Imaging in spinal trauma: current concepts and pictorial review

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Learning objectives

1. To provide an overview of imaging findings in traumatic myelopathy.

2. To discuss the advantages and disadvantages of different imaging modalities in traumatic myelopathy, including new techniques such as diffusion weighted imaging and diffusion tensor imaging.

Background

Traumatic myelopathy (TM) is defined as an acute traumatic injury to the spinal cord, leading to varying degrees of motor and/or sensory deficits\(^1\).

With an annual incidence of more than 12,000 cases in the USA\(^2\), TM remains a major cause of disability and premature death with important socio-economic consequences.

Knowledge of the broad spectrum of post-traumatic disorders and appropriate imaging modalities is mandatory to ensure correct diagnosis and timely intervention.

Imaging findings OR Procedure Details

1. Imaging criteria and modalities

a. Criteria for imaging

After clinical examination, patients should be assessed by an evidence-based guideline to determine if imaging studies are required. Both the National Emergency X-Radiography Utilisation Study (NEXUS) -criteria (Table 1) and Canadian C-spine -criteria (Table 2) are widely adopted\(^3,4\).

b. Plain radiographs

Detection of:

Osseous lesions: vertebral fractures, misalignment
**Imaging technique:**

At least 3 views (odontoid, anteroposterior and lateral) with clear visualisation of the craniocervical and cervicothoracal junction

**Advantages:**

Widely available, inexpensive

**Disadvantages:**

Very low sensitivity (as low as 28%) in detection of vertebral fractures due to low quality images and/or interpretation errors\(^5\,^6\)

c. **Computed Tomography**

**Detection of:**

Osseous lesions: vertebral fractures, misalignment

Traumatic disc herniation and/or epidural haemorrhage (if large)

**Imaging technique:**

Multi-detector CT with axial, sagittal, coronal and 3D reconstructions

**Advantages:**

Widely available, inexpensive and fast

Visualisation of associated lesions (pneumothorax, intracranial lesions)

**Disadvantages:**

High radiation dose (not preferred examination for children)

Unable to visualise spinal cord itself

Unable to visualise ligamentous integrity (and therefore ligament-associated instability)
**d. Magnetic Resonance Imaging**

*Detection of:*

Myelopathy: spinal cord edema, intramedullary haemorrhage, gliosis and myelomalacia (subacute-chronic phase)

Spinal cord compression: traumatic disc herniation, epidural haemorrhage

Ligamentous injury and osseous lesions (bone marrow edema)

*Imaging technique:*

Axial T1- and T2-weighted images

Sagittal T1-, T2- and Short Tau Inversion Recovery (STIR)-images

Sagittal T2- and STIR-images with fat-suppression for ligamentous evaluation

T2* Gradient Echo-images to detect haemorrhage

*Advantages:*

Allows direct visualisation of the spinal cord

MR-findings are well-correlated with clinical findings and outcome

Preferred imaging modality for children (no radiation)

*Disadvantages:*

Limited availability

Long duration of the examination

Patient-related contra-indications (unstable/ventilated, implants, constitutional problems, need for sedation in small children)

2. MR findings in myelopathy
1. *Spinal cord edema*: characterized by slightly decreased T1-signal and T2-hyperintensity. Based on T2-hyperintensity and demarcation, 2 types of edema are distinguished⁷ (Fig. 1):

- diffuse and only slightly T2-hyperintense: indicates a good prognosis.

- sharply demarcated and very hyperintense on T2-WI: indicates more severe transformation and less favourable prognosis.

2. *Intramedullary haemorrhage*: indicates severe injury and carries a very poor prognosis. Imaging findings range from small petechiae (in the gray matter) to large hematomas. The presence of blood degradation products (haemosiderin) can be confirmed by T2*-gradient echo (GRE) -WI (Fig. 2). Alternatively, susceptibility-weighted images (SWI) have recently been found to be even superior to T2*-GRE-WI in detecting microbleeds⁸.

3. *Gliosis and intramedullary cyst formation* ('myelomalacia'): develops in the subacute and chronic phase (Fig. 3). Gliosis is characterized by an ill-defined zone of T2-hyperintensity within the spinal cord. A discrete loss of spinal cord diameter may be noticed on axial T1-WI, secondary to neuronal atrophy.

4. *Spinal cord transection* (complete or partial): most often associated with penetrating injuries (stab- or shot-wounds). MR imaging reveals a T1-hypo- and T2-hyperintense, linear signal abnormality extending through the spinal cord. Additional T2*-GRE-WI may reveal adjacent haemorrhage. The prognosis of this type of lesion is grim: merely 20% of patients with complete spinal cord transection show (slight) improvement 5 years after trauma.

5. *Spinal cord herniation*: is rare post-traumatic complication, caused by an anterior dural defect. This is best demonstrated on sagittal T2-WI, where a typical buckling of the spinal cord is seen (Fig. 4)

Following trauma, lesions of the surrounding structures may cause *spinal cord compression*, and subsequent neurological symptoms. Compression of the dural sac and its contents is most frequent caused by traumatic disk herniation or epidural haemorrhage.

