

REVIEW ARTICLE

Clearing the cervical spine in unconscious polytrauma victims, balancing risks and effective screening

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Summary

Cervical spine injury occurs in 5–10% of cases of blunt polytrauma. A missed or delayed diagnosis of cervical spine injury may be associated with permanent neurological sequelae. However, there is no consensus about the ideal evaluation and management of the potentially injured cervical spine and, despite the publication of numerous clinical guidelines, this issue remains controversial. In addition, many studies are limited in their application to the obtunded or unconscious trauma victim. This review will provide the clinician managing unconscious trauma victims with an assessment of the actual performance of clinical examination and imaging modalities in detecting cervical spine and isolated ligamentous injury, a review of existing guidelines in light of the available evidence, relative risk estimates and a proposed management scheme.

Keywords *Spinal injuries. Neck injuries. Diagnostic imaging. Multiple trauma. Unconsciousness.*

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Cervical spine and associated spinal cord injury significantly affect the individual's functional capacity and quality of life, and carry significant implications for society. It was estimated in 1988 that a 27-year-old rendered tetraparetic would consume US\$ 1 million for lifetime care and, with 721 tetraparetic individuals per million of the population, the total aggregate costs were an estimated US\$ 5.6 billion per year [1]. In America, cervical, thoracic and lumbar vertebral fractures occur with an incidence of 50 000 per year [2], and cervical spine injury has an annual incidence of 5–10 000 cases per year [3,4]. More recent estimates suggest an incidence of 8–10 000 spinal cord injuries per year, of which 55% are cervical [5]. In the UK, there are approximately 1000 new cases of cervical cord injury each year [6]. Cervical spine injury complicates blunt polytrauma in 2–12% of cases [7–9]. However, several larger reviews that include 29 000 blunt trauma victims, and additional prospectively gathered data, demonstrate a generally lower incidence (2.0–5.2%) [10–13].

The presence of a severe head injury increases the relative risk of a cervical spine injury, possibly by

8.5 times, and a focal neurological deficit by 58 times [14]. A Glasgow Coma Scale (GCS) score of <8 is associated with a 50% increase in the incidence of cervical spine injury to 7.8% [15]. Similarly, Demetriades *et al.* [16] have shown that although the incidence of cervical spine injury in trauma victims with a GCS score of 13–15 was only 1.4%; this increased to 10.2% if GCS was < 8. 'Primary' cervical spine injury may be associated with head injury in 24–35% of cases [10,16–20], and among polytrauma victims requiring cervical spine stabilization surgery, only 74% suffered an isolated injury [21]. The prognosis in patients suffering both head and cervical injury is typically poor, with approximately 25% being discharged to a dedicated nursing facility with little prospect of recovery [22]. Traumatic brain injury has a UK incidence of 100 per 100 000 population [23], typically among young, working age males, and therefore the combined consequences of brain and spine injury both to the individual and society are common and severe. Facial fractures appear not to be independently associated with cervical spine injury, beyond the original head injury [24–26].

A missed or delayed diagnosis of cervical spine injury may produce 10 times (10.5% vs. 1.4%) the rates of secondary neurological injury [27]. Up to 4.3% of all cervical fractures may be missed, with 67% of these patients suffering neurological deterioration as a result [28] and 29.4% cases of delayed diagnosis of cervical spine injury developing permanent neurological deficits [29]. Before the widespread adoption of Advanced Trauma Life Support guidelines [30], up to 10% of patients, initially neurologically intact, developed a neurological deficit during their emergency care [31].

Although the vast majority of polytrauma victims will not have a cervical spine injury, the potential impact on neurological outcome if these injuries are missed requires that all polytrauma victims are managed in the expectation that injury is present. This will lead to the requirement that the cervical and thoracolumbar spine of 90–95% of polytrauma victims will have to be 'cleared' during their hospital stay. This is, in effect, a screening programme to detect a lesion which may be present in only 5–10% of the polytrauma population. Indeed, a significant proportion of actual injuries will be relatively stable and, if mobilised, are of little consequence. For example, only 8.6% of injuries missed by plain radiograph evaluation were ultimately unstable [32], and in one study of prehospital cervical spine immobilization, 13/15 (86.7%) of missed cervical spine injuries were subsequently regarded as stable [33].

Among unconscious or obtunded polytrauma victims, in whom clinical assessment cannot exclude cervical injury, the actual performance of the various diagnostic imaging modalities assumes central importance. Furthermore, the care of the unconscious patient's cervical spine is often complicated by the fear of missing an isolated ligamentous injury with plain films or computerised tomography (CT), on the assumption that mechanical stability can only be confirmed by a normal clinical evaluation. As a consequence, many patients remain immobilised for long periods, with a rigid or semirigid collar applied, until such time as a complete clinical examination can be conducted.

This situation is suboptimal as:

Prolonged immobilization has significant attributable morbidity, most complications appearing and rapidly escalating after 48–72 h (Fig. 1) [19,22,34–61].

There is evidence that rigid collars do not restrict the displacement of unstable cervical injuries. Indeed, paradoxical movement of adjacent vertebrae may occur particularly at the craniocervical and cervicothoracic junctions, ironically the two most common sites for injuries [62–65]. Therefore, if the cervical spine is unstable, a collar may not represent optimal immobilization.

Some patients will never regain sufficient cerebral capacity to allow meaningful clinical examination, as up to 25% of these patients suffer severe head injury and permanent impairment.

The management of many polytrauma victims requires sedation for other reasons, such as management of head injuries or repeat surgery, and clinical assessment may therefore prove impossible for prolonged periods.

As a result, the global complications associated with prolonged immobilization and cervical collar use may even approach the small risk of an undetected and unstable ligamentous injury once appropriate imaging has been performed [66]. A missed cervical spine injury is an easily recorded event and understandably tends to be remembered and publicised. Conversely, many complications of cervical collars and immobilization are difficult to document and quantify, despite being significant and with associated mortality, e.g. ventilator associated pneumonia [57]. As these risks are applied to a large population of polytrauma victims, 90–95% with no cervical injury, and as more units now record and publish complications, the situation is being re-appraised. Evaluation and management of the unconscious polytrauma victim with a potential cervical spine injury therefore becomes a balance of relative risks and benefits, and this review will quantify these variables to allow evidence-based practice.

Methods

The main sources for this review were MEDLINE 1960–2002 (using the Medical Subject Headings: Cervical Spine and Cord Injury, Isolated Ligamentous Injury, Cervical Collar, Plain Radiography, Computed Tomography, Magnetic Resonance Imaging and Dynamic Fluoroscopy and combinations thereof), Embase, PubMed and the Cochrane Library. All reference lists and review articles were searched for additional works not revealed by the literature searches, and we contacted our regional specialists in anaesthesia, intensive care, radiology, orthopaedic surgery and neurological surgery. The following internet sites were visited: <http://www.east.org> and <http://www.trauma.org>.

