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REVIEW

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Clinical review: spinal imaging for the adult obtunded blunt trauma patient: update from 2004

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Abstract *Purpose:* Controversy exists over how to 'clear' (we mean enable the clinician to safely remove spinal precautions based on imaging and/or clinical examination) the spine of significant unstable injury among clinically unevaluable obtunded blunt trauma patients (OBTPs). This review provides a clinically relevant update of the available evidence since our last review and practice recommendations in 2004. *Methods:* Medline, Embase. Google Scholar, BestBETs, the trip database, BMJ clinical evidence and the Cochrane library were searched. Bibliographies of relevant studies were reviewed. *Results:* Plain radiography has low sensitivity for detecting unstable spinal injuries in OBTPs whereas multidetector-row computerised tomography (MDCT) approaches 100%. Magnetic resonance imaging (MRI) is inferior to MDCT for detecting bony injury but superior for detecting soft tissue injury with a sensitivity approaching 100%, although 40% of such injuries may be stable and 'false positive'. For studies comparing MDCT with MRI for OBTPs; MRI following 'normal' CT may detect up to 7.5% missed injuries with an operative fixation in 0.29% and prolonged collar application in 4.3%. Increasing data is available on the complications associated with prolonged spinal immobilisation among a population where a minority have an actual injury. *Conclusions:* Given the variability of screening performance it remains acceptable for clinicians to clear the spine of OBTPs using MDCT alone or MDCT followed by MRI, with implications to either approach. Ongoing research is needed and suggestions are made regarding this. It is essential clinicians and institutions audit their data to determine their likely screening performances in practice.

Keywords Cervical spine · Trauma · Imaging · Magnetic resonance imaging · Computed tomography · Poly-trauma · Injury · Thoracolumbar · Unconscious · Obtunded · Immobilisation · Complications

Abbreviations

CS	Cervical spine
CT-CAP	Computed tomography of the Chest/Abdomen/Pelvis
Directed CT	CT of specific areas (but not the entire CS), previously used in 'clearing' the cervical spine. This is largely a historical consideration as the CT had to be directed and set up to image specific areas, e.g. the cervicocranial and cervicothoracic junctions by collecting individual 'slices' before moving on to the next level

MDCT or Helical CT	Is a modification of CT including axial movement of the CT emitter and detector during scanning, coupled with improvements in image processing, rather than collecting discrete transverse slices then moving to the next slice. The benefits of helical scanning include faster scan times and far narrower slices. Clearly the higher the number of detectors included in the scanner then the more data points can be collected and resolution increases. Modern MDCT machines have developed from six detectors to > 200. In theory if enough slices at small distances are collected ultimately a true 3D image is generated
DVT	Deep venous thrombosis
DF	Dynamic fluoroscopy. The practice of manual flexion and extension and application of a cranial axial load during real time fluoroscopy to detect spinal instability while patients are unconscious
EAST	Eastern Association of Trauma
F/E R	Flexion/extension radiography where a static radiograph is collected at the limit of active and/or passive neck movement
MRI	Magnetic resonance imaging. T1 is the longitudinal relaxation time. It indicates the time required for a substance to become magnetized after first being placed in a magnetic field or, alternatively, the time required to regain longitudinal magnetization following an RF pulse. T2 is the 'transverse' relaxation time. It is a measure of how long transverse magnetization would last in a perfectly uniform external magnetic field. Alternatively, it is a measure of how long the resonating protons remain coherent or precess (rotate) 'in phase' following a 90° RF pulse. The spin echo MR signal is greatest when the T1 is short and the T2 and proton density are high it is decreased if the T1 is long and the T2 and proton density are low. The differentiation of lesions from normal tissues can be enhanced if one is aware of the differences in the relaxation times and selects the TR and TE times accordingly
MSK	Musculoskeletal
NEXUS	National Emergency X-Radiography Utilization Study
OBTP	Obtunded blunt trauma patient
Pan-CT	CT from the head down to the pelvis including head, cervical spine, chest, abdomen and pelvis with reformats used for the thoracolumbar spine
TL	Thoracolumbar spine
VAP	Ventilator associated pneumonia

Background and limitations of the current paradigm

Controversy continues to exist in the literature and in practice over how to 'clear'.[1] the spine of the obtunded blunt trauma patient (OBTP) who is likely to remain unevaluable. Previous reviews and practice guidelines on this topic were produced in 2004, and adopted by the United Kingdom Intensive Care Society [1, 2]. Since 2004 there have been three meta–analyses on the subject [3–5] and an update from the Eastern Association of Trauma (EAST) [6]. The evidence base remains limited with the meta-analyses drawing on Individual cohort studies, which at best represent level 2b evidence [7].

[1] By 'clear' we mean enable the clinician to safely remove spinal precautions based on imaging and/or clinical examination.

Why is this still important?

Cervical spine injury complicates blunt poly-trauma in a significant minority of cases, with a typical incidence of 5% [1, 8, 9]. There is a delicate balance of risks and benefits in managing OBTPs. Certainly missed unstable spinal injuries are associated with potentially devastating neurological compromise. Balanced against this is the reality that the majority of patients have a stable spinal column and extensive imaging is expensive and delays patient mobility. Most patients are maintained with 'spinal precautions' during this time (e.g. immobile with log roll turns and a cervical collar) and this is associated with significant morbidity and on occasion mortality.

Therefore, to clear the spine of significant unstable injury while patients remain obtunded or unevaluable largely centres on imaging, possibly supported by clinical evaluation if and when patients become evaluable [10]. We will consider the imaging modalities below but the main options include:

- Plain radiographs
- Computerised tomography (CT), most commonly multidetector-row CT (MDCT)
- Magnetic resonance imaging (MRI)
- Dynamic studies, e.g. dynamic fluoroscopy (DF) or flexion/extension radiography (FE/R)

Clinicians are engaged in a 'screening' process, attempting to identify significant spinal instability while rejecting normal or minor spinal injuries, i.e. 'clearing' the spine. In common with all screening procedures, a number of concepts are important:

- Prevalence of injury, i.e. pre-test probability. This is low, typically about 5%. Therefore if no screening were applied 95% of patients would suffer little consequence, an unclear proportion of the 5% could experience a complication and any intervention based upon the screening, especially if screening has high sensitivity and poor specificity, would subject many 'normal' patients to spinal precautions.
- There remains controversy around what constitutes spinal stability following screening, and therefore the 'result' of the screening may be unclear. Furthermore, the performance of the individual interpreting the screening imaging is difficult to define beyond specialty and seniority, e.g. 'a senior musculoskeletal radiologist'.
- The sensitivity, specificity, negative and positive predictive values are not clearly defined for the various imaging modalities. As ever, there is a trade off, partly related to pre-test probability, between optimal sensitivity and specificity, and ultimately clinicians may not reach consensus on what they regard as optimal balances of these parameters [11].
- The benefit or otherwise of available 'therapies' as a result of a positive test remain unclear. It is difficult to standardise management of certain injuries, e.g. prolonged collar or halo vest application vs. surgical stabilisation.
- The complications of instituted therapies (e.g. cervical collars, radiation doses, transfers) are poorly described and this becomes important if the screening has a high sensitivity, low specificity and is applied to the '95% normal' population.
- The resource implications are significant, e.g. a 'missed' injury with associated care and legal implications must be balanced against liberal use of imaging and prolonged immobilisation.
- It is likely that a rigorous scientific analysis is only part of the solution. Individual clinician and institutional 'memory' (e.g. Mrs X with the missed broken neck) tends to be long and deeply embedded. The significance of individual values to clinicians will therefore vary, e.g. a quoted miss rate of 5% may be acceptable to one clinician but not to another; therefore, different institutions will chose to implement the research differently.
- Screening inevitably has false positives and negatives. Clinicians and patients must accept finite rates of these variables, while striving for the optimal values of them, e.g. when any patient is declared to have a 'stable' spine, mobilisation should be careful with maintained vigilance for missed injury.
- This review does not consider subsequent determination of the significance of detected injuries, i.e. if screening detects an unstable injury, individualised assessment of detected injuries is required which may require any or all of clinical evaluation, plain radiographs, MDCT, MRI or dynamic studies.

Why undertake another review?

The meta-analyses on the subject draw on broadly equivalent data but have opposite conclusions underlining the importance of an iterative review of the subject.

Imaging technology has dramatically advanced since 2004; however, worldwide clinical practice remains varied.

There is nothing in the Cochrane database, BMJ clinical evidence, the trip database or any other evidence based medicine resource on the subject.

The majority of literature is from the U.S.A. and due complex social, financial, medico-legal, and political agendas is not always directly translatable to the rest of the world.

Methods

Ovid was used to search Medline and Embase. Google Scholar, BestBETs, the trip database, BMJ clinical evidence and the Cochrane library were searched. See Figs 1 and 2. 129 articles were retrieved in the writing of this review. The bibliographies of all relevant studies were then reviewed. Hand searches of reference lists were used to identify additional references. Direct communication with authors was sought where necessary.

We focused on papers published since our previous guidelines and review (2004) and included articles considering spine screening protocols and secondary outcome measures during prolonged immobilisation of the spine in OBTPs.

