocation[1,5,13,14] (Fig. 11a–d).

The relatively inflexible transverse ligament injuries result in an 'all or none' phenomenon and present as avulsions at the atlantal tubercles or central disruption. They are best appreciated on T2/GRE axial images with heterogeneous signal intensity or complete fibre disruption[2,12] (Fig. 12a–c). Alar ligamentous injuries typically result in avulsions at their condylar attachment, which is their weakest part. The entire length of this ligament is best seen on coronal plane. Asymmetrical signal is the key to diagnosing unilateral ligamentous injury.[12]

Accuracy of MRI

Goradia et al.[15] correlated pre-operative MRI with intraoperative findings and found that MRI has high sensitivity for detection of PLL (93%) and interspinous injuries (100%), but was less sensitive for ALL (71%) and ligamentum flavum (67%) injuries. They concluded that MRI may overestimate the extent of disruptive ligamentous injury and lead to unnecessary surgery.

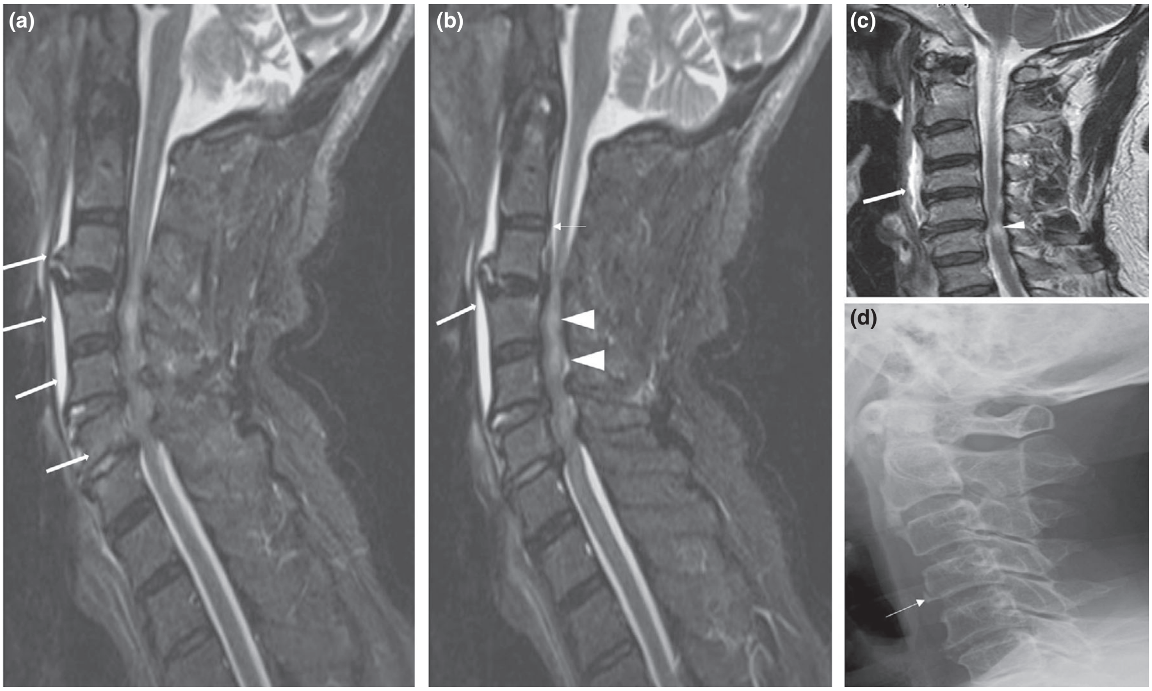

Fig. 9. Hyperextension injury in a 70-year-old man. (a) and (b) contiguous sagittal STIR MR images show the most prominent finding of fluid lifting the ALL at C3/4, C5/6, C6/7 (thick arrows) implying anterior disc/ALL tears at these levels. The ALL is seen discontinuous from C6 to T1 levels. Also seen are partial PLL tear at C3 (thin arrow) and central cord syndrome with intramedullary cord hyperintensity (arrowheads). An acutely injured ALL/ PLL is easily identified by increased T2/ STIR signal, stripping of the ligament by fluid or haemorrhage or discontinuity. Disc injuries are identifiable as STIR hyperintense oedema associated with either widening or narrowing of the disc space. (c) Sagittal T2W MR image in hyperextension injury in a different patient shows ALL tear from C2-6 levels with fluid (thick arrow). A focal cord contusion (arrowhead) is also depicted at C5/6 level (d) lateral radiograph shows a C4 corner fracture (thin arrow) which is difficult to detect on MRI. ALL injury maybe associated with anterior endplate avulsion fractures and it is advisable to correlate MRI findings with either a CT/ radiographs.

