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REVIEW

Cervical spine clearance: a review

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Summary Ethical concerns have hindered any randomised control blinded studies on the imaging required to assess the cervical spine in an unconscious trauma patient. The issue has been contentious for many years and has resulted in burgeoning but inconclusive guidance. MRI and multislice CT technology have made rapid advances, but the literature is slower to catch up. Never the less there appears to be an emerging consensus for the multiply injured patient. The rapid primary clinical survey should be followed by lateral cervical spine, chest and pelvic radiographs. If a patient is unconscious then CT of the brain and at least down to C3 (and in the USA down to D1) has now become routine. The cranio-cervical scans should be a maximum of 2 mm thickness, and probably less, as undisplaced type II peg fractures, can be invisible even on 1 mm slices with reconstructions. If the lateral cervical radiograph and the CT scan are negative, then MRI is the investigation of choice to exclude instability. Patients with focal neurological signs, evidence of cord or disc injury, and patients whose surgery require pre-operative cord assessment should be imaged by MRI. It is also the investigation of choice for evaluating the complications and late sequela of trauma. If the patient is to have an MRI scan, the MR unit must be able to at least do a sagittal STIR sequence of the entire vertebral column to exclude non-contiguous injuries, which, since the advent of MRI, are now known to be relatively common. Any areas of oedema or collapse then require detailed CT evaluation. It is important that cases are handled by a suitably skilled multidisciplinary team, and avoid repeat imaging due to technical inadequacies. The aim of this review is to re-examine the role of cervical spine imaging in the context of new guidelines and technical advances in imaging techniques.
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Contents

Introduction

Historically imaging the cervical spine in blunt trauma has been controversial. The debate has been dominated by the problem of ruling out a spinal injury in the unconscious trauma patient. There have been several reports of spinal instability despite normal radiographs, but maintaining immobilisation on the intensive care unit 'just in case' has been associated with significant morbidity. New imaging techniques have become available, but did not solve the problem, adding their own 'baggage', such as cost, availability, logistic difficulties, radiation dosage, lack of specificity and evidence of effectiveness or safety. The plethora of guidance[84,125,154,75,83,126] reflected the inability to compromise between timely yet complete examinations, on a background distinctly lacking in high quality research, resulting in widely varying practices.[76,118,82,112] A consensus is now emerging from the uncertainty, with a practical set of options to guide clinical practice.[26,47]

Background

The incidence of major trauma in the UK is relatively low and trauma system development has been slow, with no legal mandate to enforce change.[200] Prior to 1988, there was a wide variation in practice and the mortality for blunt trauma was significantly higher than in a comparable group in the United States.[220] Since their introduction into the UK in 1988, there has been a huge demand for Advanced Trauma Life

Support (ATLS) courses, together with an expectation that this would lead to a higher and more uniform standard of care.[6] There has also been an increased understanding of the "Golden Hour" and pre-hospital trauma care,[131] although occasionally applying a hard collar is deleterious as in some ankylosing spondylitis injuries.[152] Although the Trauma Audit and Research Network has indeed shown significant improvements in mortality between 1989 and 1997, there is still a marked variation in outcome between hospitals, even after adjusting for case-mix differences.[112] The majority of patients are first seen in district general hospitals, with no national, integrated system of care for the severely, multiply injured patients, in spite of 8 different reports in the last 14 years from the Royal College of Surgeons of England and The British Orthopaedic Association since 1988, culminating in their joint report of 2000 Better Care of the Severely Injured.[1] However, government legislation on seat belts and alcohol limits is believed to have reduced the deaths from road trauma and serious injury in the UK in the last decade. The UK incidence of severe trauma, with an injury severity score (ISS) over 15, is estimated to be 4 per million per week or 1 emergency case per 1000, so that the average acute hospital may not even see one severely injured patient each week (Better Care for the Severely Injured, 2000).[1] This level of experience may be insufficient to maintain skills. The injury severity score (ISS)[12] is for assessing the multiply injured, modified from the abbreviated injury scale which has been validated to correlate with mortality, severe disability and length of hospital stay.[32,187] An ISS over 25 is associated with an increased risk of permanent impairment, and people do not usually survive with an ISS of more than 50. An ISS of 20 or more is fatal in 50% of those aged 65 or over, while 1% of all multiple injury patients die with an ISS of 14 or less.[32]

The prevalence of trauma is greater in America, particularly of penetrating injury (Better Care for the Severely Injured, 2000).[1] In the USA, trauma has had a higher profile since Vietnam, with federal funding, shock trauma ATLS and regional trauma centres. Level I centres have all the acute services available on site, and have handled most multiply injured patients in America for many years. The incidence of cervical spine injury in Level I trauma centres is 2—4.2% of blunt trauma victims.[55,37,72]

Recent trends in practice

The ATLS courses spread through the UK, generally improving care,[6] and raising awareness of occult spinal injury, but also raised concern, fuelled by increasing litigation. One result has been that unconscious patients with normal plain films may remain in a rigid collar for days or weeks on the intensive care unit. CT scanning, with multislice technology, is now widely available 24 h per day and is being used more liberally. MRI scanning is still of limited availability, especially out of hours. Meanwhile, clinicians have become confused in the transition from somewhat slipshod practice to near paranoia.