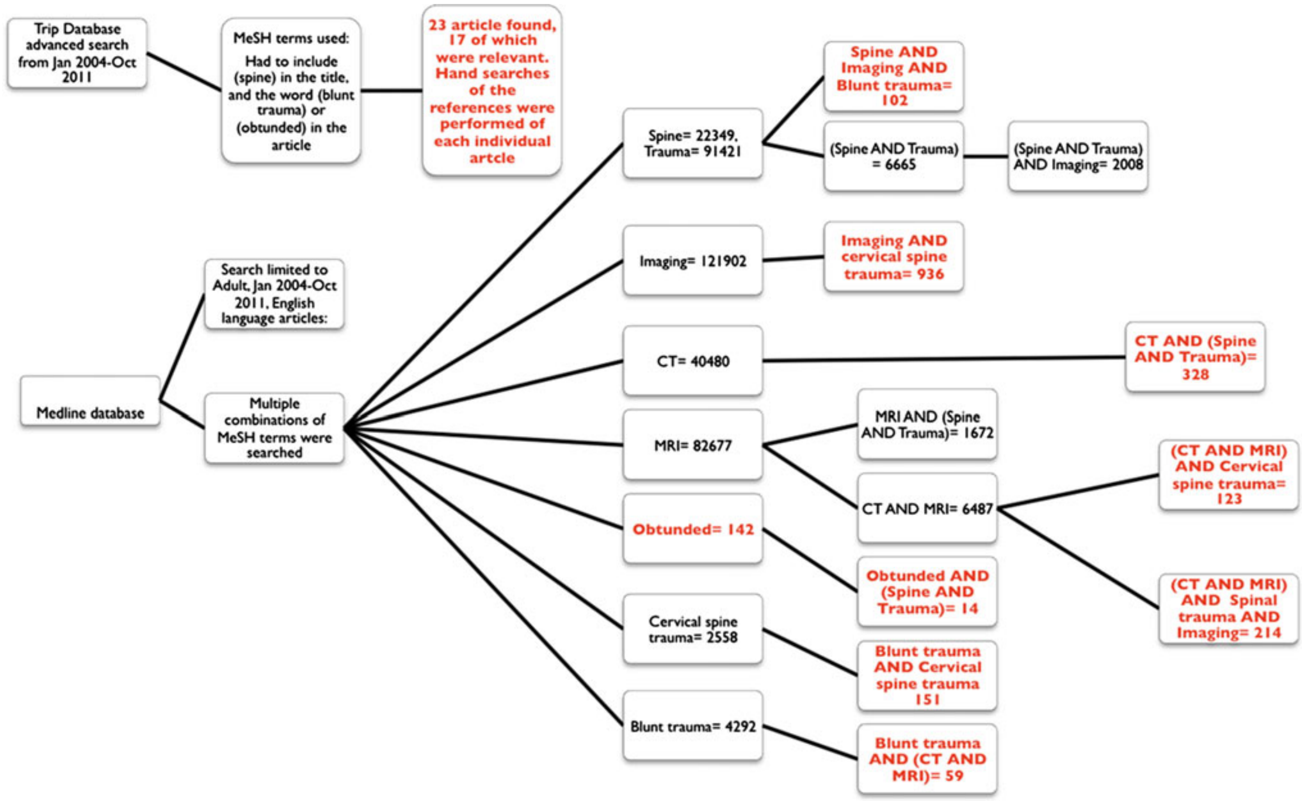

Fig. 1 Flow diagram showing MeSH terms and search combinations. The numbers refer to the number of papers found for the given MeSH term combination. The boxes in *red* show lists where titles and abstracts were read. Remaining papers and editorials were found from the reference lists of the studies

Screening protocols

Certain assumptions remain valid or have emerged since our last review [1]:

1. Clinical evaluation in multiply injured or obtunded patients is unreliable and screening imaging of the spine is mandated.
2. Plain radiography misses injuries of the spinal column in both the alert and the obtunded patient. There is overwhelming evidence for the superiority of CT over plain radiography to detect spinal injury. CT also has time and logistical advantages [6, 12–24].
3. Dynamic fluoroscopy (DF)/Flexion extension (FE/R) radiography to detect instability is hard to perform, time consuming, inaccurate and potentially harmful. There has been little advance in this area, and our previous work suggested at least 177 patients would need to undergo DF to detect one further injury beyond plain radiographs and CT [6, 25–28].
4. MRI is the gold standard if there is a positive neurological examination (referable to the spinal cord) at presentation or if it becomes clear at any stage that there is an abnormal neurological examination [1, 6, 20, 29]. Furthermore, MRI is a highly sensitive test for soft tissue spinal injury, traded against specificity (relative to CT).

Summary of the available imaging options

Plain radiography

The sensitivity of plain radiographs to detect significant[2] spinal injuries, including the three view combination of anteroposterior, lateral and open mouth ‘odontoid’ views ranges widely from 31 to 94% [12, 14, 15, 17, 18, 23, 24, 30]. Usefully Holmes quoted a pooled sensitivity of 52% [22]. Specificity is typically better and has approached 98% in some studies [23]. Most authors agree that there is little place for routine plain radiographs in the management of the OBTP, whenever alternative imaging modalities, in particular MDCT, are available.

[2] Requiring intervention either prolonged collar application of operative fixation.

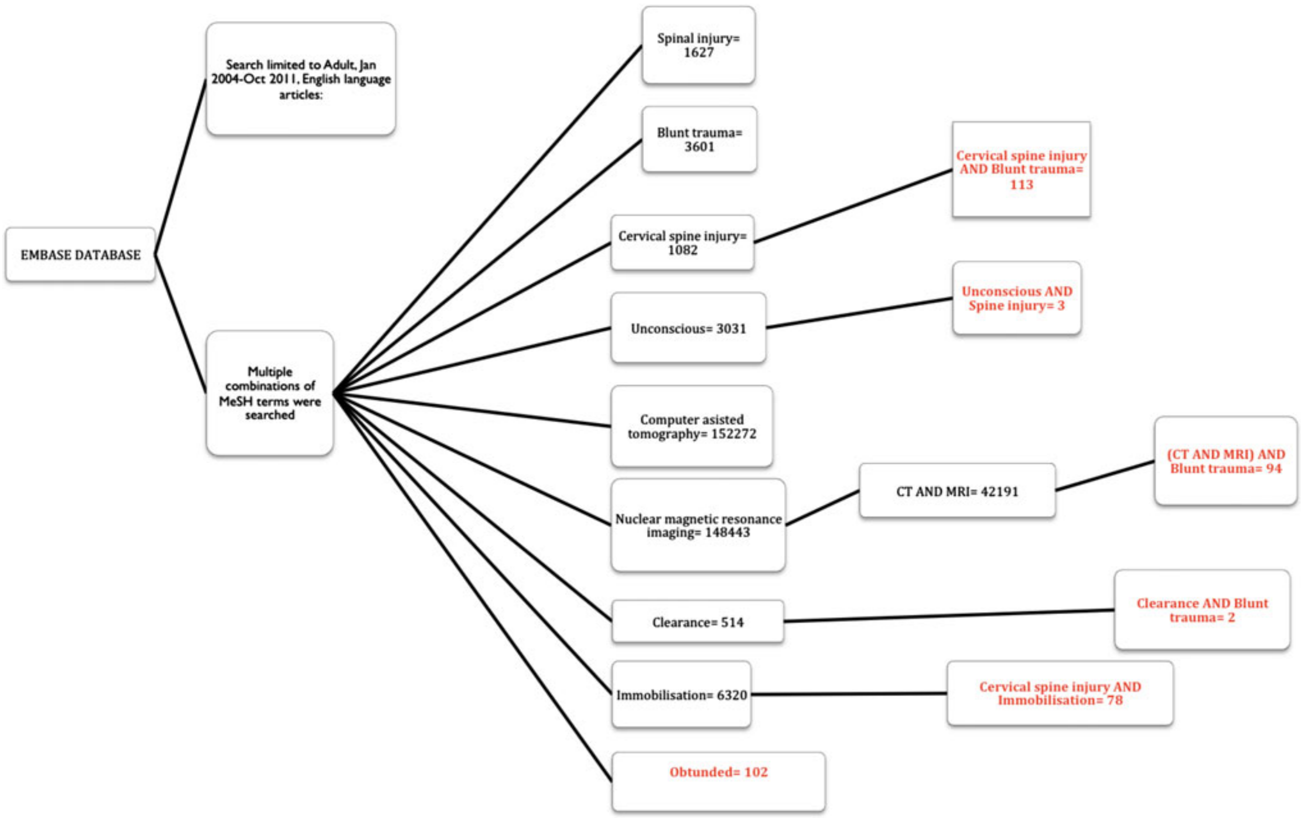

Fig. 2 Flow diagram showing MeSH terms and search combinations. The numbers refer to the number of papers found for the given MeSH term combination. The boxes in *red* show lists where titles and abstracts were read. Remaining papers and editorials were found from the reference lists of the studies

Computerised tomography (CT)

The technology behind CT has progressed considerably since 2004, with most centres using helical or multidetector-row CT rather than 'directed CT' (see abbreviations). The ability of CT to detect spinal column injury is excellent with sensitivity typically approaching 100% [1]. CT is especially good at detecting bony injuries [15, 21–23, 30–33] with specificities approaching 100%. Harris et al. [34] quote a negative predictive value of 99.7% for the ability of CT to detect clinically significant injury. It is emphasised that purely ligamentous cervical spine injuries are exceptionally rare, representing between 0.1 and 0.7% of blunt trauma victims, with most published studies at the lower end of that range [1, 34, 35]. CT is more time and cost effective than plain radiography [36–38].

It has been and remains a widely held belief that only MRI is able to demonstrate isolated ligamentous injury [39]. However, whilst MRI is undoubtedly the most sensitive modality CT can demonstrate ligamentous injury in a high proportion of cases[3] in some series approaching 100% [1, 41–43]. This is particularly true of modern CT scanners [44]. While CT is a commonly employed modality in managing poly-trauma and patients can typically be scanned 'from head to pelvis' in one investigation, CT does expose patients to significant radiation.

[3] Unstable = involving two adjacent ligament support columns as defined by Denis [40].

MRI

Most authorities state that MRI is more sensitive than CT for detecting soft tissue and ligamentous injuries that could contribute to an occult instability of the cervical spine [3, 4, 45–48]. Unfortunately MRI is less sensitive for detecting bony injury and injuries of the posterior spinal column and the significance of many detected injuries (specificity) remains controversial. Routinely performing MRI also carries significant resource implications, requires transfer and introduces the patient to the ferromagnetic environment.

Traumatologists have agreed on the use of MRI in patients with a suspected myelopathy and cord injury, and CT is well established to be inferior in this regard [29, 49]. The false positive rate for MRI has been quoted to be between 25 and 40% [50]. Oversensitivity for presumably clinically insignificant injuries has limited its widespread use as a screening modality [4].

"Postmortem data suggests that MRI demonstrates lesions within the ligaments with high sensitivity, but that many may not reflect instability. Established criteria for distinguishing significant from inconsequential apparent abnormalities on MRI do not exist. The range of 'normal' anatomical variations has only become apparent as MRI has become established, and the distinctions between 'lesion' and 'variation' are blurred. Without proven guidelines, many physicians use through-and-through tears of ligaments to indicate definite mechanical failure, with lesser evidence of injury, such as simple high signal on T2-weighted images, being considered ambiguous or suspicious. These less specific findings tend to be incorporated with clinical findings, evidence of subluxation and other imaging findings, mechanism of injury, and likelihood of successful compliance with conservative treatment." [51, 52].

