Review article

Imaging investigations in Spine Trauma: The value of commonly used imaging modalities and emerging imaging modalities

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ABSTRACT

Traumatic spine injuries can be devastating for patients affected and for health care professionals if preventable neurological deterioration occurs. This review discusses the imaging options for the diagnosis of spinal trauma. It lays out when imaging is appropriate and when it is not. It discusses strength and weakness of available imaging modalities. Advanced techniques for spinal injury imaging will be explored. The review concludes with a review of imaging protocols adjusted to clinical circumstances.

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1. Aim of imaging

The main aim of imaging is to avoid preventable neurological deterioration and to aid short and long term management of spinal injury. Significant spinal injuries have been missed in 4.6–10.5% of patients in a number of studies (Fig. 1).^{1–4} This has led to avoidable neurological deterioration in about 3% of all patients.⁵

Preventable neurological deterioration in the short term may be caused by treatable cord (or other neural structure) compression by haematoma, disc herniation or possibly mechanical compression by bone or by vascular compromise.⁶

Mechanical compression may also be due to mechanical instability.

Ideally imaging should also predict long-term neurological and mechanical stability.

Therefore we are looking for imaging modalities which identify mechanical instability in the short and the long term and neural compromise in the short and the long term.

At the same time the imaging approach has to allow for rapid and effective clinical decision making and care, be cost effective and ideally do no harm, or more realistically, do as little harm as possible and justifiable.

2. When to image

Any imaging performed will carry a cost. This may be a delay in more advanced care or treatment, a financial cost or ionising radiation incurred by the patient.^{7–14}

None of these is trivial and without clinical impact. It is therefore desirable to identify patients who do not need to undergo imaging examinations of their spine after trauma.

In particular 2 studies have come to the fore trying to address this issue, the US American NEXUS study^{15,16} and the Canadian C-spine rule (CCR) study.^{17,18} Both these studies have looked at patients with suspected neck injuries.

The NEXUS rules are inferior to the Canadian C-spine rule in sensitivity and specificity and result in a higher imaging rate than the CCR but apply to all ages while the CCR only applies to the ages 16–65 years. Both these rules are only applicable to fully alert patients with a Glasgow Coma scale (GCS) of 15.

The NEXUS criteria are as follows: if there is
no tenderness at the posterior cervical spine midline
no focal neurological deficit
normal level of alertness
no evidence of intoxication
no painful injury that might distract from the pain of a cervical spine injury
then the cervical spine can be seen as cleared.

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Fig. 1. 79 year old male, fall. Cervical spine radiographs (shown lateral cervical spine, figure a), CT cervical spine (shown sagittal reformat, figure b) and CT of the abdomen and pelvis (shown sagittal reformat, figure c), have not demonstrated a bone injury. Malalignment and subluxation at the C5/6 level was not appreciated as relevant. Cervical instability and neurological symptoms instigated repeat radiographs demonstrating instability and triggering MRI referral. MRI (figure d, sagittal STIR image) confirms marked subluxation at the C5/6 level and cord signal change indicating oedema. CT can not diagnose neural injury and may not exclude instability.

The Canadian Cspine Rule is more complex. The assessment starts with high risk criteria which mandate imaging (Fig. 2). High risk factors are: Age ≥ 65 years

Fall from ≥ 1 m/5 stairs
Axial load to head, e. g. diving
Motor vehicle collision (MVC) speed ≥ 100 km/h, rollover, ejection

Motorized recreational vehicles
Bicycle collision
Paraesthesia in extremities

If no high risk factor is present and any low risk factor is present, clinical assessment is deemed safe. Low risk factors are: Simple rear end MVC (excludes: being pushed into oncoming traffic, hit by bus/large truck/rollover, hit by high-speed vehicle)

Sitting position in emergency department
Ambulatory at any time
Delayed onset of neck pain (i.e. not immediate)
Absence of midline C spine tenderness

Assuming no high risk factor and at least 1 low risk factor is present the cervical spine can be assessed by asking the patient to rotate the neck to either side. If the patient reaches 45° on both sides, the neck is considered clear on clinical grounds, no imaging is necessary.