Clinical evaluation of the cervical spine

The clinical evaluation of the cervical spine assesses four parameters (Fig. 2). These criteria have been incorporated in American College of Surgeons Advanced Trauma Life Support (ATLS) [30,67] and Eastern Association for the Surgery of Trauma (EAST) guidelines [68–70], and are supported by more than 20 clinical studies [33,71–95]. The very concept of a 'painless cervical fracture' in an alert patient is controversial [89], and may not be

- Pressure sores are common and increase with prolonged use of collars, particularly after 48–72 h [34–40]. These may require skin grafting and have been a source of sepsis and infected cervical prostheses after operative fixation.
- Bed sores require prolonged time to heal—each ulcer costing approximately \$30,000 [41].
- Increased intracranial pressure [42–45] worsens the outcome of a population with co-existing head injury in up to one-third of cases [19].
- Airway problems can be life threatening [46–48] and are almost certainly underreported. Tracheostomy is frequently delayed and performed surgically rather than as a percutaneous procedure, although this has been questioned [49].
- Central venous access is technically difficult and poor line care is associated with bacteraemia and catheter-related sepsis [50,51].
- Poor oral care has been linked to bacteraemia and sepsis [52].
- Higher rates of failed enteral nutrition in the immobilised patient with failure to reach nutritional targets, and therefore a requirement for parenteral nutrition [53].
- Gastrostasis, reflux and aspiration are promoted by a static supine position. Ventilator-associated pneumonia, and prolonged ventilation and intensive care stay are consequences [54], increasing morbidity, mortality and costs [55,56]. Among elderly patients with cervical spine injuries, 26.8% died during treatment, principally as a result of respiratory complications [57].
- Physiotherapy regimens are restricted if an unstable spine is suspected.
- Thrombo-embolism may be seen in 7–100% of patients with tetraparesis and inadequate prophylaxis [58].
- At least four skilled staff are required for log-rolling and seven for patient transfer, with evident staffing implications [59]. Barrier nursing becomes impossible and cross-contamination is demonstrably higher, affecting the entire theatre or intensive care population [60,61].

Figure 1 Complications associated with prolonged immobilization.

After blunt polytrauma, the patient's cervical spine may be regarded as stable if:

- 1) Glasgow Coma Scale (GCS) = 15, and the patient is alert and orientated
- 2) No intoxicants or drugs have been consumed
- 3) No significant distracting injuries have occurred
- 4) No signs or symptoms on cervical examination:
 - i) No midline tenderness or pain
 - ii) Full range of active movement
 - iii) No referable neurological deficit

The reliability and performance of these criteria requires judgement and strict application by the clinician [29,67–90].

Figure 2 Clinically 'clearing' the cervical spine.

detected at clinically significant rates. In a prospective evaluation of 1000 blunt trauma victims, all patients with cervical spine injury failed at least one of the preconditions in Fig. 2, with the conclusion that 'careful evaluation of the literature reporting asymptomatic cervical spine fracture raises questions about the existence of the entity in every case' [90]. Indeed, it has been suggested that negative clinical evaluation alone, using the criteria in Fig. 2, may be more sensitive and specific for cervical injury following trauma than radiographic screening [79,85,90,91]. Unfortunately, polytrauma victims are more severely injured, one-third suffer head injury, and analgesia or sedation is typically required, therefore failing at least one precondition for clinically clearing the cervical spine.

Mass screening to predict or exclude injuries has limited performance, with only 50% accuracy and 20% of injuries missed if physical findings and mechanism of injury are used [96]. Evaluation using mechanism of injury may be misleading. Patton *et al.* [97] have stated that blunt assault victims do not suffer isolated ligament injuries and their cervical spine may be cleared with plain radiographs alone, yet Davis *et al.* [22] reported this injury in a blunt assault victim. Multivariate analysis of risk factors for cervical injury has consistently identified head injury or high energy mechanism, but the 95% confidence intervals are wide (relative risks: 4.0–17.0 and 5.4–25.0, respectively), limiting exclusion of injury in the individual patient [14]. Reviewing 100 cervical fractures, Domeier *et al.* demonstrated that all patients had altered mental status, neurological deficit, intoxication, pain or extremity fracture [92]. These workers prospectively showed that these criteria were not affected by mechanism of injury, missing 3% and 6% of injuries in high and low risk groups, respectively [93]. These two studies prompted the production of practice guidelines for selectively immobilizing trauma victims during transfer [94,95], and clinical criteria identified 280/295 (94.9%) of cervical injuries [33]. Available evidence suggests that applying prehospital clinical criteria may raise suspicion of approximately 90% of spinal injuries but has little capacity to identify individual cases, and carries an unacceptable false negative rate of 10%. It is important to note that the primary aim of the above

studies was to investigate the restrictive use of spinal immobilization during transfer and not to diagnose cervical injury in the unconscious patient after admission.

Cervical spine imaging modalities

Plain radiographs

Cross-table lateral view. An anatomically and technically adequate film will visualise the cervical spine from the craniocervical junction (occipito-atlantal articulation) to the cervicothoracic junction, with adequate penetration to see all vertebral bony structures and soft tissue relations. If anatomically and technically adequate, the lateral plain film sensitivity is high when interpreted by an expert with 73.4–89.7% of cervical injuries being detected [8,92,98–100] but, conversely, this view will therefore miss approximately 15% of cervical spine injuries. In addition, it has been estimated that 10–20% of missed injuries result from the misinterpretation of suboptimal radiographs, particularly when performed in the emergency department [101]. Other workers have estimated that 50–90% of missed injuries are due to poor quality films, inadequate views or misinterpretation [7,28,102]. In practice, many films are anatomically or technically inadequate, and rates of missed injuries may be considerably higher. It has been shown that in up to 49% of cases, the cervicothoracic junction, where up to 60% of cervical injuries may occur [103–105], could not be seen even with arm traction [8,34,103,106–108]. In one emergency department study, if the lateral film failed to reveal the middle of the seventh cervical vertebra (C7), the likelihood of arm traction revealing the cervicothoracic junction was only 7.7% [109]. Indeed, it has been shown that the most helpful imaging modality to increase detection rate was an adequate repeat lateral plain film [100]. While one retrospective study suggested a false positive rate of only 2.5% [8], a more typical specificity for the lateral plain film is poor at only 47–70% [34,99].

Soft tissue signs have low sensitivity but high specificity for cervical injury, indicating ligamentous injury in 50% [110]. Prevertebral tissue measurements of > 6 mm at C3 and > 22 mm at C6 have a sensitivity of 59% and 5%, respectively, for actual cervical injury [111]. These results have been broadly replicated, with < 50% of patients with cervical fracture showing abnormal soft tissue patterns [112–114]. However, these signs become unreliable after tracheal or gastric intubation, or while wearing a cervical immobilization collar.

A lateral plain film has often been used to ‘clear’ the cervical spine in the obtunded patient. In a recent UK survey of intensive care units, 48% of respondents were satisfied to clear the cervical spine while patients were unconscious and unable to provide clinical clues [115], and in published studies, 12–95% of clinicians have been

confident in excluding injury with this view alone [12,98,116]. While the prevalence of this practice may vary, with a sensitivity of only 85% among an unconscious polytrauma population with a > 10% prevalence of cervical spine injury, missing at least 1.5% of injuries is unacceptable.