In the USA, medico-legal concerns emerged earlier where the new technology was embraced more vigorously. Over-investigation of conscious patients led to spiralling costs but little benefit to the patient "much ado about nothing",[207] where plain radiography was overused by up to a third.[134] The North American Spine Society and the Orthopaedic Trauma Association were unable to reach a consensus on how to exclude spinal injury in both conscious and unconscious patients.[82] In unconscious patients, ATLS teaching no longer went far enough. While the course emphasised spinal precaution, provided instruction on clinical examination and on the interpretation of plain films, it was misleading in the unconscious stating, "Patients who are comatose, have an altered level of consciousness or are too young to describe their symptoms may be cleared after normal three-view cervical spine series and an appropriate clinical evaluation by an orthopaedic surgeon or neurosurgeon", which is not true. Many North American Level I trauma centres turned instead to "evidence-based" recommendations from the Eastern Association for the Surgery of Trauma (EAST),[125] even though there were no RCTs. They relied on plain radiographs of the cervical spine and targeted CT scans of abnormal and poorly visualised areas to clear the cervical spine in patients with an altered conscious level. They demanded a rigorous technical approach to imaging and reporting, but pragmatically overlooked the issue of ligamentous instability when there was no demonstrable fracture or soft tissue swelling. Before revising their guidelines, EAST carried out a postal survey of practice in 31 Level I trauma centres in North America to check compliance with their previous recommendations. It became apparent that several centres were using MRI scanning and, more controversially, some used flexion—extension fluoroscopy to clear the cervical spine in unconscious patients. When the revised guidelines were published in 2000, flexion—extension imaging was overtly recommended for patients who were predicted to remain unconscious for more than 24 h.[126] This promised rapid spinal clearance however, the safety of moving the neck in these patients, even under expert supervision, has been seriously questioned. In the revised guidelines, the apparent "safety" was based on just three papers, each reporting a very small number of patients with normal plain views and/or CT scans followed by no demonstrable instability on flexion—extension imaging. In the UK, radiological clearance was often technically inadequate and spinal precautions were sometimes withdrawn on the basis of a single lateral plain radiograph or on clinical assessment alone after consciousness was eventually regained.[76,118] In 2002 the British Trauma Society responded with three, practical management options, of increasing complexity, for institutions to discuss and choose a policy suitable for their case mix and therefore expectation of injury (BTS Injury, 2003).[26]

Anatomical distribution of injury

The NEXUS study confirmed the typical distribution of fractures (C2 23.9%, C6 20.25%, C7 19.08%, C5 14.98%) and dislocations or subluxations (C5/6 25.11%, C6/7 23.77%, C4/5 16.96%).[72] However, half of the cranio-cervical injuries may not be suspected clinically,[30,139] so identification requires a high index of suspicion and little reliance on an apparent lack of symptoms or signs. In 202 consecutive unconscious patients, 28 (13.9%) had C1 or C2 fractures and 11 of these had normal cervical radiographs, as did all except 1 of the 9 (4.4%) cases with an occipital condyle fracture.[117] Others have doubted such a high incidence of occipital condyle fractures,[66] but it is likely that the true incidence depends not only on the case mix, but also on the expectation of the clinician, which will determine how carefully they are looked for. In order to make a reliable diagnosis of an occipital condyle fracture, it is necessary to perform high resolution, thin section (1 or 2 mm) CT scan (or multislice CT scan) of the base of the skull, with both orthogonal reconstructions. The diagnosis and classification of occipital condyle fractures guides treatment for instability[213,7] and may explain persistent symptoms.

In the elderly, domestic falls are the commonest cause of cervical injury, where two-thirds of cervical fractures in this age group involve the occipital condyles or the upper three vertebrae. Such injuries are commonly associated with spondylosis or osteoporosis,[124] which complicate the interpretation plain films and contribute to delayed diagnosis in 15—40%. In the over 60s devastating cord injury may occur without fractures or dislocations, spinal cord injury without obvious radiological abnormality, or SCIWORA is relatively common.[150,107,48]

The relevance of mechanism of injury

It is intuitive that the mechanism of injury influences the risk of cervical spine trauma, but there is insufficient documented evidence to rigidly stratify risk accordingly. While the mechanism may raise the level of suspicion, it rarely allows spinal injury to be excluded.[19,21,79] This means that one cannot predict spinal injury on the basis of other injuries or vice versa. Each patient needs full evaluation of the whole spine. It must be remembered that cervical spine trauma is associated with upper rib fractures, pneumothoraces and damage to the great vessels and/or trachea, which need active exclusion in cases with a spinal injury.[38] A mechanism involving high-energy transfer merely reinforces the need to investigate thoroughly. Several authors have determined mechanisms of injury and clinical parameters which allow patients to be divided into high or low risk, with imaging reserved for the former (Table 1). If the circumstances of the injury are unclear, it is wise to err on the side of caution and investigate carefully, particularly in blunt trauma.

High velocity bullets that miss but pass close to the spinal column may cause spinal injury as a result of the associated shock wave.[16,132] On the other hand, gunshot wounds to the head rarely have any associated spinal injury[98] and it is not necessary to take spinal precautions if there is no evidence of bullets passing close to the spinal column or of a separate blunt mechanism of injury.

The incidence of spinal injuries depends on the groups studied: They were seen in 3.4% of motor vehicle occupants, 2.8% of pedestrians, 1.9% of motorbike riders and 0.9% of falls of all attendances to a major urban trauma centre.[55] Post-mortem studies of fatal motor vehicle collisions (MVCs), on the other hand show up to 24% have cervical spine and up to 40% have head injuries of varying severity.[49,5,30,31] Frontal airbags cause all types of cervical injury if the occupants are unrestrained or if children in rear facing car seats are too close to the activated air bag.[105] Rear passenger's fair worst in MVCs because they are most often unrestrained, with three point seat belts offering most protection.[43,192] High-speed MVCs and falls from a height are associated with a high risk of spinal injury.[95,10,170] Patients with clinically significant head injuries are at increased risk of cervical spine injury.[184,167,215,174,88,123,142] Up to a third of Level I trauma cases requiring head CT in Chicago for head trauma or retrograde amnesia, had fractures of C1 or C2.[104] The incidence of cervical spine injuries is inversely related to the GCS (10.2% of those with GCS 8, 6.8% of those with GCS 9—12 and 1.4% of

Table 1 Summary of criteria for cervical spine injury.[47]