The NEXUS and the CCR have found their way in guidelines produced by the American College of Radiologists and the National Institute for Health and Care Excellence, NICE,^{10,17,19,20} Great Britain.

NEXUS rules can be applied to children and have been shown to safely reduce the use of imaging for the clearance of the cervical spine.^{21,22}

It has also been suggested to apply the CCR rules to children, though strictly speaking they are not validated for the use in children.²³

NEXUS and CCR only apply to the cervical spine. However similar rules have been developed for the thoracic and lumbar spine.

The following criteria have been suggested as mandating imaging of the thoracolumbar spine:

- back pain or midline tenderness
- local signs of thoracolumbar injury
- abnormal neurological signs
- cervical spine fracture
- GCS < 15
- major distracting Injury
- alcohol or drug intoxication.

Fig. 2. 24 year old male, mountain bike accident. Lumbar and thoracic spine radiographs were obtained and show a T8 fracture with anterior wedging (figure a, lateral radiograph T-spine). CT was performed for further characterisation, a crush fracture of the vertebral body and disruption of the posterior elements was seen (figure b, midsagittal reformat; figure c parasagittal). This is clearly an unstable injury. CT is excellent for depicting extent and nature of bone injury and here determines an unstable injury. MR imaging (figure d, sagittal T2w) shows epidural haematoma with cord compromise, this can not be appreciated on CT. Bicycle injuries carry a high risk for spinal injury.

Fractures found in one level of the spine indicate an increased risk of spinal fractures elsewhere. Thus, identification of a spinal fracture may imply a need to survey the remainder of the spine.^{10,20,24,25}

If the thoracolumbar spine has been included in the imaging of a chest/abdomen/pelvis protocol, spine images can be reformatted from this, a dedicated CT examination of the thoracolumbar spine is not necessary (and would only result in time delay, cost and radiation dose to the patient). Similarly, radiographs add no information after a CT has been performed.^{24,26–28}

3. How to image: imaging modalities

3.1. Ionising radiation: radiographs and CT

Traditionally radiographs have been the mainstay of spine trauma imaging.

Advantages are availability and familiarity of attending medical personnel.

However it has long been recognised that radiographs miss spinal injuries compared with CT in particular^{29–37} though as recent as 2003 there was a paper quoting the incidence of missed injury on radiographs versus CT as low as 0.5%.⁷ While per se simple, it is not easy to obtain high quality radiographs in immobilised trauma patients and this often takes a significant amount of time, in some studies up to 30 min until the images are available. While this should be quicker now with digital radiography, CT has superseded radiography as the screening modality of choice in cervical trauma in adults.^{9,10,38,39}

It has been suggested that in rare cases fractures in the xy plane of the patient may be difficult to see on CT, this should not really be an issue with modern scanners and imaging protocols.¹⁰

Current imaging guidelines no longer recommend the use of radiographs for clearing the cervical spine in trauma patients.^{10,20}

A positive clearance of the cervical spine in particular is important. As long as there is uncertainty regarding stability of the spine the patient is treated/nursed as if a spine injury was present. In the cervical spine this means immobilising with a hard collar. Hard collars and spinal boards cause pain after as little as 30 min. From 2 days onwards hard collars can lead to skin ulceration. Hard collars also hinder nursing care, can raise intravenous and intracranial pressure and hinder access to the airways.^{10–13,40,41}

There is still controversy in imaging of the thoracolumbar spine after trauma, with some guidelines supporting the primary use of CT as in the cervical spine^{10,20} and others suggesting the primary use of radiographs with the use of CT only if an abnormality is seen radiographically (Fig. 2).^{10,20}

However, patients with significant trauma usually undergo CT of chest, abdomen and pelvis anyway and therefore do not need radiographic examination.^{27,42}

Patients with proven traumatic injury to the cervical spine or significant traumatic injury in other parts of the skeleton also should undergo dedicated CT imaging of the thoracolumbar spine if CT of chest abdomen pelvis has not been performed.