The lateral cervical plain film occupies a prestigious position within ATLS guidelines [30,67], being one of the three initial trauma screening films (lateral cervical spine, anteroposterior chest and pelvis). However, this film should never be used to ‘clear’ the cervical spine due to both inadequate sensitivity and the overall poor quality of emergency films, and all polytrauma patients will require a more complete assessment. The very existence of a normal lateral radiograph will encourage a proportion of clinicians, possibly up to 50% [115], to conclude wrongly that the cervical spine is ‘cleared’. Prospective evaluation of 60 trauma room lateral films [106] found that there was no impact on emergency procedures, which were performed before cervical spine clearance, and 43% of cervical injuries were missed, all in the C7 cervicothoracic junction region. Almost 25% of films were suboptimal.

Summary of the lateral cervical plain film. The cross-table lateral film, anatomically complete and interpreted by an expert, will miss 15% of cervical spine injuries and typically 50% of these films are inadequate. The upper and lower cervical spine are notorious for concealing injuries and are often poorly seen in this view. This film does not provide a reliable negative result and may encourage dangerous practice. The inclusion of this radiograph in emergency care may encourage dangerous practice while not allowing reliable exclusion of cervical injury, and the ATLS guidelines in this respect are unhelpful. While an essential part of the evaluation of injuries, unconscious patients require additional imaging.

Plain radiographs: the three-view cervical trauma series. As a result of the limitations of a single lateral view in the diagnosis or exclusion of cervical spine injuries, the three-view cervical trauma series (cervical series) has been developed. It has been incorporated into ATLS and EAST guidelines [30,67–70], and is widely recommended [82,101,102,117] as being able to decrease the 15% of injuries missed by the lateral film alone.

The cervical series comprises:

- Cross-table lateral view.
- Open mouth odontoid view. This examines the craniocervical junction, especially the occipito-atlantal relations [118–120].
- Anteroposterior (AP) view. This examines facet relations, seeking pedicle or lamina injuries and evidence of rotation. The value of this view is particularly disputed [100,121,122].

The sensitivity of an adequate cervical series ranges from 72% to >99% [7,8,34,100,123–125], but many studies evaluating the cervical series have either been small or retrospective. The NEXUS (National Emergency X-Radiography Utilisation Study) group conducted the largest prospective evaluation of trauma radiographs to date [32]. Involving 21 institutions and recruiting 34 069 victims of blunt trauma, the primary aim of the study was to define a population that could be evaluated clinically without the need for screening radiographs, and included 818 (2.4%) patients with 1496 separate cervical spine injuries. Plain radiographs detected 498 (60.8%) of these patients and 932 (62.2%) separate injuries. The vast majority of 'missed' injuries (237 patients, 436 injuries) actually had films reported as abnormal or inadequate but non-diagnostic; 29.0% of patients would have been missed as a result of inadequate films. Adequate radiographs were obtained in only 557 (59.8%) injured patients detecting 498 injuries, yielding a functional sensitivity for an *adequate* series of only 89.4% (95% confidence intervals (CI): 86.9–91.4%). The negative predictive value of a normal and adequate cervical series was 99.9% (95% CI: 99.9–100.0%). False negative results occurred in 23 patients with 35 injuries after an adequate cervical series. Therefore, 2.81% (95% CI: 1.89–3.63%) of all injuries screened may be missed. Only three of these injuries were deemed unstable (equivalent to 0.2% of all injuries), and 29/35 were detected by CT, dynamic studies or magnetic resonance imaging (MRI).

The odontoid view is further compromised in unconscious trauma victims by anterior artefact from tracheal or gastric tubes and cervical collars [126]. In a series of 129 patients unable to be cleared on plain films, 52 (40.3%) were due to non-visualisation of the craniocervical junction [127]. Ross *et al.* [34], Borock *et al.* [123], Kirschenbaum *et al.* [127], and Nunez *et al.* [128,129] all describe missed upper cervical spine fractures following inadequate or false negative odontoid views, commonly in the context of head injury. Furthermore, the odontoid view is an anteroposterior projection of an injury typically displaced in the same plane as the X-rays.

The cervical series does not enable further visualisation of the cervicothoracic junction, so the previously discussed anatomical and technical limitations of the lateral plain film persist. The ability of the anteroposterior view to reveal injuries not detected by either the lateral or odontoid views is disputed [100,121,122], and this projection will also be compromised by anterior artefact.

Advanced Trauma Life Support guidelines and the cervical series. The ATLS guidelines from the American College of Surgeons recommend that 'For patients who are

comatose, have an altered level of consciousness, or are too young to describe their symptoms: all such patients should at least have a lateral and anteroposterior cervical spine X-ray. Whenever possible, an open-mouth view also should be obtained. If the entire cervical spine can be visualised and is found to be normal, the collar can be removed after appropriate evaluation by a neurosurgeon or orthopaedic surgeon... When in doubt, leave the collar on... a cervical CT scan can be obtained somewhat later' [30,67].

If the cervical series has a sensitivity of 90%, many films are inadequate, and as approximately 10% of polytrauma victims suffer a cervical spine injury, then plain films alone may *miss at least 1.0%* of patients with an actual cervical spine injury. A neurosurgical or orthopaedic evaluation cannot directly improve this performance while patients remain unconscious and, to be relevant, the ATLS guidelines must become more specific in detailing evaluation beyond plain films. However, it is accepted that senior ATLS trained doctors will reject significantly more (33.7%) plain radiographs on the basis of anatomical or technical inadequacy, and this may indirectly decrease the number of missed injuries [130].

Summary of the three-view cervical trauma series. The three-view cervical series offers increased sensitivity relative to the single lateral plain film but this is still only approximately 90% among patients with an actual injury. There remain anatomical and technical limitations, particularly at the craniocervical and cervicothoracic junctions, making 25–50% of films inadequate, particularly in the emergency situation, and unconscious polytrauma victims lose image quality secondary to tracheal tube or collar artefact. Employing ATLS guidelines will *miss at least 1.0%* of cervical spine injuries in unconscious patients, and further imaging appears mandatory.

Five-view cervical trauma series and oblique views. The five-view series comprises the three-view series and two oblique projections at an angle (typically 30°) from the anteroposterior plane. The use of a five-view series is 'moderately prevalent' in the US, with approximately 25% of trauma centres using these views routinely [12], but the practice is not widely reported in the UK. Some workers suggest an improved yield by routine use of oblique projections [131]. In one series, 6% of patients had injuries detected only on oblique views and a further 3.6% were difficult to see on traditional views [132]. While the swimmer's view (an oblique radiograph performed in the coronal plane with the arm closest to the X-ray beam elevated in a fashion reminiscent of the front crawl swimming stroke) and paired oblique views visualised the cervicothoracic junction in only 40% of

cases, the latter allowed improved views of the posterior elements [133]. One study suggested routine oblique views may decrease the rate of a non-visualised cervicothoracic junction from 26% to 13%, and was cost effective [134]. Other workers have failed to demonstrate increased sensitivity, although some injuries are better visualised [135], and that oblique views are rarely helpful, other studies, i.e. CT, being required for non-visualisation [34]. Many UK clinicians lack experience in interpreting oblique cervical radiographs.