Vandemark: criteria for high-risk patients	High velocity blunt trauma; multiple fractures; evidence of direct cervical injury (cervical pain, spasm, obvious deformity); altered mental status (loss of consciousness, alcohol and/or drug abuse); drowning of diving accident Fall of >10 ft; significant head or facial injury; thoracic or lumbar fracture; rigid vertebral disease (AS, DISH); paresthesias or burning in extremities	206
University of Washington criteria		
Mechanism parameters	High-speed (>35 mph) MVA; crash with death at scene; fall from height >10 ft	
Clinical parameters	Closed head injury; neurologic symptoms or signs referred to the cervical spine; pelvic or multiple extremity fractures	
Steill: Canadian rules, no radiography		195
Absent high-risk factors	Age >65 years; dangerous mechanism (see Vandemark of University of Washington criteria); paresthesias in extremities	
Low-risk factors which allow safe assessment of range of motion	Simple rear end MVC; sitting position in ED; ambulatory at any time; delayed onset of neck pain; absent midline cervical tenderness; able to actively rotate neck 45° left and right	
NEXUS criteria (low risk)	Absence of midline cervical tenderness; absence of focal neurologic deficits; absence of intoxication; absence of painful distracting injuries; normal alertness	72

Hanson validated high risk cervical spine[80]	
Mechanism	Clinical
Speed >35 mph;	Cervical spine pain, spasm, deformity or neurology
fall >10 ft;	significant closed head injury;
death at scene	pelvic or multiple extremity #

those with GCS 13–15),[55] however there is no direct association between the severity of head injury and the incidence and nature of cervical spine[193] or occipital condyle injury.[144]

The role of clinical assessment in cervical spine clearance

In the field, opportunities for reliable clinical evaluation are limited and it is generally advisable to immobilise the spine in significant blunt trauma cases until the patient is in a more conducive environment in hospital. In the alert patient, there is agreement on how to clear the cervical spine if the conscious level has not been altered by head injury, drugs or alcohol[33,147,121] and there is no distracting pain from other injuries. Then a history and clinical examination can rule out significant injury.[62,10,147,170,136,108,13,130,180,88,116,176,61,207,221,73] This was validated, in a prospective, multi-centre, observational study in North America: the National Emergency X-radiography Utilisation Study (NEXUS). It looked only at low probability injuries, to try and identify those in whom radiography can be safely omitted.[89] Of the 34,069 patients from 21 centres, 818 (2.4%) had a radiographic cervical spine injury. Two hundred and forty of the 818 patients (29.3%) met the 5 criteria of insignificant injury: no midline cervical tenderness, no focal neurological deficit, normal alertness, no intoxication or painful distracting injury,[72] i.e. no depressed consciousness sometimes called the "Five Nos". This practice is more akin to the British practice. The Canadian cervical spine rule[195] looked at stable patients with a normal GCS of 15, excluded those with high risk factors, and set out low risk criteria including delayed onset of neck pain which then allowed active rotation of the neck of up to 45° bilaterally. Controversially if they could move the neck, even if it was painful they reported that no radiography was indicated.

In an alert patient without neurological features, clinical examination should be repeated if the radiographs are normal, this time including active movements. If pain or tenderness is still a problem, flexion—extension radiographs should be considered, but may cause false negatives in neck muscle spasm.[137]

If the patient has an altered level of consciousness or has received sedative drugs, including opioids, the clinical examination may be unreliable. Similarly, distracting pain from a separate (non-spinal) injury may cause the patient to disregard symptoms from an unstable neck injury.[4] Local pain, tenderness and neurological symptoms or signs (such as segmental weakness, numbness or paraesthesia) must be assumed to indicate a potentially unstable injury. In all these circumstances, it is essential to image the spine before moving the neck. However, clinical examination (short of moving the neck) remains an important part of the assessment and should not be omitted simply because radiographs are indicated.

Most units receiving the multiply injured rapidly perform a CXR, pelvis and lateral cervical spine radiographs after the primary survey. At a clinically appropriate time the whole neural axis must be cleared.

Plain radiographs

Despite the availability of newer technologies, there is still an important role for plain films and all staff need a basic understanding of the principles. They are ubiquitous, cheaper than CT and the radiation dose is much less for the full spine, only 0.069 mSv in our A & E. The role of plain films is likely to diminish in the unconscious as multislice MS-CT technology spreads. Previous guidelines recommend that swimmer's views are replaced by trauma obliques, which are of lower radiation doses and show the posterior elements more extensively,[202,94] allowing fracture and facet joint dislocation diagnosis. Our own experience of apparently stable radiographic uni-facetal dislocations is that there is often extensive fracturing at the level and/or adjacent vertebra on CT, the pattern of which is associated with instability. Thus, even in the conscious limited MS-CT is now indicated more often. Although all the multislice sagittal and coronal reconstructions give more information than plain films[111], the single radiograph is the baseline for follow up, and remains invaluable in MS-CT units henceforth radiography will probably be limited to a lateral with an AP.[47] However, in technically difficult patients, repeated plain films followed by extensive CT scanning is hardly saving on radiation.

Adequacy of the films

There is often a difference in quality between portable films and those taken on a fixed departmental machine, although new portable digital units are a great improvement. Good radiographic technique is essential if subtle signs are to be revealed. To be adequate, the films should show the full extent of the cervical spine, from the occiput to the upper border of T1, and should not be rotated. The penetration should be sufficient to show bone architecture without losing soft tissue detail.

Systematic radiological evaluation

The films must be evaluated by a competent practitioner who maintains sufficient activity to maintain skills. Clinicians may find it useful to have a simple system for analysing plain films, Courtesy of Dr. Peter Oakley the radiological ABC.

A(i): appropriateness—correct indication and right patient.

A(ii): Adequacy—extent (occiput to T1 upper border, penetration, rotation/projection).

A(iii): Alignment—anterior aspect of vertebral bodies, posterior aspect of vertebral bodies, posterior pillar line, spino-laminar line; cranio-cervical and other lines and relationships.