6. *Disk herniation* (Fig. 5,6): typically originates from flexion-compression injuries and is often associated with vertebral misalignment.
7. **Epidural hematoma** (Fig. 7): originates from rupture of the epidural venous plexus within the spinal canal. The onset of clinical symptoms is typically delayed, due to the gradual increase in size of the hematoma.

3. **New techniques: diffusion weighted and diffusion tensor imaging**

   **a. Diffusion Weighted Imaging (DWI)**

   *Detection of:*

   Axonal integrity. DWI measures alterations in the normal diffusion pattern within the spinal cord, caused by disruption or swelling of the axons in the white matter tracts.

   *Advantages:*

   Allows early visualisation of axonal damage (as little as 30 minutes post-trauma)

   Higher sensitivity than T1- and T2-WI in detecting TM in the early post-traumatic phase (<6h)\(^9,10\)

   *Disadvantages:*

   High amount of false-positive findings due to technical difficulties (small cross-sectional area of the spinal cord, image distortion to nearby vertebrae and motion artefacts by movement/pulsations)

   False-negative findings may occur when diffusion in one direction decreases but increases in another

   **b. Diffusion Tensor Imaging (DTI)**

   *Detection of:*

   Axonal integrity. DTI further exploits the principle of DWI, but allows quantification of the diffusion parallel ('axonal') and perpendicular ('radial') to the white matter tracts\(^11\) (Fig. 8).

   *Advantages:*

   Lower false-negative findings compared to DWI, by selectively measuring axial diffusion
Allows visualisation of white matter tracts

**Disadvantages:**

Technical difficulties (see DWI)

**Images for this section:**

<table>
<thead>
<tr>
<th>1. Midline tenderness</th>
<th>‘YES’ to any of these</th>
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<tbody>
<tr>
<td>2. Focal neurologic deficit</td>
<td></td>
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<tr>
<td>3. Altered level of consciousness</td>
<td>Imaging</td>
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<tr>
<td>4. Intoxication</td>
<td></td>
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<tr>
<td>5. Painful distracting injury</td>
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**Table 1:** Table 1. National Emergency X-Radiography Utilization Study criteria for radiographic evaluation of the cervical spine.
Table 2: Table 3. Canadian C-spine criteria for radiographic evaluation of the cervical spine

<table>
<thead>
<tr>
<th>1. Presence of high-risk factors:</th>
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<tr>
<td>Age &gt; 64 years</td>
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<tr>
<td>Dangerous mechanism (fall from &gt;5 stairs or &gt;3m, axial load to head, vehicle crash at &gt;60mph, ejection/rollover, bicycle collision)</td>
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<td>Parasthesias in extremities</td>
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<th>2. Absence of low-risk factors:</th>
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<tr>
<td>Simple rear-end MVA (excluded: rollover, high-speed accident, hit by bus/truck, pushed into oncoming traffic)</td>
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<tr>
<td>Sitting position in emergency department</td>
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<tr>
<td>No midline tenderness</td>
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<tr>
<td>Delayed onset of neck pain</td>
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<td>Ambulatory at any time</td>
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| 3. Unable to rotate neck > 45° |

‘YES’ to any of these criteria

Imaging

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**Table 2:** Table 3. Canadian C-spine criteria for radiographic evaluation of the cervical spine
**Fig. 1:** Cervical spinal cord contusion in a 19-year-old female, injured in a snow-boarding accident. (a) Sagittal reconstructed MDCT-image, (b) Sagittal T2-weighted image, (c) Sagittal T1-weighted image, (d) Sagittal STIR-image with fat suppression, 14 days after anterior instrumented fusion of the C3-C6 levels. The MDCT-examination, obtained immediately after trauma shows multiple fractures through C4 and C5, and anterolisthesis of C3 on C4. Two weeks after anterior instrumented vertebral fusion of the C3-C6 levels, a sharply demarcated T2-hyperintense lesion in the spinal cord surrounded by a more diffuse zone of T2-hyperintense edema is seen.