Dynamic fluoroscopy (DF)/Flexion extension (FE/R) radiography

The ability to visualise the relevant anatomy is poor, as low as 4% [25]. They have a low ability to detect injury [26, 28]. It is highly resource and labour intensive [26].

We will consider the available studies in more depth below but essentially plain radiographs and dynamic studies have largely been made redundant and the main debate within the literature centres on whether patients can be cleared following CT alone, or whether CT and MRI is mandated.

Summary of literature since 2004

The first meta-analysis (see Table 1): Muchow et al. [3] examined studies that prospectively or retrospectively looked at blunt trauma patients who were entered into a cervical spine clearance protocol that included MRI. They included five papers which either pre-date 2004 or are included in subsequent meta-analyses. With regard to resolving which imaging combination should be used to clear the spine of the adult OBTP this meta-analysis contains only 12 patients appropriate for consideration.

The Schuster et al. [53] paper features in the Muchow et al. [4] meta-analysis and the second meta-analysis by Schoenfeld. It looked at all blunt trauma patients (2,854) who when first examined were moving all four limbs. They didn't restrict to unevaluable patients, but of the unevaluable patients, only 12 had MRI scans despite a normal CT scan. These were all normal. This was not a true comparison of the ability of CT versus MRI to detect clinically significant injuries. However, interestingly, they conclude that, as all the MRI scans were normal, CT only is required to clear the CS of the blunt trauma victim.

The second meta-analysis (see Table 2): Schoenfeld et al. [4] included 11 studies from 2000 to 2008 consisting of 1,550 patients (1,295 of which were OBTPs) (Table 2). "Investigations included in this meta-analysis were any prospective or retrospective studies in which patients had an MRI for the purposes of cervical spine clearance after a negative CT scan." [4]. None of the 11 studies were prospective, randomized, controlled trials comparing MRI and CT to CT alone. As yet (2011) we await such a study.

The results need to be interpreted with caution. Of the 12 patients who required operative intervention after an initially negative CT and subsequent positive MRI scan, nine of them were from the Sarani et al. [45] study and none of them were obtunded. One of the patients had surgery for a chance fracture [54] at T7, leaving only two patients from the Menaker study [43, 55]. Table 1 in the paper by Menaker documents the findings of these two patients. These two patients [48], who significantly, represent the only OBTPs in the literature (when this meta-analysis was written) required operative intervention after a negative CT scan. With regard to the first patient Como claims that the injuries described would be extremely unusual without evidence of other injuries and in the second remarks that it is unclear why they needed an operation at all. The authors conclude that the 1% (12 of 1,550) is unacceptable and that any protocol should include an MRI scan to 'clear' the CS, in the OBTP.

Overall there were 182 positive MRI scans after a normal CT, 84 (46%) patients had prolonged collar application and 12 (7%) patients required surgery. It is not clear if the patients who were treated with prolonged collar application actually had significant injuries that required this treatment and it is debateable if those that had surgery required it. However, if one considers studies including OBTPs the results become: 102 positive MRI following normal CT, 61 (60%) with prolonged collar application, and 2 (2%) patients required surgery.

The EAST review from 2009 (lead author J Como) included 52 studies. Of the studies included in the Muchow paper only three were used in the EAST guidelines: [53, 56, 57].

Of the 52 studies included in the guideline the following three papers are relevant to the issue of what to do with the OBTP that are not included in the above two meta-analyses:

Ghanta et al. [58] retrospectively reviewed 51 obtunded patients who had undergone both CT and MRI; 10 of 46 patients (22%) with a normal CT CS had an abnormal MRI CS. Of these, seven were felt to be potentially unstable. Even so, it is unclear how significant these injuries are. The authors concluded that the 2000 EAST guidelines might not be sensitive enough in the obtunded patient [6].

Sanchez et al. [59] validated their own clearance protocol; they cleared the CS (provided that the patient

Table 1 Studies included in the Muchow meta-analysis [3]

Study	Total population	Age range studied	Year of publication	Technology used; Type of scanner used (if available)	Secondary endpoints/ late complications reported in the study (if available)	Extra information	Jadad score	R[a]
Benzel et al. [85]	174 (not all OBTPs)	15 months–91 years	1996	MRI- 0.064 T; T1 and T2 weighted sagittal images, supplement with axial images if needed.	Not mentioned	Not relevant to the OBTPs.	0	4
Keiper et al. [86]	52 (not all OBTPs)	5 months–21 years	1998	MRI- 1.5 T. Sagittal TR 500, TE 12 and turbo spin echo, TE 90-112 chemical or inversion recovery fat-saturated images. Sagittal or axial TR 636, TE 40, flip angle 10° gradient-echo images.	Not mentioned	This was a small paediatric study that compared CT and plain films with MRI. Not clear how many were OBTPs.	0	4
D'Alise et al. [57]	121	4–72 years	1999	MRI- 0.0064 T, 0.5 T, or 1.5 T. Sagittal T1 weighted, Sagittal T2- weighted images with fat-suppression.	Not mentioned	All patients had an MRI but only compared plain films and MRI (crucially not MDCT vs. MRI).	0	4
Albrecht et al. [56]	108 (not clear how many remained obtunded)	Age > 15	2001	MRI- 1.5T, Sagittal T1-weighted images, Sagittal fast inversion recovery images supplemented with axial T2 fat saturation.	Not mentioned	Compared MRI with plain films and or dynamic flexion extension investigations.	0	3
Schuster et al. [53]	93 (12 OBTP)	Mean age 37 years	2005	CT- GE- 2 mm sections with a 1:1.5 pitch. MRI- 1.5 T (GE Signa), Sagittal T1-weighted images and sagittal fast inversion recovery images. Axial fast spin echo T2-weighted images with fat saturation.	Clinic follow- but not separated out for the 12 OBTPs in the study so no information on further endpoints. However 1-2 weeks post discharge no patient required intervention or showed neurologic deterioration.	Only 12 patients in the OBTP group.	0	2

[a] Relevance level assigned by the authors with regard to which imaging combination should be used to clear the spine of the OBTP, CT alone, or CT followed by MRI? *1* highly relevant, *2* relevant but low numbers (<50), *3* partially relevant, *4* not relevant

Table 2 Studies included in the Schoenfeld meta-analysis from 2010

Study	Total population (OBTP with negative CT who then had an MRI)	Age range	Year of publication	Technology used; type of scanner used (if available)	Secondary endpoints/late complications reported in the study (if available)	Extra information	MRI abnormalities missed on CT (%)	What was done about the abnormal MRI?	Jadad score	R[a]
Schuster et al. [53]	93 (12)	Mean age 37 years	2005	CT- GE- 2 mm sections with a 1:1.5 pitch. MRI- 1.5 T (GE signa), sagittal T1-weighted images and sagittal fast inversion recovery images. Axial fast spin echo T2-weighted images with fat saturation.	Clinic follow- but not separated out for the 12 OBTP in the study so no information on further endpoints. However, 1-2 weeks post discharge no patient required intervention or showed neurologic deterioration.	Only 12 in the OBTP group.	23 total (0 of the 12 obtunded patients) (0%)	None required prolonged collar or operative fixation.	0	2
Diaz et al. [17]	85 (22)	15–98 years	2005	CT- HCT (occiput- T1) with - 2-mm axial collimation with HRCT RECON. (Multiplanar recons) used a 1:1 pitch Helical Thomoscan AV, Philips Medical Systems. MRI- No information on the MRI given.	Not mentioned	Only 22 patients in the OBTP group. None of them had ligamentous injury picked up on MRI.	14 (Not the OBTP group) (0%)	14 prolonged collar (not the OBPT group).	0	2
Hogan et al. [29][b]	366 (366)	Mean age 42.1 (range 13–92)	2005	CT- (Skull base to T1) MDCT-MX800 (4 Sects. 88 Pts), OR MX8000 IDT (16 Sects. 278pts) Philips Medical Systems. 4 detector row = 4.1.5 mm collimation with 3 mm thick sections 1.5 mm overlap and pitch of 0.875. 16 detector row = 16 × 0.75 mm collimation with 2 mm thick sections, 1 mm overlap pitch 0.663. RECONS were obtained. MRI- Signa 1.5 T 5.8 software with echo planar gradients (GE Medical Systems) or an Eclipse 1.5T (Philips Medical Systems). Gradient echo sequence in transverse plain, Transverse T2 weighted fast spin echo imaging was added.	Not mentioned		12 (3.3%)	None required prolonged collar or operative fixation. All were deemed stable.	0	1
Adams et al. [54]	97 (29)		2006	CT- CTCS; (GE) light speed 4 slice CT scanner, collimation of 5 mm, pitch of 1.6, and recons at 1 mm (base of the skull to T1) CTCAP-light speed 4 slice CT, collimation of 40 mm, pitch of 3, and recons at 5 mm. From T1-ischial rami. MRI- Sagittal T 1 and T2-weighted images from the posterior fossa through the 5th thoracic vertebrae. 3-mm thin section contiguous axial and sagittal T1- and T2-weighted (C2- T1). The MRI for T/L spine using 4-mm sagittal T2-weighted images of the entire thoracic and lumbar spine to the distal sacrum.		Only 29 patients in the OBTP group.	Only 2 patients but they were not in the OBTP group. (0%)	1 required operative fixation for a T7 chance fracture but this patient was not in the obtunded group.	0	2