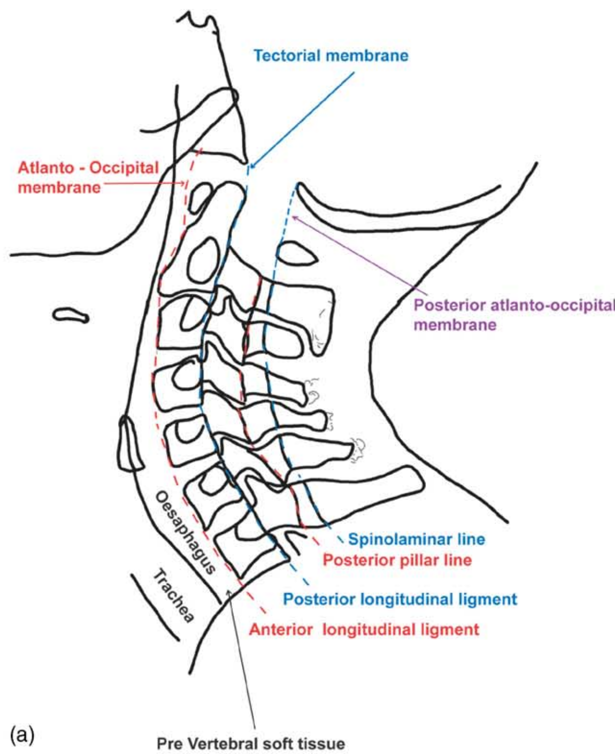
B: Bones

C: Connective tissues—pre-vertebral soft tissue, pre-dental space, intervertebral disc spaces, interspinous gaps.

How to read plain radiographs

A technically adequate lateral cervical spine radiograph will include down to the upper first dorsal vertebra, with clear bony detail. The pre-vertebral soft tissue should be assessed, even though swelling is an unreliable sign of injury,[133] as it is not always present and may require a bright light to be seen. If present it is a specific sign for ligamentous disruption. This is worth assessing early on in the radiological evaluation, as it is often otherwise overlooked and gives vital clues to the site of injuries. Adenoidal tissue in the retropharyngeal space can appear bulky, particularly in children who are crying or swallowing. Below the oropharynx, the pre-vertebral soft tissue stripe is usually less than 4 mm wide down to the level of the fourth cervical vertebra, where it widens to approximately the width of a vertebral body due to the oesophagus.[87] Using absolute measurements as an indicator of abnormality is unreliable, and localised bulging due to haematoma is generally more revealing.

The classical way to assess the radiology is in relation to the smooth bony alignment Fig. 1a and b, but it is important to understand what other structures make up each line of alignment, as assessed on the lateral radiograph, displayed in Fig. 1b. The first line to be assessed on the lateral radiograph extends from the anterior margin of the atlas down the anterior margins of the other cervical vertebrae, which corresponds to the anterior longitudinal ligament. Analysis of intervertebral body movement overall is required, and usually there is a smooth "C", and no "foraminae" are seen and the facets are not superimposed on the vertebrae. Minor degrees of tilt cause either a smooth, regular change of successive levels of vertebrae or a progressive one (Fig. 2). A disproportionate amount of



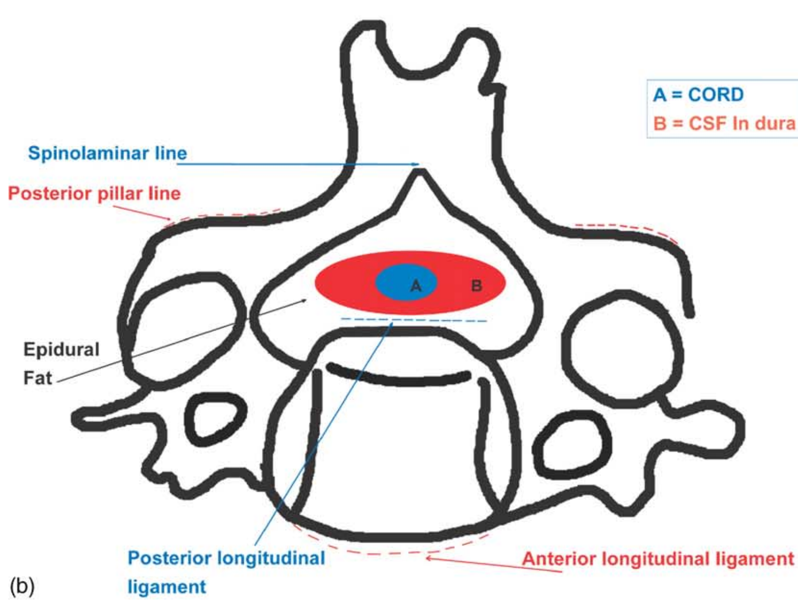


Figure 1 (a) The lateral cervical radiograph; (b) the anatomy compromising the radiological lines seen (a).

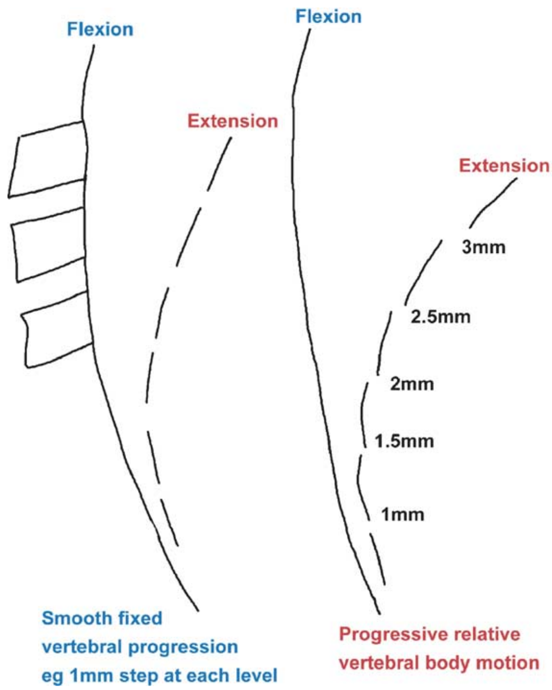


Figure 2 Normal cervical intervertebral body movement: The effect of flexion/extension on the radiographs.

rotation or forward subluxation at one level is pathological. Usually there is less than 3 mm of forward displacement of successive vertebrae, but more than 3.5 mm or an 11° angle between adjacent endplates suggests instability, be it degenerant or traumatic. The anterior ligaments contribute more to stability in extension and the posterior ones in flexion.[214] Pathologically widened and narrowed discs may be traumatic in origin.