The swimmer's view may improve visualisation of the cervicothoracic junction but the ability to do so may only be 40% and no better than a five-view series [133,134]. Reports of the displacement of an unstable cervicothoracic injury during the swimmer's view exist, thus questioning the use of the swimmer's view at all [135]. Given the plain film alternative of supine oblique views or CT to visualise the lower cervical spine, the routine use of a technique that may displace injuries is questionable.

Computerised tomography

Before CT, complex motion tomography (TOMOS) was used. It may perform slightly better for certain injuries [136], but is not widely available and involves patient movement, and will not be discussed further.

For the purpose of research, CT has been subdivided into two main types:

'Directed' CT: The scan is directed towards specified regions or to investigate suspicious or non-visualised plain film regions.

'Non-directed' CT: The entire cervical spine is imaged.

Computerised tomography is rapidly evolving, e.g. multiplane, three-dimensional and real-time scanning, and is a highly specialised field well beyond the scope of this article. Therefore, we have reviewed the forms of CT imaging available at most hospitals, i.e. transverse sections with sagittal or coronal reconstructions. Even when considering 'regular' CT imaging, it becomes difficult to extrapolate studies conducted over 10–15 years ago due to the rapid evolution of CT technology during the 1990s. Older scanners required several minutes to obtain one 'slice', and therefore wider collimation and pitch was used. Modern scanners have decreased acquisition times to seconds. Some studies use up to 5 mm slices [129], and it has been argued that injuries 'missed' by CT, e.g. axially orientated fractures, can be seen with higher resolution (1.5–2 mm) and reconstructions [137].

Directed CT scanning. In supplementing anatomically inadequate plain films (63% at the cervicothoracic junction and 41% C1/C2), directed CT scanning

performs with a sensitivity of 100% [34,138]. However, the sensitivity of directed CT following suspicious plain films decreases to 78% (specificity 91%) and the overall sensitivity of CT for spinal injury may only be 81%, significantly less than a cervical series [138]. Computerised tomogram sensitivity for injuries ranges from 92% to 98–100% [34,127,136–139] and the specificity of directed CT may be 86–91% [34,138].

Routine directed scanning of the craniocervical junction following blunt polytrauma has been advocated, given the limitations of plain films in this region. Kirschenbaum *et al.* [127] described 7/53 (13.2%) patients suffering severe head injury with false negative craniocervical plain films but fractures apparent on CT. Similarly, routinely replacing the odontoid plain film with CT revealed upper cervical fractures in 8% of victims, and all survivors required halo stabilization [140]. Almost 9% of patients may have upper injuries revealed by CT alone [141], with 28.0–39.3% of C1/C2 fractures missed by plain films [142,143]. It would therefore seem a minimum standard to perform directed craniocervical scanning in patients after head injuries, and certainly if a head or brain scan is being performed [127,140–143].

Non-visualisation of the cervicothoracic junction on plain films may occur in up to 63% of cases [127,132–138], typically requiring CT supplementation. Cervicothoracic injuries are characteristically more stable than upper cervical injuries but this cannot be assumed. In a series of 73 trauma victims undergoing tracheal intubation at the scene [105], 20 spinal fractures had occurred with 12 (16.4%) involving the cervicothoracic junction. Plain films missed 2/12 (16.7%) cervicothoracic injuries and demonstrated five associated injuries. Computerised tomography may detect occult injury in a further 0.8–3.0% of cases of blunt polytrauma [126,144].

Computerised tomography and plain films should be considered complementary diagnostic techniques since they often detect different patterns of injury. In one series, plain films detected 58% of fractures and 93% of subluxations or dislocations (94% of all abnormalities), while CT detected 90% of fractures and 54% of subluxations or dislocations (92% of all abnormalities) [136]. Therefore, CT may miss more ligamentous injuries and malalignments, and plain films more fractures [125,127,138], but the combination is especially powerful, consistently achieving 100% sensitivity in a number of studies [33,125,127–129,136–138]. Furthermore, in addition to excellent sensitivity, the use of combined plain films and CT in 879 patients allowed 'major' (associated mechanical instability or neurological findings) and 'minor' injuries to be reliably and functionally distinguished [145].

Computerised tomography does allow evaluation of injuries beyond the vertebral column and its stability: transverse process fractures may account for 13.2% of cervical fractures, and CT has revealed that 78% of these fractures may extend into the intervertebral foramen, involving the nervous system or the vertebral artery [146]. Routinely using CT may detect otherwise unsuspected non-cervical injuries in 7–9% of patients, e.g. fractured mandible, pneumothorax and base of skull fracture, all missed on plain films [13,105].

Eastern Association for the Surgery of Trauma Guidelines 1998. The American EAST group recommended in 1998 that: ‘...a three view spine series supplemented by thin cut axial CT images with sagittal reconstruction through suspicious areas or inadequately visualised areas provides a false negative rate of less than 0.1%... CT alone, MRI and flexion/extension radiographs have all been shown to miss injuries and have not been shown to be more accurate...’ [68,69]. There was insufficient evidence to allow level I recommendations, i.e. based upon the highest methodological quality prospective, randomised, controlled trials, but these guidelines are supported by a number of studies. Schenarts *et al.* [13] prospectively recruited unevaluable trauma patients requiring CT of two or more body areas. Among 1356 patients, 70 (5.2%) patients suffered 95 upper cervical injuries. The combination of plain films and directed CT had a sensitivity of 100%; no injuries were missed. Computerised tomography alone would have missed three ligamentous injuries, and plain films alone had a sensitivity of only 54.3%. One patient with an unstable C4 fracture was missed with directed scanning but was diagnosed with entire cervical spine CT. Significant non-cervical injuries were revealed in 9% of patients. Chiu *et al.* [10] reviewed 14 577 trauma admissions including 2605 patients with GCS < 15 of whom 143 (5.5%) suffered cervical injury. There were 14 ligamentous injuries of which 13 were seen on the original lateral plain film, one being seen on CT. Using the combined modalities, no cervical injuries were missed.

Demetriades *et al.* [11] reviewed 14755 trauma admissions that included 292 (2.0%) patients with cervical injury. Fractures accounted for 85.6% of injuries and all were detected by combined plain films and a mixture of directed and entire cervical spine CT scans. Isolated ligamentous injury, i.e. subluxation without fracture, occurred in 31 (10.6%), and 30 (96.8%) of these were detected with the plain lateral film, CT detecting the remaining injury. Contrary to classical teaching, the combination of plain films and CT detected all ligamentous injuries. Had helical CT been used without plain

radiographs, two injuries would have been missed (false negative rate = 11.8%).