Table 2 continued

Study	Total population (OBTP with negative CT who then had an MRI)	Age range	Year of publication	Technology used; type of scanner used (if available)	Secondary endpoints/late complications reported in the study (if available)	Extra information	MRI abnormalities missed on CT (%)	What was done about the abnormal MRI?	Jadad score	R[a]
Stassen et al. [46]	52 (44)	>18 year, average age 44 years	2006	CT- GE Helical scanner. 3 mm × 1.5 mm helical with 1:1 pitch from skull base to top of T1 with sagittal recons. MRI- GE Signa 1.5T, T1 and T2 weighted images axial and sagittal planes from skull base to top of T2 using 3 mm slices.	Average LOS IN ICU 14 days. Follow up showed no missed injuries, the LOS, ICU LOS, ISS, AIS were not statistically different for obtunded patients with or without a c-spine injury. No C-collar related pressure ulceration or skin breakdown was seen.		13 (30%)	All 13 had ligamentous injury and were maintained in an ASPEN collar for 6 weeks.	0	1
Como et al. [60]	115 (115)	Mean age 43.9 years	2007	CT- Philips Brilliance Power 16 slice. Skull base- T1. 16 × 0.75 mm collimation with 1 mm interval recons and 0.5 mm overlap. Sagittal and coronal multiplannar recons were performed at 1 mm intervals on the axial data sets. Axial data sets were also obtained for sagittal and coronal data sets. 9 CTs were done elsewhere on 4 slice scanners. MRI- 1.5T Philips Infinion or Eclipse unit with high res cs coil, sagittal T1, sagittal fast spin echo and sagittal short tau inversion recovery sequence with axial gradient echo sequence of the entire CS. Sagittal slice 3 mm, axial also 3 mm.	6 collar complications – all decubitus ulceration. No adverse events related to transport or obtaining MRI occurred.	Of the six patients; 3 micro-trabecular injuries, intra-spinous ligament injury in 2 patients, and a minimal capsular injury, a questionable cord signal abnormality, and a cervical epidural haematoma in 1 patient each.	6 (5.2%)	None required a prolonged collar application or operative fixation.	0	1
Sarani et al. [45]	164 (46)	Mean age 42 years	2007	CT- imaging was performed using a 16-slice multidetector scanner. MRI- No information given	No information available		5 of the 46 (10.9%) OBTPs with a normal CT had a +ve MRI scan. 4 ligamentous injuries and 1 herniated disc.	4 of the 5 were maintained in a hard collar.	0	2
Stelfox et al. [66]	140 in first half CT then MRI or clinical examination protocol. 75 in second half HCT recon protocol.	Mean age 42.9 years	2007	CT- HCT RECON (C1-T1). No further details	1- Duration of c-spine collar: 4 days shorter in the CT recon group. 2- Complications of immobilisation- overall 186 complications in 117 patients. CT recon group were 67% less likely to experience a complication. 3- No missed injuries in either group.	Complication differences: • Pressure ulcers p = 0.018 less in CT recon group • Health-care-associated pneumonia p = 0.065 less in CT recon group • Mechanical ventilation less days for CT recon group p = 0.011 • Less ICU days for CT recon group- p = 0.028 • Les hospital days in CT recon group 16 vs. 14 days p = 0.043 • Delirium significantly higher in he MRI/clinical group, 68 vs. 20 patients. P = 0.003	Compared 2 protocols separated in time from the same institution. The first required CT AND MRI or clinical examination to 'clear' the CS, the second required only HRCT with further investigation at the discretion of the treating clinicians.	N/A	0	1

Table 2 continued

Study	Total population (OBTP with negative CT who then had an MRI)	Age range	Year of publication	Technology used; type of scanner used (if available)	Secondary endpoints/late complications reported in the study (if available)	Extra information	MRI abnormalities missed on CT (%)	What was done about the abnormal MRI?	Jadad score	R[a]
Menaker et al. [48][c]	203 (203)	Mean age 42.3 years	2008	CT- 16-slice Philips- Brilliance MDCT. Using 2 mm slices with 1 mm overlap. Axial, coronal and sagittal recons. MRI- Picker Eclipse Philips, GE Signa Horizon and Siemens Avanto all = 1.5 T. Included short time inversion recovery, T1, T2, and proton-density sagittal images. Axial images also included gradient echo and T2 fast spin echo format.	90.9% of patients had a negative MRI and collars were removed with no patient subsequently developing neurological deficit. No detail is given about why 2 patients had had their collars removed at the discretion of the attending physician or why the 14 patients who had collars on for extended periods did so.		18 (8.8%)	14 prolonged collar application and 2 operative repair (The only 2 patients in the literature)	0	1
Tomycz et al. [42]	195 (180)	Mean age 45.7 years	2008	CT- Multidetector with sagittal and coronal reformats. GE Litespeed Plus 4 slice from skull base to C7/T1 disc. 4 × 1.25 mm detector configuration beam collimation of 5 mm and a pitch of 1.5. Axial images were reconstructed at either 1.25 mm or 2.50 mm without overlap. Routine coronal and sagittal reformats were performed at 2.0 mm thickness without overlap. MRI- 1.5T GE, T1 AND T2 weighted sequences both axial and sagittal from skull base to top of T1. As well as sagittal and axial gradient-echo pulse sequences with 3 mm slice thickness.	Retrospective review of electronic records revealed that none of the 180 patients developed evidence of delayed cervical instability or required surgery for c-spine injury.		38 (21%)	None required operative fixation. 16 were maintained in a rigid Miami J cervical collar.	0	1
Schoenwaelder et al. [87]	55 (55)	Mean age 37.5 years	2009	CT- GE- Single slice helical scanner. 1 mm collimation from C0–C3 with 3 mm collimation from C3-T4. Coronal and sagittal reformats from C0–C3 were performed as well as sagittal reformats from C3–T4 MRI-No data	Not mentioned.	None of the patients in the cohort had complete ligamentous injuries of 2 or more columns, and no patients required surgery or prolonged cervical spine immobilisation. No patient had cord injury, transection, or epidural haematoma.	10 (18%)	None required prolonged collar or operative fixation. All were deemed stable.	0	1
Total:	1,550 (1,295)						102	61 prolonged collar, 2 operated		

[a] Relevance level assigned by the authors with regard to which imaging combination should be used to clear the spine of the OBTP, CT alone, or CT followed by MRI? *1* highly relevant, *2* relevant but low numbers (<50), *3* partially relevant, *4* not relevant

[b] Note that the studies by Hogan et al. and Menaker et al. both came from the same institution

[c] Note that the studies by Hogan et al. and Menaker et al. both came from the same institution. "Of interest, an earlier study from this institution found no unstable injuries in 366 patients." [43]

was moving all four extremities when initially examined) on the basis of a normal CT. They only used MRI where there was neurological abnormality. From a population of 2,854 they claim to have missed one injury (0.03%) using their protocol (in a patient with syringomyelia). They concluded that CT is adequate for a clearance protocol.

EAST concludes that for the OBTP: "The risk/benefit ratio of obtaining MRI in addition to CT is not clear, and its use must be individualized in each institution (level 3)."

Additional (more recent) relevant papers not included above: (See Table 3)

The following two studies by Menaker et al. [47] and Brown et al. [44], both published in the same journal 2 months apart, re-emphasise the contrasting opinion in the literature. Menaker et al. [47] presented a retrospective cohort study to ascertain if newer CT technology (40-detector row CT) was sufficient for ruling out CS injury in OBTPs. Ninety-six were OBTPs (see Table 3). Of these; 15 (15.6%) had an abnormal MRI scan, seven (7.3%) were managed with a hard cervical collar and one (1%) patient was managed operatively. They found that 8.7% of patients in the 2010 study vs. 8.3% of patients in the 2008 study had their management changed on the basis of the MRI. Only one patient required surgery (1%) suffering a cord compression without contusion but the authors conclude that MRI must be part of any spinal evaluation algorithm because it alters management in approximately 8% of patients [47].

Conversely, Brown et al. [44]: This study was the first to directly compare two different CT scanners with MRI (106 patients). They compared the missed injury rate between a four-slice (43 patients) and a 64-slice MDCT scanner (63 patients). CT missed three injuries that were picked up by MRI (all were in the four-slice group), only one of which required operative fixation. They conclude that newer CT scanners do not appear to miss clinically significant injuries and may allow clearance of the CS in OBTPs without MRI.

Steigelman [41]: cleared the spine after a negative MRI in the OBTP group. With a large cohort of >14,000 patients (Not all OBTPs) 120 in the OBTP group; they concluded that the use of MRI in patients with normal results on CS MDCT (four-row detector) does not appear to alter treatment [41].

Como et al. [43]: Como's group prospectively evaluated their revised protocol with 197 patients. Their view of MRI for the OBTP is clear: "Use of MRI in OBTPs is costly, time-consuming, and potentially dangerous. Our study evaluated the safety of a protocol to discontinue the cervical collar in OBTPs based on CT scan alone" [43]. They all had to be moving all four extremities on admission and have a negative CT prior to collar removal; they were then (importantly) followed up for any developing signs of injury.

Third meta-analysis

Panczykowski et al. [5] recently published a meta-analysis from the Tomycz et al. group [42] and considered studies comparing CT with other imaging modalities. Of the 17 studies that were included 12 of them have been discussed in detail above [17, 21, 23, 29, 30, 34, 41, 42, 48, 53, 54, 60]. Sekula et al. did not look exclusively at obtunded patients (it is not clear how many were obtunded) and they did not compare patients with a negative MDCT with MRI [61]. Spiteri et al. [62] retrospectively analysed a clearance protocol from 1994 to 2004, which did not compare CT to MRI. The remaining three were published prior to 2004 and have been considered elsewhere [1]. The following papers [21, 23, 30, 34] have all been considered above comparing plain radiographs to CT. The remaining eight studies [17, 29, 41, 42, 48, 53, 54, 60], which can be used to answer the question: 'Which screening combination should be used? MDCT alone or MDCT followed by MRI for the OBTP?' were included in the meta-analysis by Schoenfeld [4] apart from Steigelman et al. [41] due to publication timing.

The paper essentially uses the same data as the meta-analysis by Schoenfeld et al. but concludes the opposite, stating that CT alone is sufficient to detect unstable cervical spine injuries.

Complications of 'spinal precautions': prolonged immobilisation and cervical collars (See Table 4)

The numerous serious complications of cervical collars and their ability to stabilise the neck have been reviewed elsewhere. The risks of prolonged immobilisation, beyond 48–72 h, are poorly appreciated and exceed those of a serious missed cervical spine injury [1, 2]. Whilst most clinicians are cognisant and have experience of the many complications of 'spinal precautions' and immobilisation with collar complications, there is paradoxically sparse literature available on this topic. The Cochrane group found little evidence that spinal immobilisation improves outcomes following unstable spinal injury. [63].

Stelfox et al. demonstrated that clearing the CS based on MDCT was associated with less delirium and less ventilator associated pneumonia (VAP), both of which have been associated with increased mortality in critically ill patients [64, 65]. To illustrate the complexities in decision-making VAP may have an attributable mortality (6%), in some series approaching that of the incidence of unstable spine injury itself (5%). They also proved that morbidity increased with increasing duration of collar application in line with previous research [66]. Hence, strategies with high sensitivity but low specificity will inevitably result in liberal collar application and prolonged immobilisation, the risks of which must be balanced against the risks of missed injuries [1, 67].