The posterior margins of the vertebral bodies form the second line and includes the posterior aspect of the odontoid process. At the cranio-cervical junction, the second line forms an angle of 150—180°, Wackenheim Clivus baseline (Fig. 3), which extends up to the back of the clivus to the odontoid peg. The vertical distance from the basion (the anterior margin of the foramen magnum) to the peg, the basion-dental interval, should be less than 12.5 mm. The anterior margin of the foramen magnum sits just above the tip of the odontoid process. In normal cranio-cervical alignment, the tip of the odontoid lies below Chamberlain's line. The latter, extends from the posterior pole of the hard palate to the opisthion, the posterior margin of the foramen magnum. The atlanto-dental distance, the space between the posterior margin of the anterior arch of the axis and the anterior margin of the odontoid process, is less than or equal to 3 mm in adults. It may be between 4 and 5 mm in a child due to incomplete ossification. When the transverse ligament is intact, the distance should remain unaltered on flexion/extension views. On the AP the joint spaces between the lateral masses of C1 and C2 are bilateral and symmetrical, as is the distance from C1 to the peg (Fig. 4). There is much normal variation in the size of C1 and C2 lateral masses. In trauma this must be investigated with high resolution CT to exclude fractures. The commonest cause of offset of the lateral masses of C1 and C2 is positional, as part of the normal tilting process, and should move in the same directions, if not investigation is indicated, similarly asymmetry at the peg and C1. The centre of rotation of C2 is normally within the odontoid peg[172] on CT.

The next line, is the posterior pillar line, which is made up of the backs of the lateral masses, which have the facet joints obliquely orientated between

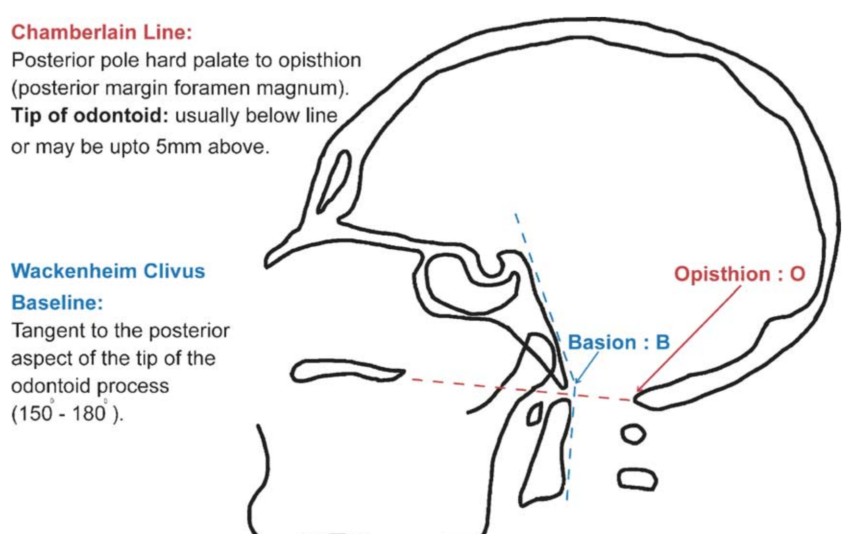


Figure 3 Lateral cranio-cervical alignment.

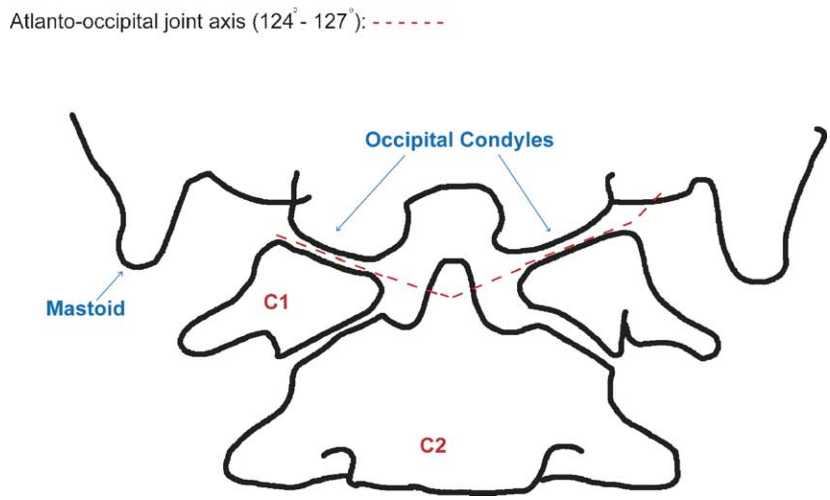


Figure 4 Antero-posterior cranio-cervical alignment.

adjacent levels.[189] If the facet joints fail to lie like roof tiles, with the superior one overlapping the one below then disruption should be excluded.

Next is the spinolaminar line, which passes down in a smooth arc from the posterior margin of the foramen magnum along the anterior aspect of the spinous processes, where the laminae fuse. It is along this line, that the distance between the spinus processes is assessed most accurately. It is unreliable to assess the line joining the tips of the spinus processes, as the radiographic appearance of the spinous processes are highly variable as the tips are bifid. The disruption of the spinolaminar line at a specific level, implies complex spinus process fractures, which extend to the laminae and therefore are likely to effect the spinal canal. They are often associated with posterior longitudinal ligament injury and therefore have the potential for instability and neurological deficit.[128]

Uni-facetal dislocation can cause anterior displacement of one vertebra, by up to 25% of the width of the vertebral body, whereas between 40 and 50% or worse overlap suggest bilateral facet dislocation. Uni-facetal rotatory subluxation closes the space between the spinolaminar line and the cortex of the facet, causing a 'butterfly' or 'bow tie' appearance of the facet, which are locked. In addition the degree of rotation may mean that pedicles and foraminae, not normally seen on the lateral, become visible. Conventionally uni-facetal dislocations are considered stable, whilst bilateral ones are unstable.[14] The use of CT at our institution commonly finds other injuries both bony and ligamentous, not visible on the radiographs, which often make uni-facetal injuries unstable.

The hyperflexion teardrop fracture is the hallmark for severe soft tissue injury resulting in ligamentous disruption, and disc rupture with relatively little bony injury. The anterior triangle or "flake" of bone as it is miss named, may be the only clue to a complete three column soft tissue injury causing an unstable spine. The ruptured disc is usually narrow, but may be pathologically widened.