CT has also been found to be cost effective when compared with radiography in the work up of cervical injuries unless the risk of injury is low.¹⁴

CT imaging is best suited for the assessment of bone injuries and also displays alignment well. Soft tissue injuries are harder to diagnose though (Fig. 2).

One great advantage of CT is the relative simplicity and speed with which it can be performed. Transfer onto the CT scanner table is usually straightforward. CT can be performed on intubated patients with relative ease and once the scan is started the whole

body can be imaged in about one minute time. CT scanners are nowadays close to emergency departments, if not part of them and access is easy.

The main concern in regards to patient safety with both radiographs and CT is radiation dose.

The radiation dose incurred by CT is significantly higher than that incurred by radiography. Either way the thyroid gland is exposed to radiation and the thyroid is rather radiosensitive.

If the whole spine is imaged with CT, either as a dedicated exam of the spine or as part of a chest abdomen pelvis protocol, the

Fig. 3. 87 year old male, fall. T2weighted MRI of the whole spine demonstrates multilevel fractures, in the upper and mid thoracic spine and in the upper lumbar spine (figure a). Sagittal STIR images of the cervical spine show focal cord signal change at the C4 level, pre-existing OA, typical central cord injury in an elderly patient with pre-existing OA and no evidence of instability (image b). Flexion (image c) and extension (image d) CT images show no evidence of instability. CT can not directly visualise neural injury. Multilevel injuries of the spine are common.

Fig. 4. 26 year old male, knife injury to the C2/3 level. Sagittal T2 w MRI images (figure a) show partial transection of the cervical spinal cord. Tractography (image b, posterior projection) confirms the injury. However diffusion weighted imaging does not add any significant new information.

radiation dose can be very high, with actual measurements recording up to 41.5mSv for CT imaging of cervical, thoracic and lumbar spine. This is much higher than previously estimated.^{43,44} However, strategies to lower the incurred dose with CT have been described.^{45,46}

Dose estimates vary widely. For routine radiographs of the spine effective doses of about 0.14mSv for a cervical exam and 3.7mSv for a lumbar exam have been recorded.⁴⁷

It has been estimated that the radiation dose to the thyroid is about 14 higher in CT exams than in radiography.⁴⁸ This has also been shown for more modern CT scanners⁴⁹ and measurements in trauma patients undergoing CT have calculated significant doses and cancers risk.⁴⁴

This is of particular concern in children where a significantly increased risk of thyroid cancer has been shown when undergoing CT investigation rather than radiographs.^{50,51}

This would be a mute point if CT was definitely the investigation of choice in children. However it is not. This is due to the difficulty in interpreting CTs of the neck in the immature skeleton and the higher incidence of isolated soft tissue rather than bone injuries compared with adults. This is due to decreased muscle strength and increased ligament laxity.^{52,53} These are better visualised with MRI.^{52–57} Therefore some guidelines advise primary imaging screening with radiographs followed by MRI rather than CT, if deemed necessary.²⁰ Older studies have found as many as 7% of significant neck injuries missed with CT.⁵⁸

However some authors argue that spinal injury without CT abnormality in children is very rare and that CT should be the investigation of choice just like in adults.⁵⁴

Flexion/extension radiographs, either dynamic or static, in obtunded patients should now be obsolete. They do not reliably show instability and risk worsening neurological compromise.^{59–63} If there is any role then they should be performed by well trained personnel with high quality equipment under fluoroscopic supervision to recognise instability early.^{63–66} If flexion extension imaging has to be performed in obtunded patients, monitoring of somatosensory evoked potentials (SSEP) can add a layer of safety. This has been used in a study investigating cervical spine clearance in obtunded paediatric patients.⁶⁷