Table 3 Relevant studies published post the Schoenfeld meta-analysis [4]

Study	Total population (OBTP with negative CT who then had an MRI)	Age range	Year	Technology used; Type of scanner used (if available)	Secondary endpoints/late complications reported in the study (if available)	Extra information	MRI abnormalities missed on CT (%)	What was done about the abnormal MRI?	Jadad score	R[a]
Steigelman et al. [41]	120 (120)	Mean age 38 years (range 0–91 years)	2008	CT- either a single or a 4-row-detector system was used (GE). Majority with the single row scanner. For the last 2 months of the study a 16-row-detector scanner was used (Philips Medical Systems). The standard protocol: 1 mm multiple axial images from the skull base to C3 and 2 mm slices through the remainder of the CS to the thoracic inlet, with sagittal and coronal reformations. MRI- T1,T2 short T1 inversion recovery, and axial T1 weighted and T2 weighted sequences from skull base through entire CS.	Not mentioned.		7 (5.8%)	None required operative fixation. 1 was cleared with FE views. 2 prolonged cervical collars: the first patient with a spinal canal contusion, disk protrusion, and degenerative joint disease remained in a collar for 12 weeks. The other patient, with a chronic interspinous ligament injury and degenerative joint disease, remained in a collar for 6 weeks. On follow-up 1 year later, the patient had no further treatment. The remaining 4 patients had no additional treatment.	0	1
Menaker et al. [47]	213 (96)	Mean age 44.2	2010	CT- 40-slice Philips Brilliance (Philips Medical Systems). (skull base to the T1). Forty-detector row CT was performed by using 40 × 0.625 mm collimation with 1 mm thick sections, 0.5 mm overlap, and a pitch of 0.675. The trauma protoco1 included axial as well as coronal and sagittal reconstruction views. Multiplanar reformations were reformatted to 2-mm thickness every 2 mm through the entire CS. MRI- Picker Eclipse (Philips Medical Systems), GE Signa Horizon (GE Medical Systems), and Siemens Avanto (Siemens). All MRIs were 1.5 Tesla. Protocol: including: short time inversion recovery, T1, T2, and proton-density sagittal images. In addition, axial images included 0grathent echo and T2 fast spin echo format.	The outcomes of the 15 patients are well described in Table 4 of the paper. No data is given on sequelae from immobilisation or other long or short-term complications.	MRI was performed on post injury day 8.5 (±8 days). All CT were done using 40-slice MDCT.	15 (15.6%)	7 remained in a hard collar and 1 underwent operative repair (8.3% patients had management changed). (The 3rd such patient in the literature reported by the same group.)	0	1

Table 3 continued

Study	Total population (OBTP with negative CT who then had an MRI)	Age range	Year	Technology used; Type of scanner used (if available)	Secondary endpoints/late complications reported in the study (if available)	Extra information	MRI abnormalities missed on CT (%)	What was done about the abnormal MRI?	Jadad score	R[a]
Brown et al. [44]	106 (Not stated)	37 (±16 years)	2010	CT- either a four-slice or 64-slice multidetector scanner (Siemens CT). Non-contrast images of the entire CS were obtained in the axial plane with 1 mm collimation followed by 1 mm sagittal and coronal reconstructions. MRI was performed with a (GE) 1.5-T with 3 mm axial, coronal, and parasagittal scans through the entire CS.	Unfortunately no information on complications or long term follow up. No details about the patient who was operated on (only the 4th such patient in the literature.)	All three missed injuries were longitudinal ligamentous injuries of the midcervical spine, two required treatment with a cervical collar and one required operative fixation. Two of the three CT scans in which the injury was missed demonstrated degenerative joint disease of the cervical spine.	3 (2.8%) in the 4-slice CT, 0 in the 64 slice CT group.	2 prolonged collar applications, 1 operative fixation but it is unclear if this patient was in the OBTP group?	0	1
Como et al. [43]	197 (patients were cleared if moving all 4 limbs on admission and had a normal CT scan.)	Mean age 47.1 (range 4-99)	2011	CT- 16 Slice- Philips Brilliance Power 16 or Philips Big Bore multislice detector. The 64 slice scans were obtained with a Philips Brilliance Power multislice detector scanner. (Skull base to at least T1). 16 × 0.75 mm collimation with 1 mm recons and 0.5 mm overlap. 64 × 0.625 mm collimation with 0.9 mmslice thickness and 0.5 mm overlap. Sagittal and coronal multiplannar recon data sets were performed at 1 mm intervals using the axial data set.	127 patients (64.5%) were re-examined by a physician when no longer obtunded; 122 were found to have no CS pain or tenderness and no motor dysfunction in their extremities. Five of these patients (2.5%) had persistent CS symptoms for which an MRI was negative for injury. 25 (12.7%) died before re-examination; autopsy reports were performed in two-thirds of patients. No autopsy revealed missed spinal cord injury. One individual had a report of an isolated C5-C6 ligament injury on autopsy. The patient had rupture of the anterior longitudinal ligament, a one column injury, which was deemed to be a stable injury not requiring continued cervical collar use per our attending neurosurgeon. An additional 23 patients (12%) were followed up by phone or chart review. No patient reported quadriplegia or a new onset neurologic deficit. These patients were either contacted directly or the chart was reviewed for follow-up within our hospital system. The remaining 22 patients (11.2%) were lost to follow-up. One patient (0.5%), a 64 year-old woman, who had her collar removed on hospital day 3, developed a grade 1 submental decubitus ulceration.	5 scans were done on the 64-slice MDCT and 192 on the 16-slice MDCT. In comparison to their previously published study, the revised policy led to earlier collar removal. In this study, the cervical collar was removed on hospital day 3.3 compared with hospital day 7.5 in their previous report. At that time, cervical collars were not removed until an MRI had been obtained.	N/A	There were no reported missed injuries of the cervical spine.	0	1
Total	399						25	12 prolonged collar, 2 operated		

[a] Relevance level assigned by the authors with regard to which imaging combination should be used to clear the spine of the OBTP, CT alone, or CT followed by MRI? *1* highly relevant, *2* relevant but low numbers (<50), *3* partially relevant, *4* not relevant

Table 4 Complications of prolonged immobilisation and spinal precautions

Cutaneous pressure ulceration
Elevated intracranial pressure and venous obstruction
Difficult intubation and loss of the airway
Difficulty in obtaining central venous access
Inability to provide good oral care
Failed enteral nutrition
Gastrostasis, reflux, and pulmonary aspiration
Restricted physiotherapy regimens
Thromboembolism
Increased risk of cross infection

Dunham et al. [68] reviewed the risks of prolonged cervical collars and MRI scanning. They concluded that secondary brain injury was more likely than CS instability in OBTPs, and therefore advocated individualised risk assessments.

Clearing the thoracolumbar spine

Full evaluation of the entire spine (i.e. cervical and thoracolumbar) should be considered after identification of a fracture, because there is an estimated 16% incidence of non-contiguous spine fractures [69]. Isolated ligamentous injury is rare in the TL spine without a fracture due to the centripetal location and supporting musculature. There is therefore less controversy around screening protocols for the T/L spine.

Thoracolumbar (TL) spinal injuries occur in 2–3% of all blunt trauma victims, increasing to 10% in the OBTP population [15]. CT is superior to plain imaging for the detection of significant injury to the TL spine [15, 16, 70–72]. Berry et al. [73] quote 100% sensitivity and 97% specificity for CT to detect TL fracture compared to 73% sensitivity and 100% specificity for plain radiographs. Furthermore, radiographs are inherently compromised in the lateral projection due to the shoulders and hence the cervicothoracic junction region tends to be evaluated and cleared on the anteroposterior view alone.

Where a CT of the chest/abdomen/pelvis (CT-CAP) has already been performed on admission then the use of reformats is superior to plain imaging [73]. In the rare circumstances where a CT-CAP has not been deemed necessary then we would argue that a CT of the entire spine should be performed. Some authors have advocated a ‘pan- CT’ approach to the ‘poly-trauma victim’ in recent years, although this has been called into question [74]. When Tilou et al. [75] attempted to reduce their scan rate they concluded that they would have missed 17% of injuries. Therefore, we would strongly advocate including routine CT to screen the thoracolumbar spine in obtunded blunt trauma victims, and not performing plain radiographs as previously suggested [1].

Limitations of the research

- The trials are almost exclusively retrospective cohort series of institutional protocols
- There seems a persistent reluctance to balance the costs and impacts of missed injuries against those of subjecting a broadly ‘normal’ population to prolonged immobilisation, transfers and imaging [43]
- CT technology has advanced and continues to advance since 2004, see abbreviations [20, 44]. At present only Brown et al. [44] have studied this. The advancement in scan technology is vast and is beyond the scope of this review. It has been reviewed elsewhere [20]. The ability of helical scanners to gather submillimeter section data has become more rapid with larger numbers of detection rays, 256-slice scanners now becoming commonplace. These systems cover 128 mm of anatomy with 0.5 mm slices in a single rotation of the gantry
- The evidence for the timing of MRI is controversial. EAST state that MRI should be performed within 72 h. More recently this had been questioned and needs further research. Menaker et al. claim that the notion that MRI has low sensitivity after 48 h is ‘based on poorly documented anecdotes, poor image quality and no evidence that the delay between injury and imaging was responsible for the false negative MRI’ [47].
- MRI detects injury with high sensitivity and significant rates of false positive studies, perhaps up to 40% [3, 39, 50, 79, 80].
- The literature is now including increasing numbers of reviews and meta-analyses while the methodological quality of the included studies is poor. Accordingly many, analyses are reaching diametrically opposed conclusions based on the same original data

What constitutes stability of the spine?

- Absolute stability or instability of the spine is relatively easy to determine, however the gradations between these are less easy to quantify [76–78].
- Hogan et al. highlighted that many studies lacked outcome data about the stability of injuries of the patients that were kept in cervical collars for prolonged periods. There is some agreement in the literature regarding ligamentous columns and what constitutes instability. “The question of greater import is whether MDCT can depict unstable ligament injuries, that is, injuries involving two adjacent ligament support columns as defined by Denis [40].” [29] The limitations of the widely applied Denis model include it being based around thoracolumbar spine stability and predominantly based upon plain radiographs i.e. it was never validated with CT or MRI.
- There is generally very poor information regarding the details of ligamentous injuries, i.e. the structures that were injured aside from the work by Steigelman et al. [41]. Many authors would argue that newer CT technology could detect these injuries [41, 43, 44, 53].