These three studies strongly support the use of the combination of plain films and at least directed CT (1998 EAST guideline), with a strong suggestion that the number of missed injuries could be decreased further with entire cervical spine CT scanning.

Entire cervical spine CT scanning. While craniocervical and cervicothoracic spinal injuries are the most common, isolated mid-cervical injuries are well recognised. In one series, had entire cervical spine CT been omitted while patients were unconscious, three cervical injuries at C2, C5 and C6/C7 would have been missed [125]. No cervical spine injuries were missed following 158 entire CT scans in combination with plain films [147]. Entire CT may represent a minimum standard once an injury is detected because 10–31% of cervical fractures have associated non-contiguous fractures [148,149]. Nunez *et al.* [128,129] reviewed 88 patients with fractures previously diagnosed on plain films or directed CT. Entire helical CT detected 32 (36.4%) patients who had suffered 50 additional injuries. Seven (8.0%) were unstable and four were missed by plain films of the area. Entire scanning detected an additional four (4.5%) injuries beyond combined plain films and directed CT, with a number needed to treat (NNT) of 1.76 for all injuries and 22 per unstable injury.

Among 58 critically ill trauma patients with a mean GCS of 8.9, Berne *et al.* [150] found plain films had a sensitivity of 60%, and for eight unstable injuries, entire CT had a sensitivity of 100%. Had directed rather than entire helical scanning been used, one (12.5%) unstable multiple level injury at C3 and C5/C6 would have been missed. This generates a NNT of 8 per unstable cervical injury, in favour of entire CT.

Some objections to entire cervical CT include increased scan time and radiation dosage, but in one study, helical CT added 20–30 min and there was a reduction in overall imaging time from repeat plain films [151]. In performing 156 helical cervical CT scans [152], the additional time was only 12 min if added to a head scan and 11 min if performed in isolation, approximately 50% of the time for plain film evaluation. In addition, the dose of radiation is relatively small; a CT scan of the brain exposes the patient to 1–2 mSv and a helical neck scan to only 0.5 mSv [153]. By comparison, an abdominal scan represents 35 times (15–20 mSv) the dose of the cervical scan. Within this analysis of radiation dose, one must also include the inevitable repeat plain films and additional views, e.g. the swimmer’s views, which are incurred by omitting CT scanning.

Summary of studies of computerised tomography. Computerised tomography may reveal more fractures than plain films and may allow evaluation of the cervicothoracic and craniocervical junctions, both areas traditionally poorly visualised on plain films and with high rates of concealed injury. After severe head trauma, the addition of craniocervical junction CT will detect injuries not revealed by plain films in approximately 10% of patients scanned. Scanning the entire cervical spine in blunt polytrauma detects significantly more injuries than plain films or directed scanning with a NNT of 2 for all injuries and 8–22 per unstable injury. The time involved may actually be less than that required for a full plain film evaluation and the doses of radiation represent 33% of a head scan and 3% of an abdominal scan.

A number of useful principles and recurring themes emerge when we consider plain films combined with CT (Fig. 3). Most studies suggest that the combination of a plain film series and directed CT may be reasonably expected to exclude >99% of injuries. Indeed, it is possible the incidence of missed injuries may approach <0.1% [68]; the use of *entire* CT will reduce the incidence of false negative imaging further.

Magnetic Resonance Imaging

Magnetic resonance imaging holds an undisputed position as the investigation of choice in evaluating spinal *cord* injuries, and has replaced conventional and CT myelography. It is recommended that any patient with a neurological deficit referable to the cervical spine should undergo plain film skeletal survey and MRI [30,67–70, 110,154–162].

An unstable thoracolumbar spine injury is almost always associated with a fracture, and therefore should be apparent on plain films [11,62,148,163]. However, there is a recognised minority of isolated cervical spine

ligamentous injuries that have no associated fracture and may not appear on plain films or CT. If the patient is mobilised and lacks ligamentous stability, there is a possibility of progression to cord injury and neurological catastrophe. Unlike plain films and CT, only MRI and dynamic fluoroscopy have the potential to directly demonstrate ligamentous pathology or instability. Plain films and CT frequently at least infer such injury [10,11,34,138].

Following polytrauma, MRI may reveal unsuspected soft tissue injury in approximately 25% of cases. D'Alise *et al.* [164] examined unconscious patients who had undergone tracheal intubation and showed that 25.6% suffered injury to bone, disc, or paravertebral ligaments not seen on plain films, although CT revealed 10.7% of fractures. Albrecht *et al.* [165] examined 150 trauma victims in intensive care and found that 27 (25.0%) had MRI abnormalities despite normal plain films and/or CT. Benzel *et al.* [166] further evaluated 174 patients in whom clinical evaluation or plain films had indicated injury; MRI revealed ligamentous injury in 35 (20.1%) of these cases. Katzberg *et al.* [167] showed that plain films revealed only 23% of abnormalities amongst patients with suspected cervical injury, while MRI revealed 79%.

Ghanta *et al.* [168] reviewed 51 obtunded polytrauma victims after a normal cervical series. Of these, 22% had both false negative plain film and entire CT survey, but only two (3.9%) had a ligamentous injury on MRI, and these patients were severely traumatised (injury severity score = 24.3) and in coma (mean GCS = 6.6). Criteria for ligamentous stability were not given and the significance of these ligamentous injuries is not clear, particularly in the light of profound residual disability.

The recurring suggestion from MRI studies is that 25% of polytrauma victims suffer significant soft tissue injuries

- Suboptimal and anatomically incomplete imaging combined with misinterpretation account for the largest number of missed injuries.
- Computerised tomography detects more fractures, plain films detect more malalignment and the two modalities are complementary.
- The craniocervical and cervicothoracic junctions frequently conceal injuries, and 25% of plain films are technically inadequate. Computerised tomography allows superior evaluation, especially among patients who have tracheal tubes in place.
- Three-view plain film series and directed CT detects >99% of cervical spine injuries.
- Non-directed entire cervical spine CT may detect injuries in a further 8–14% of patients.
- Computerised tomography scanning does not add excessive time to trauma evaluations and is time-effective and cost-effective.
- High resolution CT at 1.5–2 mm collimation and pitch may be the best compromise between sensitivity, scan time and radiation dose.

Figure 3 Results of combined plain film and CT studies.

that would otherwise remain entirely occult. However, this is clearly at odds with everyday clinical experience and the results from plain film, CT and dynamic fluoroscopy studies. Magnetic resonance imaging is an extremely sensitive investigation for certain soft tissue injuries, and the significance of many MRI abnormalities is unknown. In the study by Benzell *et al.* [166], only two (5.7%) patients underwent surgical fusion and both abnormalities were revealed on CT. One interpretation is that MRI and CT perform equally in detecting unstable ligamentous injuries requiring surgery. In the study by D'Alise *et al.* [164], eight (25.8%) of the injuries were deemed unstable, yet all could have been detected by high resolution CT and all were managed conservatively. Among the 27 injuries detected by Albrecht *et al.* [165], three were cleared clinically, one had subluxation on plain films on review, and of the 10 patients followed up, all were stable at 4–6 weeks following conservative management. Unfortunately, we have no way of knowing whether an unknown proportion was stable and immobilised unnecessarily, or whether these injuries were genuinely unstable and healed after immobilization. It is perhaps most revealing that the diagnosis of instability was made by clinical examination or dynamic studies, not by MRI itself.