In alert patients the situation is slightly different. The patient is able to note neurological symptoms with movement and is therefore able to protect his neck. However the usefulness of flexion/extension views in acute trauma is limited due to pain and muscle spasm.^{68–70} This is also true for the use in children.⁷¹

In the case of persistent discomfort from one week onwards after an injury there may be a role for elective flexion extension radiographs.⁷² CT can, though rarely, miss instability after cervical trauma and this may be demonstrated by flexion/extension views (Fig. 3).^{73,74} This may also be applied to paediatric patients.⁷⁵

3.2. MR imaging

MR imaging has a number of advantages over CT. It does not use ionising radiation and it is sensitive for soft tissue injury and various causes of neural injury and compromise, much more so than CT (Fig. 1–3). MRI can assess the ligamentous structures of the spine important for stability, CT struggles with this.^{6,76–78} MRI can also make outcome predictions after spinal injury.^{79–81}

However MRI is not safe in a number of patients due to electronic implants or for example previous surgery with aneurysm clips. Only fully alert and oriented patients would be able to be reliably assessed for suitability for MR imaging.

MRI is also much more time consuming than CT and relies on a fully cooperative patient. MRI in ventilated patients is much more difficult and not all departments are set up for this. MRI also misses a significant number of bone injuries compared with CT.⁸²

However, in cases of proven neurological injury or impairment, MR imaging is the imaging modality of choice for further assessment.

MRI is also an important part in the imaging workup of children with spinal injury and is given preference over CT by some guidelines.²⁰

There has been a long discussion in the literature whether CT alone is able to rule out unstable injury of the spine.^{14,83–86} It is now accepted that CT is the imaging investigation of choice for patients with suspected cervical spine injury.^{14,77,87} That does not mean that CT diagnoses all relevant injuries and in the author's practice there are several cases of significant (ie unstable) cervical spine injuries missed by CT every year (Fig. 1). This is also reflected in the published literature.^{6,66,76,78,88–92}

However it should not be forgotten that MRI in an obtunded patient in particular is time consuming and traumatic even for an intubated and ventilated patient and in a risk benefit analysis the benefit of additional MRI screening “just in case” is probably not there.¹²

MRI should be performed (as long as safe to do so) in all cases of clinical neural compromise after spinal trauma. MRI can define the level and nature of injury. Importantly it may also show causes of treatable neurological compromise ie cord compression due to disc herniation or haematoma. MRI may show root injuries and define the type, ie pre- or postganglionic.

MRI may also show ligament injury leading to instability not seen on CT.⁸⁴ This should be clinically apparent in adults and in this case flexion extension radiographs or possibly flexion extension CT may be of help.

In children MRI is even more important as often injuries affect the soft tissue only, rather than bone.^{53,54,57,93}

In the past cervical spine clearance protocols based on radiographs combined with MRI have also been investigated and found to be sensitive for all relevant injuries.⁹⁴ However, this approach is nowadays reserved for paediatric imaging.

4. Advanced imaging options

Vascular compromise can have devastating neurological consequences. Obviously spinal cord or brain infarction through vascular compromise is at best difficult and more commonly impossible to mitigate but incomplete vascular compromise (ie arterial dissection) may be treatable and therefore has to be diagnosed.

Vascular compromise is more reliably seen on contrast medium enhanced CT rather than on plain MRI, though alteration to the normal flow pattern may well be visible on MRI. Bone injury next to vascular structures (ie fracture of the foramen transversarium) or significant instability should alert to the risk of vascular compromise and dedicated imaging should be considered. CT angiography will usually be the investigation of choice in these circumstances. However, MRI or MR angiography, direct arterial angiography and possibly ultrasound are imaging alternatives.