Resolving the controversy between clearing the spine on imaging: CT or CT and MRI?

As discussed, the on-going controversy largely revolves around the need for routine MRI to supplement CT, or whether CT alone is adequate to clear the cervical spine. One of the key obstacles in resolving the CT or CT + MRI controversy is that the performance, in particular, sensitivity for significant injuries, of CT alone has been so variously reported. The ‘miss rate’ for unstable injuries following a 'normal CT' (variously described as needing prolonged collar application, halo vest or surgical stabilisation) varies from almost 0% [59], <1% [60], 2.5% [68] to approximately 4.3% as we have described above, among whom approximately 0.29% would require surgical stabilisation. This must be balanced however against the false positive rate with MRI, perhaps up to 25–40% [50], which if applied routinely would require all OBTPs to undergo prolonged stabilisation (with associated complications), even though 95% have no actual injury. Furthermore, difficulties in standardised interpretation of imaging of any modality make exact rates of sensitivity and specificity difficult to define.

There are therefore two valid interpretations of the available literature and little prospect of resolving their disparate conclusions; namely it appears both modern CT and combined CT + MRI are acceptable ways of screening for spinal instability. The decision as to which modality to use will depend on the features outlined above when considering 'screening' but also:

- Previous performance by individuals and the institution. It is essential centres audit their data because it is likely this data will be more informative than research in determining what the likely screening performance (sensitivity, specificity, etc.) is for a patient in any given institution.
- It is likely that a strategy that revolves around CT alone will result in faster liberation from spinal precautions and associated complications and have a lower rate of false positive tests.
- Conversely it is likely that a routine strategy of combined CT and MRI is likely to have the best sensitivity for injuries, including ligamentous injuries. This will be at the expense of an increased rate of false positive tests and prolonged application of spinal precautions, amongst a population where the actual injury rate approximates 5%.
- The decision around which strategy to adopt is partly scientific but also influenced by previous events (e.g. missed injuries or complications of spinal immobilisation) at any given institution.
- It is likely clinicians will continue to struggle to reach consensus on what constitutes an 'acceptable' rate of missed injuries or unnecessary spinal precautions. It is likely, therefore, that a dichotomous approach remains for the foreseeable future (Table 5).

What recommendations for practice can be made?

Given the low level of higher quality evidence, considered in more detail above, we would make the following recommendations for practice based upon the GRADE system [81], the recommendations being 'strong' or 'conditional'. (See Appendix).

1. Document movement of limbs at first presentation; if intubated ensure robust handover from pre-hospital team (strong).
2. Routine plain radiographs and dynamic flexion/extension views are out (strong).
3. MRI if there is a positive neurological examination referable to the spinal cord (myelopathy) (strong).
4. CT the entire (cervical, and thoracolumbar) spine in OBTPs using a modern MDCT (strong).
5. Get images reported by a senior radiologist who is skilled in musculoskeletal/neuro-radiology (strong).
6. Some centres may still feel an MRI is mandated after a normal CT and the consequences of this must be carefully considered (conditional).
7. It remains acceptable to remove spinal precautions after CT and combined CT and MRI but there are clear implications to both approaches (conditional).
8. Considering that only approximately 5% of OBTP have an actual injury whatever strategy is used, spinal precautions and the cervical collar should be removed as soon as is feasibly possible and mobilisation should be achieved (strong).
9. Be vigilant for developing neurological signs despite a spine having been 'cleared' (strong)

Table 5 Advantages and disadvantages of CT alone vs. CT followed by MRI

	Advantages	Disadvantages
CT alone	• Sensitivity and specificity can be close to 100% • Easily performed during CT based poly-trauma evaluation 'pan-CT' • CT widely available and technology continues to evolve • Skilled interpretation generally widespread • No requirement for additional transfers TL spine can be evaluated at same time	• Some workers report significant missed injuries, perhaps approximately 4% amongst whom some require surgical stabilisation (0.29%) • Significant radiation exposure
Combined CT and MRI	• Arguably the most sensitive screening test and probably cannot be improved upon	• Controversial additional yield of significant injuries: false positive rate may reach 40%. • Requirement for transfers and ferromagnetic environment • Significant additional expense • Skilled interpretation may not be available, and scanner availability, especially for the critically ill cannot be guaranteed

Suggestions for future research and audit

As has been suggested above, it is as important for individual institutions to undergo rigorous audit rather than solely awaiting a definitive research study. The complexity of processes involved in screening for spinal injuries from scanner capability, image acquisition to interpretation and correlation of clinical features means that all centres must be able to demonstrate the typical performances of screening in their practice. Suggested end points for audit would be related to the recommendations for practice above including:

- Accurate rates of sensitivity, specificity, and predicative values for any imaging undertaken for screening for spinal injuries.
- Time to clearing the spine and rates of prolonged collar or halo vest application or surgical stabilisation.
- The multidisciplinary team reviews all missed injuries.
- Complications related to screening, e.g. during transfer, pressure sores, rates of ventilator associated pneumonia, outcomes from traumatic brain injury and intracranial pressure records.

Despite the challenges there is precedent in conducting high quality research of this nature in screening for spinal injuries [8, 82]. Many of the conclusions drawn from recent meta-analyses on this subject and older research called for good quality prospective trials of MDCT versus MRI in their respective abilities to detect unstable spinal injuries in the OBTP population [6, 29, 79]. We believe the study that would be most informative would be a prospective, multiple centre comparison of clearing the cervical spine in OBTPs by comparing MDCT versus combined MDCT and MRI. This study would need to be powered to detect a difference in detection rates at the lower end of the quoted ranges (i.e. approaching 0%) and given pre-existing clinician practice, prejudice or lack of equipoise this could be run most feasibly as a cluster randomised model. In addition to accurately defining the true performances of these imaging modalities such a large cohort could also include secondary tiers of research [83, 84], e.g. comparing different brands of cervical collars and pressure sore rates.

In the absence of such work comparative audit and centres publishing their series and cohorts, can do much to inform likely best practice. It is hoped that industry can become involved more energetically when one considers the return from installing and running modern scanning machines.

This review is principally limited by the quality of the studies, notably there have been no prospective randomised controlled trials comparing CT with MRI for the OBTP, and therefore our primary conclusion is that MDCT and combined MDCT and MRI are both acceptable approaches. The paucity of follow up data and indications for prolonged collar application along with a lack of information about decisions that occurred to keep a cervical collar on limit our ability to interpret the relevance of some of these studies.

Conclusions

From the data that we have presented in Tables 2 and 3 for all studies that compared CT with MRI for the OBTP group, where the patient had an MRI after a ‘normal’ CT scan. We have worked out a ‘worst case’ operative fixing rate of 0.29% and a prolonged collar application rate of 4.3% with a positive MRI scan rate of 7.5%. Many workers suggest modern CT can identify all significant injuries in their practice. The key issue clinicians need to consider is what is the screening performance (sensitivity, specificity and predicative values) of the imaging undertaken in their institution, and what rates do they conceptually find acceptable to work with. This must be considered in the context of a population where 95% do not have an actual injury, and failure to remove spinal precautions produces secondary morbidity and mortality that could potentially rival the rates of complications due to missed injuries. In common with all screening processes false positive and negative results will occur and have consequences. All clinicians must be vigilant to missed injuries and attempt to clear the spine of instability as soon as possible following injury.

Conflicts of interest No conflicts of interest declared.

Appendix

See Fig. 3

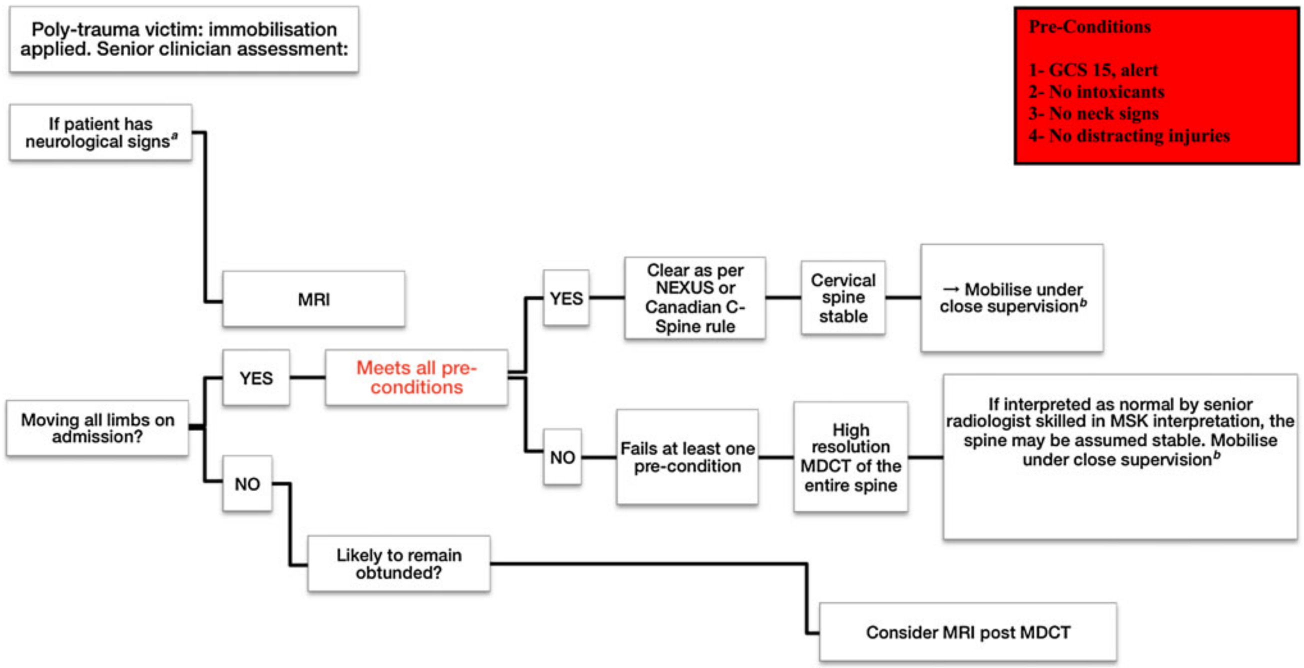

Fig. 3 Updated guidance on proposed screening of the cervical spine in the OBTP. NOTE: [a]Neurological deficit referable to the spine requires urgent consideration of magnetic resonance imaging (MRI). Management of a detected injury must involve a senior neurosurgeon or orthopaedic surgeon. [b]Subsequent weakness, paraesthesia, spinal pain may indicate a missed injury