Far from allowing patients to mobilise early, there is the very real risk that 25% of trauma patients will have an abnormal MRI scan and will have a cervical collar applied for a period of weeks. If only 5.7% of injuries require surgery and could be seen with CT, over 90% of patients with a stable cervical spine are therefore subjected to unnecessary immobilisation. The correlation of MRI findings with acknowledged standards is often poor. In a series of 11 surgical patients, MRI detected all injuries but included two false positive longitudinal ligament ruptures [168]. Using a cadaveric injury model, MRI correlated with the anatomical diagnosis in only 79% of cases [169]. In one series, only 60.7% of MRI abnormalities were correlated with *post mortem* anatomic findings [170].

Since MRI is very sensitive in detecting soft tissue injury [119,120,171–173], a number of authors advocate a normal scan as evidence of a stable cervical spine. In these studies, only 223 patients were 'cleared' by MRI [164–166]; follow-up details are incomplete, and despite normal imaging, patients remained in collars until they could be assessed clinically [165]. Evaluating abnormalities seen on plain films or CT, it has been suggested MRI can reliably predict stability but numbers are again small and injuries highly specific, i.e. unilateral facet or lateral mass fractures [174]. Conversely, Flanders *et al.* [155] reviewed 78 cervical cord injuries and found associated bone or soft tissue abnormalities had no influence on the extent of

cord or neurological deficit. In a series of 35 patients who suffered traumatic spinal injury, MRI did not disagree with any declaration of spinal stability made on plain film, CT or intra-operative inspection [175], plain films and CT having an established ability to predict stability [145–176].

Magnetic resonance imaging has a recognised false negative rate and is known to have a low sensitivity for posterior fractures, with a sensitivity of only 11.5–25% compared to that of CT of 71% [155–177]. Magnetic resonance imaging may also perform poorly at the upper cervical spine due to variation in the normal appearances of the upper ligaments, encouraging false positive results [178]. Using a cadaveric injury model, 1 mm CT detected all 16 upper cervical fractures and six ruptured alar ligaments; MRI detected only nine and six, respectively [179]. At present, there is insufficient evidence to equate a normal MRI scan with a stable cervical spine, and MRI should never be performed in isolation, requiring plain film and CT supplementation at least for posterior and upper cervical spine evaluation [171].

One must consider the implications of routinely obtaining cervical MRI scans in a population of critically ill polytrauma patients. There is a limited number of scanners and typically these run during office hours. There are also severe restrictions on the availability of skilled staff to transfer, manage and image such patients, with only one-third of modern MRI units providing any regular anaesthetic sessions at all [180]. Most scanners are remote from the hospital main site and require an ambulance transfer, a process with well-recognised complication rates [181,182]. The ferromagnetic environment contraindicates scanning in a further 5% of patients [165], particularly in the presence of invasive cardiorespiratory monitoring and certain orthopaedic stabilisation prostheses, demanding significant modification of anaesthetic and monitoring techniques [183,184]. Finally, the cost of routinely obtaining MRI scans is likely to remain high, and in one series of 479 obtunded patients would have added \$700 000 without one single additional injury being detected [176].

Summary of findings from magnetic resonance imaging studies. While MRI has an undisputed role in assessing cord injuries and neurological deficits, its role in evaluating acute cervical spine trauma and mechanical stability is far from clear. High sensitivity for soft tissue injury may well be a major limitation, as many injuries are of uncertain significance and result in unnecessary and prolonged immobilization. Suggested rates of 20–25% significant soft tissue injury missed by not performing MRI are at odds with most plain film, CT and dynamic fluoroscopy studies, and everyday clinical experience.

Routinely 'clearing' the cervical spine on the basis of a normal MRI has not been validated, and MRI has a significant failure rate at the upper and posterior cervical spine. Therefore, if MRI is used, it must complement plain films and CT, not replace them. A number of inherent issues will make more widespread use of MRI extremely difficult and there is a material risk during patient transfer if MRI becomes used routinely.

Dynamic fluoroscopy

Dynamic fluoroscopy involves passively manipulating the neck under real time (lateral view) imaging to demonstrate instability. It is a pragmatic technique: if the cervical spine is unstable, then it will be demonstrated upon stressing. Following normal baseline plain films or directed CT, published studies use varying combinations of axial stress, i.e. traction along the line of the cervical spine, to reveal joint space widening [116] and/or flexion/extension views. Dynamic fluoroscopy must be distinguished from static maximal flexion/extension views, which are inherently unsafe in the unconscious as the spine is not imaged during mobilization. Griffiths *et al.* [176] reviewed forced passive flexion/extension radiographs in 479 obtunded patients. While no complications occurred as a direct result of the procedure, 40% of tests were anatomically incomplete, typically (69.6% of cases) at the cervicothoracic junction. Six (1.3%) patients had new injuries discovered as a result of testing, but only two (0.4%) required surgery and these had been previously diagnosed. No patient with a GCS <15 required surgery as a consequence of forced flexion/extension testing.

Using the dynamic fluoroscopy technique, unconscious patients receive sedation and pharmacological neuromuscular blockade, their shoulders are moved to the top of a firm bed or spinal board and the cervical spine is subjected to passive movement. It is assumed that instability will be demonstrated under real time imaging, and the test can be terminated before significant cord injury occurs. While this may not be unreasonable, the procedure could potentially be made safer by performing a preceding axial 'stretch test' [116] or monitoring somatosensory evoked potentials [185]. Most studies use criteria for instability similar to those defined by White & Panjabi [186] of 3 mm displacement of adjacent vertebrae or >11° of angulation, but this is by no means standard.

The worldwide literature reports 887 patients undergoing dynamic fluoroscopy in 10 separate studies [22,24,36,37,116,187–191] (Table 1).

A total of 15 (1.7%) cervical injuries were detected following normal baseline imaging, typically plain films and directed CT. Of these 15 patients, one was detected

with plain films [189], four with CT [22,24,36] and two were missed. Among the remaining eight, high resolution CT was never performed at the injured level, so combined plain films and CT detected 5/7 (71.4%) unstable injuries. Dynamic fluoroscopy therefore revealed 10 (0.9%) cervical injuries and five (0.6%) required surgery with a NNT of 177 patients per unstable injury. However, if combined plain films and CT can detect at least 70% of unstable injuries, the NNT increases to 295 patients, or over 500 to detect an injury requiring surgery.