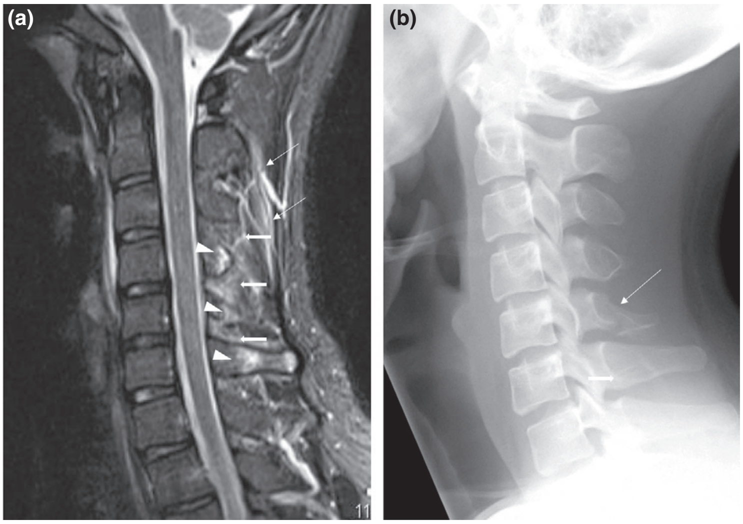

Fig. 10. Hyperflexion injury in a 45-year-old man. (a) Mid-sagittal STIR MR images show C4-T1 interspinous (thick white arrows), supraspinous (thin white arrows) ligament tears and C4,5,6 spinous process marrow oedema (white arrowheads). Supraspinous and interspinous ligamentous injuries are usually seen as increased STIR signal but fractures of the posterior elements, widening of the interspinous space and haemorrhage are clues to more severe/ complete tears. (b) Lateral radiograph confirms a slightly displaced C5 spinous process fracture (arrow). The C4 and C6 spinous process changes on MRI are likely to be due to bone bruises. Injuries to the posterior ligamentous complex of Holdsworth (ligamentum flavum, interspinous, supraspinous ligaments and the facet joint capsules) are usually accompanied by fractures of the posterior elements.