Disruption of the 'ring', or junction of the body and lateral structures of C2, as seen on a lateral radiograph, indicates a low (Type III) odontoid fracture.[81]

A radiologically 'fat C2', where there is increased distance between the anterior and posterior margins of C2 on a lateral, is due to an oblique fracture of the body of C2,[155] which may not be visible on plain films and requires a CT.

On the AP the lateral extent of the vertebral lateral masses make a "wavery" contour. The uncinate processes, lateral vertebral body margins and tips of the spinous processes make straight lines, with malalignment indicating malrotation. Facet joints are not seen on an AP.

Radiological analysis of the cranio-cervical junction

Powers et al. described the plain radiographic criteria for the diagnosis of atlanto-occipital dislocation on a lateral radiograph (Fig. 5).[159] The ratio of BC/OA > 1.0 is consistent with atlantoocipital dislocation and less than 1.0 are normal. This method relies on being able to identify clearly the anterior margin of the foramen magnum (basion: B) which is at the distal end of the clivus, the posterior margin of the foramen magnum (Opisthion: O), the posterior margin of the anterior (A) and anterior margin of

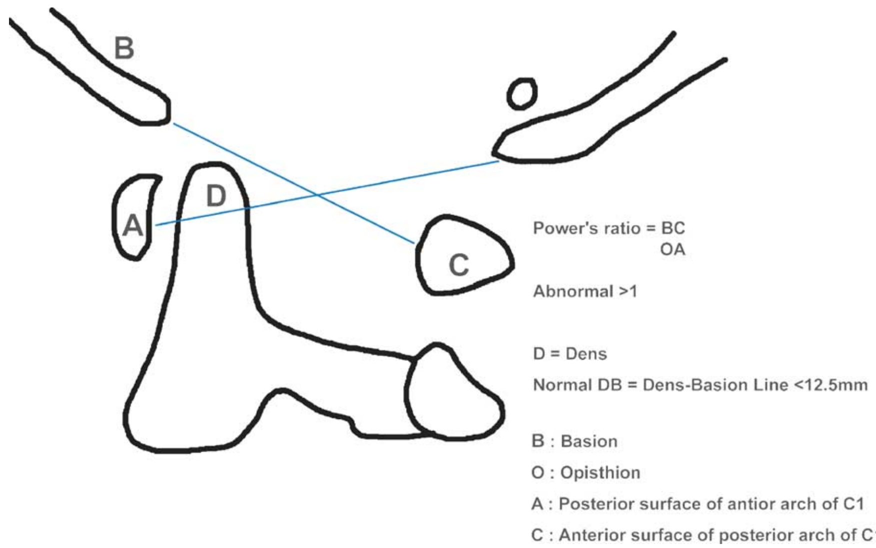


Figure 5 Lateral cranio-cervical alignment: The Power's ratio.

the posterior arch of C1 (C). False positives and false negatives are common and usually result from inadequate visualisation of these points on plain radiographs. In addition, because it relies on displacement for diagnosis, it will always miss the cases, which end up normally aligned after the injury. Thankfully thin slice CT has replaced this type of analysis, but cranio-cervical dislocation can be subtle, although usually they need ventilating for the associated brain stem injuries.

Radiographic normal variants which simulate pathology in the cervical spine

There are a large number of normal variants which in the context of trauma, may require CT to allow confident diagnosis by the demonstration of well corticated bony margins: anterior or posterior tilting of the dens, aplasia or clefts in the ring of C1, vascular channels, accessory ossicle and less than 2 mm asymmetrical alignment between the lateral masses of C1 and C2 on the peg view, due to rotation or tilt.[100] Bony and ligamentous causes of asymmetry at C1 and C2 are common.[156]

Physiological pseudosubluxation of C2 on C3 is assessed by the displacement of the anterior surface of the posterior arch of C2, relative to the posterior cervical line, the straight line that joins the spino-lamina lines of C1 and C3 on a lateral radiograph.[197] In physiological displacement of C2 on C3, the anterior cortex of the posterior arch of C2 passes through, touches or is up to 1 mm behind the posterior cervical line. Pseudosubluxation was first reported in 19% of normal volunteers[36] and subsequently in up to 21.7% of London paediatric helicopter polytrauma cases, being more common below age 8.[190]

The limitations of plain radiographs

Intoxication, unconsciousness, and pain from multiple injuries, hamper clinical diagnosis.[166] A good quality, technically adequate, three film trauma series miss 0.07% of all cervical injuries[137] or 1% of cervical fractures,[120] however, in routine practice, in polytrauma the films are often technically inadequate, due to positioning difficulties, overlying nasogastric, or endotracheal lines. Although a lateral may be adequate[92] particularly if the patient is alert,[221] most studies have shown that a three or five FTS is superior.[14,57,65,129,202] The sensitivity of a lateral is 82–85% in adults[175,212] and 79% in children.[11] That of a three film series is up to 92% in adults[175,212] or 94% in children[11] with a negative predictive value of 97 and 99%, respectively.[175] The three film series has a low specificity 37% and moderate positive predictive value of 70% in adults.[175]

Radiographs at the cranio-cervical and cervico-dorsal junction are often technically inadequate or incomplete, commonly failing to demonstrate the peg or upper border of D1,[9,2,166,29,106,136,185,24,39,52,217,146,206] which reduces the specificity of plain films.[20] When the three film trauma series fails to show the distal cervical spine, the use of antero-posterior or trauma obliques is beneficial.[14,129,65] When the three FTS fails to show the cervico-dorsal junction (26%), the addition of obliques[52] demonstrates it adequately in a further 13%, reducing the necessity for CT, making the five film trauma series (5FTS) cost effective.[97]

Missed injuries on plain radiographs

The precise incidence of missed fractures varies with the patient population studied, and in many papers it is not clear exactly which radiographs were performed routinely or who was evaluating them. Causes of missed injuries and delayed diagnosis include failure of the patient to seek medical attention, failure to take the relevant radiographs, and failing to identify fractures which were visible on the films[165,166,52,27,138,140,206] and film misinterpretation.[53] Delayed diagnosis of cervical spine fractures may occur in up to 23% of patients, especially when complicated by other factors such as intoxication or, altered level of consciousness.[166]