References

1. Morris CG, McCoy E (2004) Clearing the cervical spine in unconscious poly-trauma victims, balancing risks and effective screening. Anaesthesia 59:464–482
2. Morris CG, McCoy EP, Lavery GG, McCoy E (2004) Spinal immobilisation for unconscious patients with multiple injuries. BMJ 329:495–499
3. Muchow RD, Resnick DK, Abdel MP, Munoz A, Anderson PA (2008) Magnetic resonance imaging (MRI) in the clearance of the cervical spine in blunt trauma: a meta-analysis. J Trauma 64:179–189
4. Schoenfeld AJ, Bono CM, McGuire KJ, Warholic N, Harris MB (2010) Computed tomography alone versus computed tomography and magnetic resonance imaging in the identification of occult injuries to the cervical spine: a meta-analysis. J Trauma 68:109–113 discussion 113–114
5. Panczykowski DM, Tomycz ND, Okonkwo DO (2011) Comparative effectiveness of using computed tomography alone to exclude cervical spine injuries in obtunded or intubated patients: meta-analysis of 14,327 patients with blunt trauma. J Neurosurg 115:541–549
6. Como JJ, Diaz JJ, Dunham CM, Chiu WC, Duane TM, Capella JM, Holevar MR, Khwaja KA, Mayglothling JA, Shapiro MB, Winston ES (2009) Practice management guidelines for identification of cervical spine injuries following trauma: update from the eastern association for the surgery of trauma practice management guidelines committee. J Trauma 67:651–659
7. Phillips B, Ball C, Sackett D, Badenoch D, Straus S, Haynes B, Dawes M, Howick J (1998) Oxford Centre for Evidence-Based Medicine-Levels of Evidence (March 2009) Disponible en: http://www.cebm.net/index.aspx.o1025
8. Hoffman JR, Mower WR, Wolfson AB, Todd KH, Zucker MI (2000) Validity of a set of clinical criteria to rule out injury to the cervical spine in patients with blunt trauma. National Emergency X-Radiography Utilization Study Group. N Engl J Med 343:94–99
9. Anderson PA, Muchow RD, Munoz A, Tontz WL, Resnick DK (2010) Clearance of the asymptomatic cervical spine: a meta-analysis. J Orthop Trauma 24:100–106
10. Halpern CH, Milby AH, Guo W, Schuster JM, Gracias VH, Stein SC (2010) Clearance of the cervical spine in clinically unevaluable trauma patients. Spine (Phila Pa 1976) 35:1721–1728
11. Yentis SM (2006) Predicting trouble in airway management. Anesthesiology 105:871–872

12. Antevil JL, Sise MJ, Sack DI, Kidder B, Hopper A, Brown CV (2006) Spiral computed tomography for the initial evaluation of spine trauma: a new standard of care? J Trauma 61:382–387
13. Barba CA, Taggert J, Morgan AS, Guerra J, Bernstein B, Lorenzo M, Gershon A, Epstein N (2001) A new cervical spine clearance protocol using computed tomography. J Trauma 51:652–656 discussion 656–657
14. Bailitz J, Starr F, Beecroft M, Bankoff J, Roberts R, Bokhari F, Joseph K, Wiley D, Dennis A, Gilkey S, Erickson P, Raksin P, Nagy K (2009) CT should replace three-view radiographs as the initial screening test in patients at high, moderate, and low risk for blunt cervical spine injury: a prospective comparison. J Trauma 66:1605–1609
15. Bagley LJ (2006) Imaging of spinal trauma. Radiol Clin North Am 44: 1-12, vii.10.1016/j.rcl.2005.08.004
16. Brandt MM, Wahl WL, Yeom K, Kazerooni E, Wang SC (2004) Computed tomographic scanning reduces cost and time of complete spine evaluation. J Trauma 56:1022–1026 discussion 1026–1028
17. Diaz JJ, Aulino JM, Collier B, Roman C, May AK, Miller RS, Guillamondegui O, Morris JA (2005) The early work-up for isolated ligamentous injury of the cervical spine: does computed tomography scan have a role? J Trauma 59:897–903 discussion 903–904
18. Gale SC, Gracias VH, Reilly PM, Schwab CW (2005) The inefficiency of plain radiography to evaluate the cervical spine after blunt trauma. J Trauma 59:1121–1125
19. Griffen MM, Frykberg ER, Kerwin AJ, Schinco MA, Tepas JJ, Rowe K, Abboud J (2003) Radiographic clearance of blunt cervical spine injury: plain radiograph or computed tomography scan? J Trauma 55:222–226 discussion 226–227
20. Goldberg AL, Kershah SM (2010) Advances in imaging of vertebral and spinal cord injury. J Spinal Cord Med 33:105–116
21. Hashem R, Evans CC, Farrokhyar F, Kahnamoui K (2009) Plain radiography does not add any clinically significant advantage to multidetector row computed tomography in diagnosing cervical spine injuries in blunt trauma patients. J Trauma 66:423–428
22. Holmes JF, Akkinepalli R (2005) Computed tomography versus plain radiography to screen for cervical spine injury: a meta-analysis. J Trauma 58:902–905
23. Mathen R, Inaba K, Munera F, Teixeira PG, Rivas L, McKenney M, Lopez P, Ledezma CJ (2007) Prospective evaluation of multislice computed tomography versus plain radiographic cervical spine clearance in trauma patients. J Trauma 62:1427–1431
24. McCulloch PT, France J, Jones DL, Krantz W, Nguyen TP, Chambers C, Dorchak J, Mucha P (2005) Helical computed tomography alone compared with plain radiographs with adjunct computed tomography to evaluate the cervical spine after high-energy trauma. J Bone Joint Surg Am 87:2388–2394
25. Bolinger B, Shartz M, Marion D (2004) Bedside fluoroscopic flexion and extension cervical spine radiographs for clearance of the cervical spine in comatose trauma patients. J Trauma 56:132–136
26. Freedman I, van Gelderen D, Cooper DJ, Fitzgerald M, Malham G, Rosenfeld JV, Varma D, Kossmann T (2005) Cervical spine assessment in the unconscious trauma patient: a major trauma service's experience with passive flexion-extension radiography. J Trauma 58:1183–1188
27. Hennessy D, Widder S, Zygun D, Hurlbert RJ, Burrowes P, Kortbeek JB (2010) Cervical spine clearance in obtunded blunt trauma patients: a prospective study. J Trauma 68:576–582
28. Padayachee L, Cooper DJ, Irons S, Ackland HM, Thomson K, Rosenfeld J, Kossmann T (2006) Cervical spine clearance in unconscious traumatic brain injury patients: dynamic flexion-extension fluoroscopy versus computed tomography with three-dimensional reconstruction. J Trauma 60:341–345
29. Hogan GJ, Mirvis SE, Shanmuganathan K, Scalea TM (2005) Exclusion of unstable cervical spine injury in obtunded patients with blunt trauma: is MR imaging needed when multi-detector row CT findings are normal? Radiology 237:106–113
30. Brohi K, Healy M, Fotheringham T, Chan O, Aylwin C, Whitley S, Walsh M (2005) Helical computed tomographic scanning for the evaluation of the cervical spine in the unconscious, intubated trauma patient. J Trauma 58:897–901
31. Platzer P, Jaindl M, Thalhammer G, Dittrich S, Wieland T, Vecsei V, Gaebler C (2006) Clearing the cervical spine in critically injured patients: a comprehensive C-spine protocol to avoid unnecessary delays in diagnosis. Eur Spine J 15:1801–1810
32. Berne JD, Velmahos GC, El-Tawil Q, Demetriades D, Asensio JA, Murray JA, Cornwell EE, Belzberg H, Berne TV (1999) Value of complete cervical helical computed tomographic scanning in identifying cervical spine injury in the unevaluable blunt trauma patient with multiple injuries: a prospective study. J Trauma 47:896–902 discussion 902–903
33. Brown CV, Antevil JL, Sise MJ, Sack DI (2005) Spiral computed tomography for the diagnosis of cervical, thoracic, and lumbar spine fractures: its time has come. J Trauma 58:890–895 discussion 895–896
34. btunded patients. 33: 1547-53
35. Chiu WC, Haan JM, Cushing BM, Kramer ME, Scalea TM (2001) Ligamentous injuries of the cervical spine in unreliable blunt trauma patients: incidence, evaluation, and outcome. J Trauma 50:457–463 discussion 464
36. Blackmore CC, Ramsey SD, Mann FA, Deyo RA (1999) Cervical spine screening with CT in trauma patients: a cost-effectiveness analysis. Radiology 212:117–125
37. Daffner RH (2001) Helical CT of the cervical spine for trauma patients: a time study. AJR Am J Roentgenol 177:677–679
38. Daffner RH (2000) Cervical radiography for trauma patients: a time-effective technique? AJR Am J Roentgenol 175:1309–1311
39. Harrison JL, Ostlere SJ (2004) Diagnosing purely ligamentous injuries of the cervical spine in the unconscious trauma patient. Br J Radiol 77:276–278
40. Denis F (1984) Spinal instability as defined by the three-column spine concept in acute spinal trauma. Clin Orthop Relat Res 189:65–76
41. Steigelman M, Lopez P, Dent D, Myers J, Corneille M, Stewart R, Cohn S (2008) Screening cervical spine MRI after normal cervical spine CT scans in patients in whom cervical spine injury cannot be excluded by physical examination. Am J Surg 196:857–862 discussion 862–863
42. Tomycz ND, Chew BG, Chang YF, Darby JM, Gunn SR, Nicholas DH, Ochoa JB, Peitzman AB, Schwartz E, Pape HC, Spiro RM, Okonkwo DO (2008) MRI is unnecessary to clear the cervical spine in obtunded/comatose trauma patients: the four-year experience of a level I trauma center. J Trauma 64:1258–1263