The single largest study [22] recruited 301 patients with 297 (98.9%) true negative results and two (0.66%) true positive results (both injuries were 'relatively stable' partial ligament tears and managed conservatively). Contrast CT revealed one injury and the other was outside the directed CT range. There was one false positive result and, most worryingly, one false negative result (following protocol violations after initial plain films revealed the injury). The patient developed a permanent lower cord injury when mobilised. This multiple level injury involving C6, C7 and T1 would almost certainly have been seen with entire cervical spine CT, and Davis *et al.* do not advocate routine dynamic fluoroscopy in unconscious patients. The second largest evaluation of dynamic fluoroscopy by Marciano *et al.* [187] detected no additional injuries in 194 patients with GCS < 8.

Therefore, while dynamic fluoroscopy may detect a small number of ligamentous injuries (0.9% of all evaluations), it is likely that the true positive rate is very close to the false negative and positive rates, and that plain radiographs and high resolution entire cervical spine CT can detect the vast majority of injuries, making the NNT high (> 500 for injuries requiring surgery). Many listed injuries had no criteria given for instability [188], and ultimately only half (5/10) required surgery.

There are legitimate concerns regarding manipulation of an unconscious trauma victim's cervical spine, since they lack protective reflex muscle spasm or the ability to report symptoms [192]. While 887 patients suffered no direct complication as a result of dynamic fluoroscopy, the procedure has only been evaluated in 15 actual unstable spines. The entire cervical spine may not be seen during 5.4–40% of evaluations [116,176,190], with potentially catastrophic cord compromise at non-visualised sites. The inadequacies of the lateral plain film at the cervicothoracic and craniocervical junctions translate equally to fluoroscopy.

The study by Ajani *et al.* [36] emphasises the point that plain films and entire CT, MRI and dynamic fluoroscopy require urgent prospective comparison, and that on available evidence they appear to have very similar sensitivity for unstable injuries.

Table 1 Summary of dynamic fluoroscopy studies.

Study	No. of evaluations	Results	Notes
Davis <i>et al.</i> [22]	301	2 'relatively' stable injuries	1 false negative
Marciano <i>et al.</i> [187]	194	No unstable injuries	
Harris <i>et al.</i> [116]	149	3 unstable injuries	8 studies inadequate
Cox <i>et al.</i> [188]	91	4 unstable injuries	1 required surgery
Brooks <i>et al.</i> [189]	73	1 unstable injury	Suggested on plain films
Ajani <i>et al.</i> [36]	48	1 unstable injury	Seen on CT and MRI
Sees <i>et al.</i> [190]	20	1 unstable injury	Seen on CT
Chendrasekhar <i>et al.</i> [37]	8	No unstable injuries	
Beirne <i>et al.</i> [24]	2	2 unstable injuries	Seen at CT
Robert <i>et al.</i> [191]	1	1 unstable injury	
TOTAL	887	15 cervical spine injuries	5 seen otherwise, 8 lesions not CT scanned

Summary of dynamic fluoroscopy studies. Dynamic fluoroscopy currently requires further evaluation and lacks sufficient evidence of sensitivity, specificity or safety to recommend its routine use in unconscious trauma victims. While no formal prospective comparison with high resolution CT or MRI exists, the high NNT (295–500) to detect significant injuries makes the yield of questionable clinical significance. Its use would be best assessed in prospective clinical trials.

Revised EAST guidelines. Following a meta-analysis, the EAST group revised their recommendations in 2000: 'Altered mental status and return of normal mental status not anticipated for two days or more, e.g. severe traumatic or hypoxic brain injury: Plain films... axial CT images at 3-mm intervals with sagittal reconstruction from the base of the occiput through C2... if normal, flexion/extension lateral cervical spine fluoroscopy' [70]. It is of note that this small meta-analysis ($n = 227$, including five ligamentous injuries) radically revised the original estimated false negative incidence following plain films and directed CT from $< 0.1\%$ [67] to 2.2%.

The evidence used to draw these conclusions is obsolete and used the initial smaller study of 116 patients by Davis *et al.* [35]. This was incorporated into the same groups reappraisal of 301 patients [22]. Our literature review suggests a significantly lower false negative rate for combined plain film and CT evaluation and a lower true positive rate for dynamic fluoroscopy. It seems curious that the EAST group moved to recommend the unproven technique of dynamic fluoroscopy when, on the available evidence, extending directed to entire cervical CT could probably have produced similar sensitivity. In the absence of a prospective study, the correct strategy remains unknown and the original 1998 and 2000 EAST updates remain level II-III recommendations (supported by lower methodological quality studies than prospective randomised controlled trials or by expert or consensus opinion).

Can we ever safely 'clear' the cervical spine of unconscious unevaluable polytrauma victims?

It would seem that currently there are unacceptable variations in practice when 'clearing' the cervical spine in unconscious or obtunded blunt polytrauma victims [12,67,68,71,115]. In 2000, a survey of the American Orthopaedic Trauma Association and National Association of Spinal Surgeons failed to obtain a consensus regarding the optimal management of a polytrauma patient with a closed head injury [116]. Over the years, a number of guidelines have been published on this problem but none have been universally accepted [30,67–70].

The 'conservative' extreme contends that plain films and CT can never 'clear' the cervical spine due to the possibility of isolated ligamentous injury. Therefore, in the absence of MRI or dynamic fluoroscopy, immobilisation must continue until adequate clinical assessment meets all four requirements (Fig. 2). There are many problems associated with this approach, including the complications (Fig. 1) produced by prolonged immobilisation and the fact that up to 25% of patients will never recover cerebral function that will allow clinical assessment. Furthermore, cervical injury can certainly be missed after clinical evaluation in polytrauma patients, a figure of 2% was quoted in one series [21].

The 'liberal' extreme allows the removal of immobilization while patients remain unconscious, based on a single normal lateral plain film. Worryingly, almost 50% of UK intensive care units may follow this approach [115], as did 12–16% of US orthopaedic and spinal surgeons [116] despite a consistent false negative rate of approximately 15%.

The clinician must determine the likelihood of missing a cervical spine injury, particularly an isolated ligamentous injury, if the patient is mobilised while unconscious or obtunded, balancing this against the risks of immobilization. A number of surveys, reviews and studies quantify the risk of isolated ligamentous injury, i.e. malalignment

or abnormal unstable motion of vertebral levels with no associated fracture, amongst blunt polytrauma patients as consistently under 1%, ranging from 0.1% to 0.7% [7,11–13,22,32,68,69,116] (Table 2).

No screening procedure for any disease has 100% sensitivity or specificity, and whether clinical examination, plain films, CT, MRI or dynamic fluoroscopy are employed, it is a tragic reality that cervical injuries will be missed in the future. We have quantified these risks, balancing them against immobilization and reviewed the available evidence to achieve a false negative rate for detecting cervical spine injury as close to 0% as possible, being aware of the potential consequences of missed injuries.