A retrospective study in Phoenix, with a four film cervical trauma series (AP, peg, lateral and swimmer's views) supplemented by directed CT in 1331 multiple injuries patients, mean ISS of 30 and GCS of 11, found cervical fractures or dislocations in 61 (4.6%).[69] There were nine fatal atlanto-axial dislocations and, of the 50 survivors, there were neurologic deficits in 15 with complete cord lesions in 8.[69] Five patients had delayed diagnosis of their cervical injuries (2—21 days), due to inadequate or incomplete plain radiography.[69]

In a retrospective study in Philadelphia, of 372 spinal injury cases to the regional spinal centre, 3.2% of spinal injuries were missed on radiographs, and 25% of these were associated with a progressive neurological defect attributed to incorrect initial immobilisation.[203]

In the National Spinal Injuries Centre, Stoke Mandeville, UK, of 353 consecutive admissions with spinal cord injury, 11 cervical injuries were missed at presentation (3.1%) and 10 of these (2 paraplegic, 8 tetraplegic) were considered to have deteriorated as a result of the initial management.[165]

Noncontiguous vertebral injuries, which are reported between 4.5 and 15.2% cases are often missed at presentation.[34,78,76,85,203] The NEXUS,[90] study which avoids radiographing those with clinically insignificant injury, found that plain radiographs failed to detect 10.5% (60/570) of cervical injuries, but in the majority, 89.5% the cervical spine was not the primarily injured area.[137] Thus, the whole vertebral column should be assessed in a multiply injured patient in a timely fashion, depending on the nature of the other injuries.

The evolving role of CT scanning

Patients with clinically significant head injuries are at increased risk of cervical spine injury,[184,167,174,215,88,123] inversely related to the GCS.[55] In a prospective study of blunt trauma patients requiring intubation and ventilation, spiral CT of the cervico-dorsal junction detected fractures in 10%, which were occult on lateral and both oblique plain radiographs.[96] Thirty four percent of ICU blunt trauma admissions (21/58), who could not be evaluated clinically, had cervical fractures on CT.[18] In unconscious patients at the time of the initial brain CT, cranio-cervical junction CT should be performed with sagittal and coronal reconstructions as a minimum, assuming that the AP and lateral whole cervical spine are adequate and normal (NICE, 2003; RCR 2003).[143,177] The technique must be meticulous with 1—3 mm axial slices.[117,22,23,125] Multislice CT allows axial reconstructions at 1 mm or submillimetre widths, which allows one to diagnose small cortical breaks invisible even on 2 mm slices.[178] It must be remembered that CT will miss up to 10% of fractures especially if in the plane of the axial CT slice, if both reconstructions are omitted[196] typically at the peg. Axial fractures are missed, when slices are over 3 mm thick, usually at the dens, or between C6 and D1.[218,178]

Good quality, thin-section spiral CT is the optimal means of imaging fractures, particularly where plain radiography is poor, at the cranio-cervical and cervico-dorsal junction.[199] In addition, for high risk cases of cervical spine fractures, the specificity of radiography is relatively low.[20] Although plain films show dislocations more reliably,[218] sagittal reconstructions from spiral CT give similar information. Spiral CT of the whole cervical spine is used routinely in most high risk or polytrauma cases in North America,[146,21,45,79,113,161] where MS-CT has been freely available for 3 or 4 years, and has just been recommended by the American College of Radiology,[47] and AP radiography can probably be safely omitted.[179] The diagnostic performance of conventional CT for injury is good,[18] sensitivity 95% (95% CI, 90—100%) specificity 93% (95% CI, 91—95%) accuracy 93% (95% CI, 91—95%), but false negatives are usually ligamentous, and false positives are common, also often ligamentous.[79]

The cost effectiveness of CT

In North America, in high risk trauma patients, whole cervical spine spiral CT at the time of the initial body or head CT is quick, and cost effective.[145,104,18,21] In children, CT of the cervical spine when the head injury was scanned resulted in fewer cervical spine radiographs.[101] CT only minimally increases the total imaging time by around 20 min,[45,46] but is much more expensive than plain films alone,[21] particularly in the USA. CT Cost effectiveness depends on the probability of injury and the consequences of misdiagnosis in the group undergoing the scan. In America, in patients with severe head injury, the probability of detecting concurrent cervical spine injury is 11.2%,[21] where the cost can easily be justified. If the probability of an injury is less than 4%, CT scanning is not cost effective in the American health system, even though it has been considered to contribute to preventing paralysis.[21] It has been suggested that if plain radiographic analysis of the cervico-dorsal junction is inadequate, localised CT is also cost effective, because the patients are often young,[199,198] with large financial implications over many years for any missed injuries.

In Britain however, CT of the whole cervical spine is rarely performed,[76,118] reflecting fewer multislice CTs, the low incidence of major trauma in DGHs, with only six North American style Level I Trauma Centres (Better Care for the Severely Injured, 2000).[1] No cost effectiveness analysis is available in the UK, where the NHS health economics mean that preventing disability is likely to be cost effective, even for low probability cervical injury cases, as CT is relatively cheap, and the huge long term rehabilitation costs are usually state funded.