43. Como JJ, Leukhardt WH, Anderson JS, Wilczewski PA, Samia H, Claridge JA (2011) Computed tomography alone may clear the cervical spine in obtunded blunt trauma patients: a prospective evaluation of a revised protocol. J Trauma 70:345–349 discussion 349–351
44. Brown CV, Foulkrod KH, Reifsnyder A, Bui E, Lopez I, Hummell M, Coopwood B (2010) Computed tomography versus magnetic resonance imaging for evaluation of the cervical spine: how many slices do you need? Am Surg 76:365–368
45. Sarani B, Waring S, Sonnad S, Schwab CW (2007) Magnetic resonance imaging is a useful adjunct in the evaluation of the cervical spine of injured patients. J Trauma 63:637–640
46. Stassen NA, Williams VA, Gestring ML, Cheng JD, Bankey PE (2006) Magnetic resonance imaging in combination with helical computed tomography provides a safe and efficient method of cervical spine clearance in the obtunded trauma patient. J Trauma 60:171–177
47. Menaker J, Stein DM, Philp AS, Scalea TM (2010) 40-slice multidetector CT: is MRI still necessary for cervical spine clearance after blunt trauma? Am Surg 76:157–163
48. Menaker J, Philp A, Boswell S, Scalea TM (2008) Computed tomography alone for cervical spine clearance in the unreliable patient–are we there yet? J Trauma 64:898–903 discussion 903–904
49. Parizel PM, van der Zijden T, Gaudino S, Spaepen M, Voormolen MH, Venstermans C, De Belder F, van den Hauwe L, Van Goethem J (2010) Trauma of the spine and spinal cord: imaging strategies. Eur Spine J 19(Suppl 1):S8–S17
50. Richards PJ (2005) Cervical spine clearance: a review. Injury 36:248–269 discussion 270
51. Daffner RH, Hackney DB (2007) ACR Appropriateness Criteria on suspected spine trauma. J Am Coll Radiol 4:762–775
52. Daffner RH, Wippold FJ II, Bennett DL, Blebea JS, Cornelius RS, Fries IB, Hartl R, Holly L, Morrison WB, Prall JA, Resnik CS, Schweizer ME, Seidenwurm DJ, Sloan MA, Weissman BN, Zimmerman RD (2009) Expert Panels on Musculoskeletal and Neurologic Imaging. ACR Appropriateness Criteria® suspected spine trauma. [online publication]. Reston (VA): American College of Radiology (ACR);http://guidelines.gov/content.aspx?f=rss&id=15742#Section420
53. Schuster R, Waxman K, Sanchez B, Becerra S, Chung R, Conner S, Jones T (2005) Magnetic resonance imaging is not needed to clear cervical spines in blunt trauma patients with normal computed tomographic results and no motor deficits. Arch Surg 140:762–766
54. Adams JM, Cockburn MI, Difazio LT, Garcia FA, Siegel BK, Bilaniuk JW (2006) Spinal clearance in the difficult trauma patient: a role for screening MRI of the spine. Am Surg 72:101–105
55. Como JJ (2010) The role of MRI in the clearance of the cervical spine in the obtunded blunt trauma patient. J Trauma 68:1269–1270
56. Albrecht RM, Kingsley D, Schermer CR, Demarest GB, Benzel EC, Hart BL (2001) Evaluation of cervical spine in intensive care patients following blunt trauma. World J Surg 25:1089–1096
57. D'Alise MD, Benzel EC, Hart BL (1999) Magnetic resonance imaging evaluation of the cervical spine in the comatose or obtunded trauma patient. J Neurosurg 91:54–59
58. Ghanta MK, Smith LM, Polin RS, Marr AB, Spires WV (2002) An analysis of Eastern Association for the Surgery of Trauma practice guidelines for cervical spine evaluation in a series of patients with multiple imaging techniques. Am Surg 68:563–567 discussion 567–568
59. Sanchez B, Waxman K, Jones T, Conner S, Chung R, Becerra S (2005) Cervical spine clearance in blunt trauma: evaluation of a computed tomography-based protocol. J Trauma 59:179–183
60. Como JJ, Thompson MA, Anderson JS, Shah RR, Claridge JA, Yowler CJ, Malangoni MA (2007) Is magnetic resonance imaging essential in clearing the cervical spine in obtunded patients with blunt trauma? J Trauma 63:544–549
61. Sekula RF, Daffner RH, Quigley MR, Rodriguez A, Wilberger JE, Oh MY, Jannetta PJ, Protetch J (2008) Exclusion of cervical spine instability in patients with blunt trauma with normal multidetector CT (MDCT) and radiography. Br J Neurosurg 22:669–674
62. Spiteri V, Kotnis R, Singh P, Elzein R, Madhu R, Brooks A, Willett K (2006) Cervical dynamic screening in spinal clearance: now redundant. J Trauma 61:1171–1177 discussion 1177
63. Kwan I, Bunn F, Roberts I (2001) Spinal immobilisation for trauma patients. Cochrane Database Syst Rev CD002803.10.1002/14651858.CD002803
64. Kollef MH, Shorr A, Tabak YP, Gupta V, Liu LZ, Johannes RS (2005) Epidemiology and outcomes of health-care-associated pneumonia: results from a large US database of culture-positive pneumonia. Chest 128:3854–3862
65. Ely EW, Shintani A, Truman B, Speroff T, Gordon SM, Harrell FE, Inouye SK, Bernard GR, Dittus RS (2004) Delirium as a predictor of mortality in mechanically ventilated patients in the intensive care unit. JAMA 291:1753–1762
66. Stelfox HT, Velmahos GC, Gettings E, Bigatello LM, Schmidt U (2007) Computed tomography for early and safe discontinuation of cervical spine immobilization in obtunded multiply injured patients. J Trauma 63:630–636
67. Morris CG, McCoy E (2003) Cervical immobilisation collars in ICU: friend or foe? Anaesthesia 58:1051–1053
68. Dunham CM, Brocker BP, Collier BD, Gemmel DJ (2008) Risks associated with magnetic resonance imaging and cervical collar in comatose, blunt trauma patients with negative comprehensive cervical spine computed tomography and no apparent spinal deficit. Crit Care 12: R89. 10.1186/cc6957
69. Patel RV, DeLong W, Vresilovic EJ (2004) Evaluation and treatment of spinal injuries in the patient with poly-trauma. Clin Orthop Relat Res 422:43–54
70. Wintermark M, Mouhsine E, Theumann N, Mordasini P, van Melle G, Leyvraz PF, Schnyder P (2003) Thoracolumbar spine fractures in patients who have sustained severe trauma: depiction with multi-detector row CT. Radiology 227:681–689
71. Hauser CJ, Visvikis G, Hinrichs C, Eber CD, Cho K, Lavery RF, Livingston DH (2003) Prospective validation of computed tomographic screening of the thoracolumbar spine in trauma. J Trauma 55:228–234 discussion 234–235
72. Campbell SE, Phillips CD, Dubovsky E, Cail WS, Omary RA (1995) The value of CT in determining potential instability of simple wedge-compression fractures of the lumbar spine. AJNR Am J Neuroradiol 16:1385–1392
73. Berry GE, Adams S, Harris MB, Boles CA, McKernan MG, Collinson F, Hoth JJ, Meredith JW, Chang MC, Miller PR (2005) Are plain radiographs of the spine necessary during evaluation after blunt trauma? Accuracy of screening torso computed tomography in thoracic/lumbar spine fracture diagnosis. J Trauma 59:1410–1413 discussion 1413

74. Tien HC, Tremblay LN, Rizoli SB, Gelberg J, Spencer F, Caldwell C, Brenneman FD (2007) Radiation exposure from diagnostic imaging in severely injured trauma patients. J Trauma 62:151–156
75. Tillou A, Gupta M, Baraff LJ, Schriger DL, Hoffman JR, Hiatt JR, Cryer HM (2009) Is the use of pan-computed tomography for blunt trauma justified? A prospective evaluation. J Trauma 67:779–787
76. White AA, Panjabi MM (1987) Update on the evaluation of instability of the lower cervical spine. Instr Course Lect 36:513–520
77. Panjabi MM, White AA, Keller D, Southwick WO, Friedlaender G (1978) Stability of the cervical spine under tension. J Biomech 11:189–197
78. White AA, Johnson RM, Panjabi MM, Southwick WO (1975) Biomechanical analysis of clinical stability in the cervical spine. Clin Orthop Relat Res 109:85–96
79. Ackland HM, Cooper DJ, Malham GM, Stuckey SL (2006) Magnetic resonance imaging for clearing the cervical spine in unconscious intensive care trauma patients. J Trauma 60:668–673
80. Goradia D, Linnau KF, Cohen WA, Mirza S, Hallam DK, Blackmore CC (2007) Correlation of MR imaging findings with intraoperative findings after cervical spine trauma. AJNR Am J Neuroradiol 28:209–215
81. Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Alonso-Coello P, Schünemann HJ, GRADE Working Group (2008) GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ 336:924–926
82. Stiell IG, Wells GA, Vandemheen KL, Clement CM, Lesiuk H, De Maio VJ, Laupacis A, Schull M, McKnight RD, Verbeek R, Brison R, Cass D, Dreyer J, Eisenhauer MA, Greenberg GH, MacPhail I, Morrison L, Reardon M, Worthington J (2001) The Canadian C-spine rule for radiography in alert and stable trauma patients. JAMA 286:1841–1848
83. Brunkhorst FM, Engel C, Bloos F, Meier-Hellmann A, Ragaller M, Weiler N, Moerer O, Gruendling M, Oppert M, Grond S, Olthoff D, Jaschinski U, John S, Rossaint R, Welte T, Schaefer M, Kern P, Kuhnt E, Kiehntopf M, Hartog C, Natanson C, Loeffler M, Reinhart K, German Competence Network Sepsis (SepNet) (2008) Intensive insulin therapy and pentastarch resuscitation in severe sepsis. N Engl J Med 358:125–139
84. NHLBI ARDS Network http://www.ardsnet.org. Accessed 13 Dec 2011
85. Benzel EC, Hart BL, Ball PA, Baldwin NG, Orrison WW, Espinosa MC (1996) Magnetic resonance imaging for the evaluation of patients with occult cervical spine injury. J Neurosurg 85:824–829
86. Keiper MD, Zimmerman RA, Bilaniuk LT (1998) MRI in the assessment of the supportive soft tissues of the cervical spine in acute trauma in children. Neuroradiology 40:359–363
87. Schoenwaelder M, Maclaurin W, Varma D (2009) Assessing potential spinal injury in the intubated multitrauma patient: does MRI add value? Emerg Radiol 16:129–132