This review has demonstrated that a plain film cross-table lateral view alone will miss approximately 15% of cervical injuries and a three-view cervical series will miss up to 10% of injuries, with 25–50% of films being anatomically or technically inadequate. Adding oblique views, i.e. a swimmer's view or a five-view series, may not increase sensitivity or the proportion of adequate plain films, and can displace some injuries. Directed CT scanning, using 1.5–2 mm collimation and pitch, will detect fractures at C1/C2 and the C7/T1 junction in a further 10% of polytrauma patients at each site. Combining plain films and directed cervical spine CT detects most cervical spine injuries, consistently missing <1%. This was the original standard recommended by the 1998 EAST guidelines [68,69], revised in 2000 to include dynamic fluoroscopy routinely [70] for Group 2 patients (see below), and shares some similarities with the more general recommendations within ATLS [29,67]. Combined plain film three-view cervical series and directed CT is a reasonable and attainable standard of imaging:

- Units accepting trauma almost always have 24-h access to expertly interpreted plain radiography and CT.
- Computerised tomography of unconscious trauma patients is time-effective and cost-effective. The number of patients ultimately requiring cervical CT represents only 2.5% of the number of plain films required during trauma screening [145].
- The radiation doses are reasonable [153].
- Almost all unconscious polytrauma patients find themselves in a scanner, having a legitimate indication for CT of one or more body areas, i.e. no further transfer is required.

However, with little further effort, the incidence of missed cervical spine and ligamentous injuries could be consistently decreased to fractions of a percent [10,123,127,128,147,150]. Among 15 injuries from 887 dynamic examinations, five could have been detected by plain films and CT, and a further proportion (possibly as high as 71%) detected by entire cervical spine CT. By

Table 2 Incidence of isolated ligamentous injury amongst adult blunt polytrauma victims.

Study	Imaging used	Risk of isolated ligamentous injury
Davis <i>et al.</i> [7]	Plain films, CT	0.1%
EAST [68,69]	Review plain films, CT, MRI and dynamic studies	0.1%
Schenarts <i>et al.</i> [13]	Plain films and CT	0.22%
Demetriades <i>et al.</i> [11]	Plain films and CT	0.3%
Mower <i>et al.</i> [32]	Plain films	0.37%
Davis <i>et al.</i> [22]	Plain films, CT and dynamic fluoroscopy	0.45%
Harris <i>et al.</i> [116]	Plain films, CT and dynamic fluoroscopy	0.5%
Grossman [12]	Survey of US institutions	0.7%

performing plain films and high resolution entire cervical spine CT scans, the incidence of missed unstable injuries may be reduced to less than 8/887 (0.9%) and possibly to 2–3/887 (0.2–0.3%). Importantly, one must note the following:

- High resolution CT, MRI and dynamic testing have never been prospectively compared. Their performance is probably more comparable than assumed [36,128,129,147,150].
- Given the risks and complications of the transfer of critically ill patients, it is unacceptable not to obtain as much information as possible from the first CT scan.
- Unsuspected injuries may be revealed in 8–14% of patients in the mid-cervical spine using entire cervical spine scanning, with a NNT of only 8 to 22 beyond directed CT [129,147,150]. Up to 31% of injuries in this high-risk population are associated with a non-contiguous injury of the cervical spine [149].
- The routine use of MRI is questionable given its high sensitivity for abnormalities of uncertain significance, lack of sensitivity for the upper and posterior cervical spine, and problems of safety, availability, and cost.
- Dynamic fluoroscopy requires further evaluation. The high NNT to detect one further injury beyond plain films and CT (177–887) is of questionable clinical relevance. The false positive and negative rates approach the true positive values, and the procedure has only been reported in 15 actual unstable cervical spines.

Proposed screening of the cervical spine in the unconscious polytrauma victim

In evaluating and managing an unconscious polytrauma victim's cervical spine, patients may be divided into two groups according to their clinical condition and anticipated course:

Group 1. If the patient is likely to cooperate with a valid clinical evaluation at 48–72 h, then a three-view plain film series complementing the clinical evaluation at that time is probably sufficiently sensitive and specific. This is supported by many studies if the clinical conditions are rigidly applied [29,67–90]. Such patients may include the intoxicated, those with no significant head injury or postoperative patients undergoing brief periods of ventilation, and in one series up to 41% of such patients became clinically evaluable by a trauma service consultant [189].

Group 2. Patients unlikely to be evaluable within this 48–72-h period may include patients with severe head injuries, multiple injuries, organ failure or combinations of these. Prolonged immobilization places the patient at significant risks and the vast majority (90–95%) will not actually have a cervical injury. We propose that in these patients the cervical spine may be cleared without clinical evaluation following adequate and complete:

- Cervical plain films (lateral, anteroposterior and odontoid views);
- High resolution entire cervical spine CT at 1.5–2 mm collimation and pitch, with sagittal reconstructions.

With expert interpretation of these investigations, one may reasonably expect to detect > 99.5% of cervical spine

injuries, missing less than five ligamentous injuries per 1000 evaluations. It is not known if routinely adding MRI or dynamic testing represents a useful or safe improvement in detection. There is no evidence available to suggest that routine clinical evaluation after blunt polytrauma improves on this performance. Currently available evidence suggests that this is an effective and attainable regimen of imaging to ‘clear’ the cervical spine, remove the cervical collar and allow supervised mobilization of patients who are unconscious or obtunded and cannot be evaluated clinically. The risks of prolonged immobilization beyond 48–72 h for the individual patient and the vast majority (90–95%) of uninjured patients outweigh and justify the very small risk of missing an unseen cervical injury. A proposed management scheme is given in Fig. 4.

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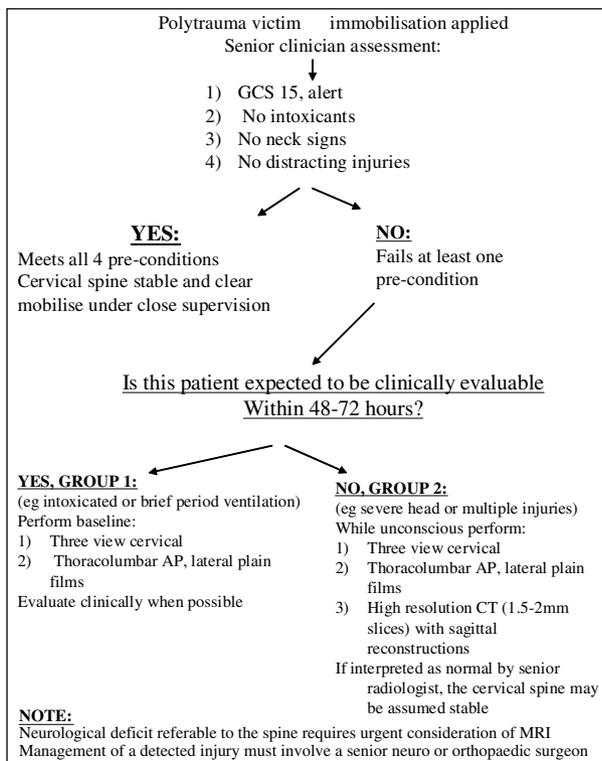


Figure 4 Proposed screening of the cervical spine in the unconscious polytrauma patient.

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