Flexion extension CT (Fig. 3) has been suggested as a method for clearing the cervical spine in alert and obtunded patients.⁹⁵ The authors propose to perform a standard CT first and if there is no clear instability to perform a flexion and extension CT. However one can argue that the same problems encountered with flexion extension radiographs in the acute phase are then present. In the alert patient pain and muscle spasm may mask instability. In the obtunded patient passive positioning in flexion and extension is potentially dangerous and may actually induce neural compromise either by instability which would only be visualised once the CT scan is performed or by soft tissue compromise of neural structures i.e. by a disc herniation which may not even be visible on CT.

The ability of MRI to predict neurological outcome after spinal cord injury has been recognised many years ago.^{96–98} More

recently advanced MRI techniques such as diffusion tensor imaging (Fig. 4) has been suggested as supplementing techniques.⁹⁹ These are technically difficult and have as yet no found their way into routine spinal cord imaging. As yet they have not been shown to help in clinical management of the patient.^{100–102}

Nerve root injuries particularly in the cervical spine can be assessed with dedicated MRI sequences giving a high spatial resolution and depicting whether root injury is pre- or postganglionic (Fig. 5). The rootlets themselves are usually directly visualised. Meningoceles may be seen, usually markers of a preganglionic injury. Signal change in the spinal cord at the junction of the cord with the root must be considered abnormal. This may be more easily appreciated with contrast medium enhancement, focal contrast enhancement of roots or in the cord are abnormal.¹⁰³

Contrast medium enhancement is also an early sign of denervation after nerve root injury and may be seen just 24 h after injury. Conventional MRI can demonstrate muscle signal change, either oedema or fatty atrophy, with time but not as rapidly and clearly as contrast enhanced MRI. The multifidus

Fig. 5. 41 year old man with brachial plexus injury. Axial T2 space and coronal space STIR images show absent right sided rootlets (figure a) and meningocele formation (figure b). MRI is able to directly visualise rootlet injuries of the spine.

muscle is here particularly useful as it is segmentally innervated by a single nerve root only.¹⁰³

In patients where MRI is not possible or feasible, CT myelography may be used alternatively.

MR myelography may be used for an overview in brachial plexus injury but the spatial resolution is inferior to conventional MR sequences.

3d sequences with very high spatial resolution can be highly useful¹⁰⁴ and are used in the author's practice. This technique can also be combined with diffusion weighted imaging of the brachial plexus/diffusion weighted neurography.^{103,104}

5. Imaging protocols

Few controversies remain in the imaging of spine trauma.

One remaining question is whether CT imaging is always sufficient to clear the spine in obtunded patients or whether MRI should be considered also.

Another controversy is whether in trauma of the thoracolumbar spine radiographic clearance is acceptable or whether CT should be obtained.

Finally, it is not universally agreed how trauma spine imaging in children should be performed, whether and if so which role CT plays, or whether radiographs supplemented by MRI are the imaging investigations of choice.^{10,20,52–54}

The issues outlined above result in some variation in currently published spine trauma clearance guidelines.

The basic principle is the same though.

1. It is now accepted that in skeletally mature patients the miss rate of a quality CT scan is sufficiently low to declare the spine cleared if a CT of the spine is considered normal. This holds true for the fully alert and the obtunded patient.
2. If patients have neurological symptoms, MRI is indicated for further assessment.
3. If patients have symptoms of vascular compromise dedicated imaging is indicated, usually with CT angiography. It may be prudent to also do this in patients with significant injuries adjacent to relevant vessels.
4. In children radiographic assessment followed by MRI if suspicious on imaging or clinically may be a better approach than CT imaging. However, regional and local preferences may dictate the imaging approach in these cases.
5. Trauma to the thoracolumbar spine can be cleared with CT. If trauma CT of chest abdomen pelvis is not undertaken, dedicated CT of the spine or radiographs may be considered as first line investigations. Again regional and local preferences may prevail here.

Radiation protection and quick and safe clinical management must be the concern of all medical personnel involved but not to the detriment of missing relevant spinal injury. This remains and will remain the challenge in diagnosing, treating and caring for patients with possible or definite spinal injury.

Conflict of interest

The author has none to declare.

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