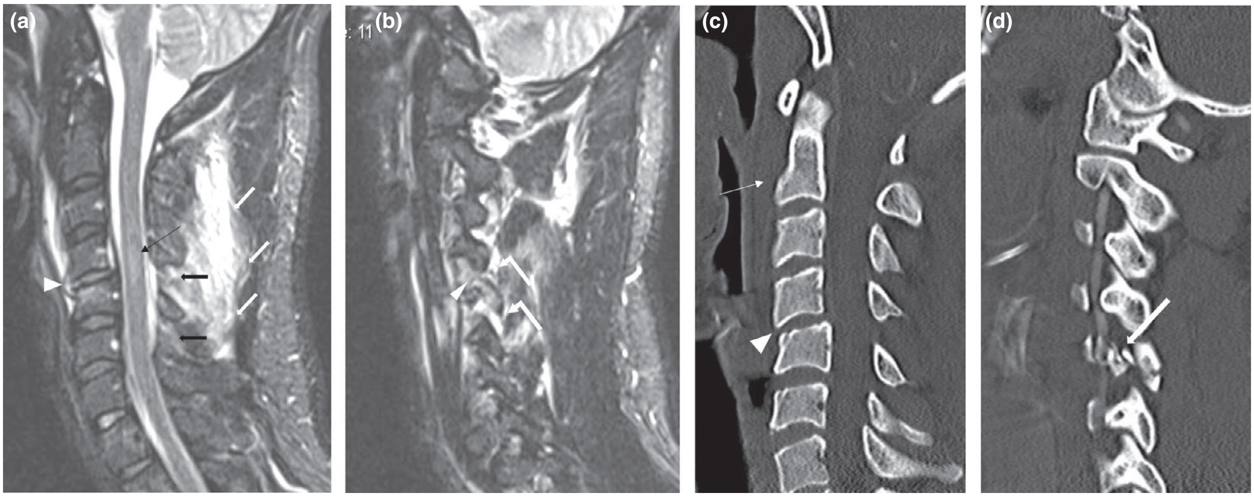

Fig. 11. Mixed rotation injury in a 27-year-old man. (a) Mid-sagittal STIR MR image show C4/5 ALL tear (white arrowhead), C4/5 and C5/6 interspinous (black arrows), C2-7 supraspinous (white arrows) ligamentous injury, and a focal cord contusion at C4/5 level (thin black arrow). (b) Left parasagittal STIR MR image shows extensive hyperintense signal in the C4/5, C5/6 facet capsules (bent arrows) and left C5 articular process and concomitant laminar injury (arrowhead). Facet joint capsular injuries are best seen on axial or sagittal images and present as STIR hyperintensity, >2mm widening or dislocation. Rotational injuries usually result in facetal injuries and are often associated with posterior ligamentous and cord injuries. (c) Mid-sagittal and (d) Left parasagittal CT images show prevertebral soft tissue widening (thin white arrow), C4/5 disc narrowing and mild anterior subluxation (white arrowhead) and left pedicle, lamina and inferior facet process fractures (solid white arrow).

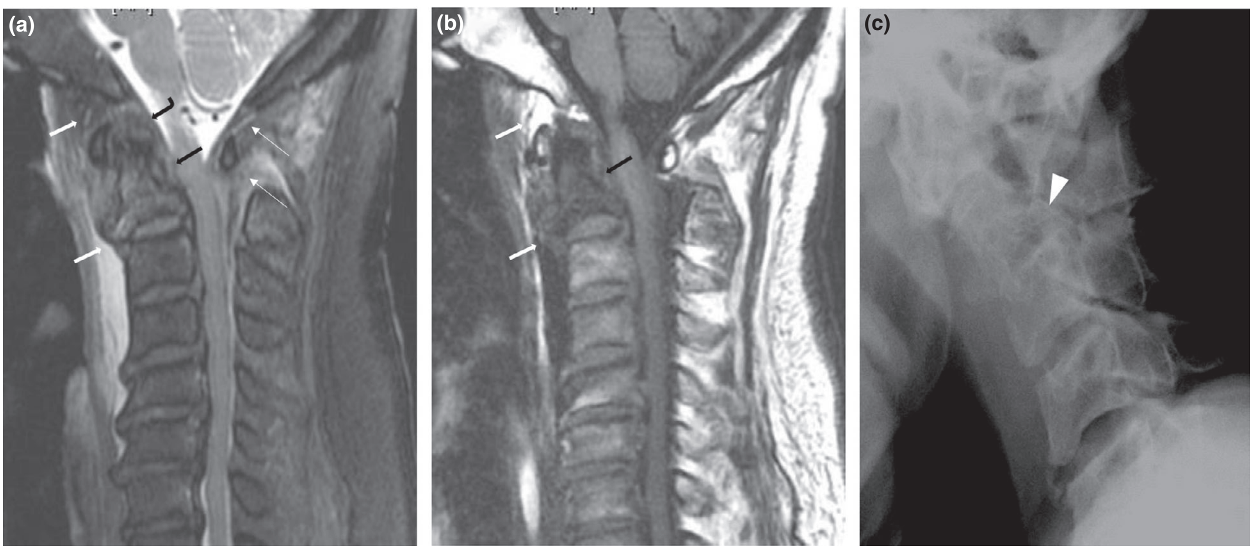

Fig. 12. CCJ injury in a 67-year-old male. Mid-sagittal (a) STIR and (b) T1-W MR images show C2 oedema and cortical discontinuity, AAOM and AAAM tears (thick white arrows), tectorial membrane (black bent arrow) and transverse ligament tears (thick black arrows), PAOM and PAAM tears (thin white arrows). Also seen are prevertebral fluid and ALL injury from C3-5 levels. (c) Corresponding radiograph shows a fracture of the odontoid process (arrowhead). Tectorial membrane, transverse and alar ligamentous injuries may occur together and cause disruption of the atlanto-axial relationship. It is advisable to look for associated C1 and C2 fractures, avulsion fractures at the lateral processes of the atlas (indicating transverse ligament injury) or occipital condylar avulsions (indicating alar ligament injuries).

Summary

MRI has revolutionised the evaluation and treatment of ligamentous injuries of the cervical spine, particularly in patients with neurological deficits having a normal CT. Nonetheless, MRI has its limitations, which reiterates the importance of clinicoradiological correlation, as well as assessment together with other imaging modalities such as radiography and CT.

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