**Fig. 2:** Fracture luxation C3-C4 with cervical spinal contusion in a 22-year-old male. (a) Sagittal reformatted MDCT-image, (b) Sagittal T2-weighted image, (c) Sagittal T1-weighted image, (d,e) Axial T2* gradient echo image. There is a fracture-luxation at the C3-C4 level, with traumatic anterolisthesis of C3 relative to C4. The spinolaminar line is disrupted, indicating ligamentous injury to the posterior elements as well. This causes marked narrowing of the cervical spinal canal, with obliteration of the CSF-spaces and compression of the cervical spinal cord. There is a cord contusion, with intramedullary edema extending in the cord segments proximal and distal to the contusion. The axial T2* gradient echo images reveal hemorrhagic foci in the cord, which are seen as hypointense areas, reflecting blood breakdown products.
Fig. 3: 38-year old man with history of compression fracture (Th6) and traumatic myelopathy after a diving accident, 7 years ago. (a) Sagittal T1-weighted image, (b) Sagittal T2-weighted image, (c) Axial T2-weighted image. Hyperkyphosis of the thoracic spine is caused by the wedge deformity of Th6. A sharply demarcated intramedullary cyst is present anterior in the spinal canal with adjacent zones of T2-hyperintensity, compatible with myelomalacia/gliosis. At level Th6-Th8, a meningocele is present posterior of the spinal cord, which is anterolateral displaced. Note the subtle decrease of spinal cord diameter (atrophy) proximal and distal to the injured level, indicating an old injury.
**Fig. 4:** Spinal cord herniation in a 33-year-old man. (a) Sagittal T2-weighted image, (b) Sagittal T1-weighted image, (c) Sagittal STIR-image with fat suppression, (d) Axial T2* gradient echo image. The sagittal views (a,b,c) show a focal buckling of the thoracic spinal cord, which is displaced anteriorly at the Th3-Th4 level. The CSF-space between the anterior surface of the cord and the posterior wall of the vertebral column has completely disappeared (d). These findings are consistent with herniation of the spinal through a tear in the anterior dura mater.
Fig. 5: Vertebral burst fracture and associated disc herniation in a 43-year old man, involved in a motorcycle accident and presenting with paraplegia. (a-c) Sagittal and axial reconstructions of MDCT in bone (a,b) and soft-tissue (c) window, (d) Sagittal T2-weighted image. The CT-reconstructions demonstrate a burst fracture of Th7, with retropulsion of the posterior wall and anteroposterior narrowing of the spinal canal. The large, post-traumatic disc herniation at the Th6-Th7 level with severe marrow compression is only visible on the MR-examination.
Fig. 6: Traumatic disc herniation in a 44-year-old woman. (a) Sagittal T2-weighted image, (b) Sagittal T1-weighted image, (c) Sagittal STIR image with fat suppression. A focal C5-C6 disk herniation is present, with narrowing of the anteroposterior diameter of the spinal canal, and impression upon the cervical spinal cord; the disc herniation was assumed to be of posttraumatic origin, though most likely there was a pre-existent degenerative changes at this disc level. In addition, there are multiple vertebral fractures involving the upper endplates of the vertebral bodies C7, Th1, Th2 and Th3. The traumatic bone marrow edema is best seen on the sagittal STIR images with fat suppression (C).
Fig. 7: 69-year-old woman with subacute epidural hematoma. She presented with progressive back pain after fall, 4 days earlier. (a,b) Sagittal and axial T2-weighted images with fat-suppression, (c,d) Axial and sagittal T1-weighted images. The sagittal images show a lens-shaped, hypointense mass posterior in the spinal canal with compression and anterior displacement of the spinal cord. The mass consists of layers of variable signal intensity (d), representing bleedings of different age. The displacement of the nerve fibers is better visualized on the axial images. The dura mater can be seen as a thin hyperintense line, separating the hemorrhage and nerve fibers (c).
Fig. 8: 2,5-year old toddler with craniocervical distraction injury and spinal cord disruption. The child underwent a high velocity MVA with acceleration-deceleration trauma (‘whiplash’). Immediately after trauma, flaccid tetraparesis was present. (a) Sagittal reconstructed MDCT-image, (b) Sagittal T2-weighted image 6 days after trauma, (c) Diffusion Tensor Image. The CT-image reveals a fracture of the apophysis C2 and an increased distance between the posterior arch of C1 and C2. On MRI, the increased distance between the posterior arches is confirmed and the nuchal ligament appears T2-hyperintense, indicating ligamentous injury/elongation. Within the spinal cord, diffuse T2-hyperintensity compatible with severe myelopathy/spinal cord edema is noted. At the C1-C2 level, there are multiple hypointense lesions consistent with intramedullary hemorrhagic transformation. Diffusion Tensor Imaging with fiber tracking reveals complete spinal cord transection with disruption of all fibers.
Conclusion

1. Traumatic myelopathy is a frequent and invalidating condition with important socio-economic consequences due to the poor prognosis.

2. The application of established guidelines, such as the NEXUS or Canadian C-spine rules, is essential in the selection of patients requiring imaging.

3. Conventional radiographs have a low sensitivity for detection of osseous lesions.

4. CT is the gold standard for evaluation of vertebral fractures, but is limited by its inability to visualize the spinal ligaments and spinal cord.

5. MRI is the preferred imaging modality for the evaluation of traumatic myelopathy, both in the acute and subacute stage, and recognising the different patterns of spinal cord injury is not only of diagnostic but also of prognostic value.

6. DWI and DTI are promising new techniques that allow evaluation of the axonal integrity by measuring diffusion in the spinal cord, although further research is required to overcome technical limitations.

References


Personal Information