CT even with volume scanning or isotopic images and reconstructions in two planes, can only diagnose significant disc or ligament injury if there is malalignment. More experience with multislice CT may change this view, but there are no comparative or randomised controlled studies as yet. However, it must be remembered that intervertebral malalignment of or over 4 mm may be inadvertently reduced by long spinal board extraction and head blocks. The advantages of MS-CT are clear, but the radiation dose savings though small may be lost with increasing coverage (Table 2). In the UK the simple increase in CT usage has increased the effective dose of radiation from 20 to 40% in the 1990s, which predates multislice CT,[141,93] and every doctor must weigh the benefits and risks of such exposure.[148,40]

Controversy over flexion—extension (F/E) imaging

Active F/E is a safe, good test in conscious, cooperative patients to screen for ligamentous instability.[157,115,158,8] Instability is confirmed if there is more than 3.5 mm of intervertebral body motion or more than 11° of relative angulation. Normally there is either a smooth, fixed step in vertebral body alignment or a progressive change (Fig. 2). Cervical instability occurred in 8% of alert, trauma patients in a Missouri Level I Trauma Centre, nearly half of whom had a normal three film series.[115] The addition of F/E views to a three film series increases sensitivity (99%), specificity (93%) with a high positive (89%) and negative (99%) predictive value, with false negatives largely due to spasm.[115] F/E radiography is unable to exclude instability, even if the other radiographs are normal until the spasm has resolved.[137,138]

Passive F/E views or fluoroscopy in unconscious or sedated patients are technically inadequate in up to a third,[8] and they may cause devastating neurological deficit, and remains controversial.[115,50] It is avoided in the overwhelming majority of UK centres.[77,118] Fortunately the incidence of isolated ligamentous injury is rare,[37] in a retrospective review of 14,577 blunt trauma victims in a tertiary referral centre in Baltimore, 614 (4.2%) had cervical spine injuries, of which only 87 (0.6%) had isolated ligamentous injuries. There were 2605 patients in the series with a GCS less than 15 and only 14 (0.5%) had isolated ligamentous injuries. Interestingly, 13 were identified on the initial lateral radiograph and the other was diagnosed on CT. In these cases of isolated ligamentous injury, flexion—extension views were not needed to reveal instability. The pre-vertebral soft tissue swelling on plain films or CT scans implies ligamentous disruption, but may be absent in rapid helicopter transfers. In a series of 14,755 trauma cases in Los Angeles, 292 patients

Table 2 Comparison of CT radiation doses at UHNS, a) conventional spiral b) multislice.

Conventional spiral CT	kV, mAs	FFD	Entrance surface does (mGy)	Effective dose (mSV)
(a) Cranio-cervical junctions C0—C3	120, 150	FOV 6 cm, pitch 1—3 mm, slices 3 mm, 2 mm	Not applicable	0.8
Cervical dorsal C5—D2		FOV 5 cm, 3 mm slices	Not applicable	1.9
Base of occiput to D2 C0—D2	120, 140	FOV 12cm, 3mm slices	Not applicable	2.7
(b) Multislices-16 C0—C3	120, 130	Pitch 0.88 coll. 0.75 mm, 9mm irradiated slice width	Not applicable	0.6
C5—D2	120, 130	Pitch 0.88 coll. 0.75 mm, 9mm irradiated slice width	Not applicable	1.5
C0—D2	120, 130	Pitch 0.88 coll. 0.75 mm, 9mm irradiated slice width	Not applicable	2.1

had cervical spinal injuries. Of these, 250 (85.6%) had fractures, 10% had subluxations (presumably with ligamentous disruption) and 3.8% (11 patients) had isolated cord injury without fracture or obvious ligamentous damage.[55] There are few advocates, but with less than 20 cases of instability out of less than 2000 pooled cases of unconscious patients,[51,186,41,50,28,8] the numbers are too small for it to be recommend. The ACR[47] no longer recommend F/E views in those with altered consciousness, and they should be reserved for follow up assessment of ligamentous instability in conscious patients whose muscle spasm has resolved. Somatosensory evoked potentials (SSEP) need further evaluation as a monitoring method[182] for F/E in the unconscious, as the delayed or decreased amplitude SSEPs due to compression or ischaemia of the dorsal column, which means the damage to the cord has already occurred, so fails to prevent damage at all. Thus, F/E should only be done after informed consent of the relatives of an unconscious patient, when part of a randomised and controlled study, assuming ethical approval is obtained. In the current legal climate, it is doubtful if any ethics committee would allow such a study. In addition as so few UK institutions use it, if a disaster occurred, the patient may be able to sue for malpractice, as it probably does not pass the Bowlam test[25] of reasonable practice. In today's world it cannot be recommended.

The place of MRI

MRI is unequivocally the modality of choice for evaluation of patients with neurological signs or symptoms:

1. To assess soft tissue injury of the cord, disc and ligaments. MRI gives excellent soft tissue and cord detail, showing cord compression from haematoma and disc prolapses, often allowing the cause of focal neurology to be analysed.[110,109,135,15,71,60,63,168,56,17,102,205,98] To assess soft tissue injury without MRI the extent of disc and ligamentous injury are underestimated.[64,98,194]

   Previously asymptomatic necks with spondylosis causing spinal stenosis may cause direct impingement on the cord at the time of injury. Cord injury is more likely with spondylosis ($P = 0.5$) and canal stenosis ($P = 0.001$),[98] where acute central cord injury is particularly associated with a poor prognosis in the over 1960s.[58,48] Although cord injuries are associated with acute cervical fractures ($P = 0.001$),[98] there may be no relationship between the extent of bone and soft tissue injury.[64] In as many as 3.5% of spinal injuries isolated cervical cord injury may occur usually due to established spondylosis, without fractures or subluxations.[55] In children the relatively large size of the head and inherent skeletal mobility, leaves the cord particularly vulnerable to damage seen on MRI with normal radiography, called significant cord injury without obvious radiological abnormality or SCIWORA.[151,150,107] Interestingly in the 34,069 patient NEXUS study, with over 3000 children, there were no cases of SCIWORA.[208,86] Even minor hyperextension in spondylotic cervical spines may cause cord injury. This is because osteophytes narrow the spinal canal and buckling of the ligamentum flavum occurs on hyperxtension,[163] without there necessarily being fractures[55] or obvious cord abnormality on the initial MRI.[71]

   Hyperextension injuries may be unstable because of ligamentous or acute disc ruptures.[53] Even if no specific intervention is indicated on the basis of the scans, the prognosis is often clarified,[109,219,183,127,114] as acute cord haematoma at presentation is predictive of a complete lesion and has a poor outcome,[63,219,64,164] whilst extradural haematoma evacuation[149] or disc resection is associated with a lower morbidity.[135] MRI may be beneficial in hyperextension injuries, due to direct craniofacial trauma or whiplash, where the plain radiography abnormalities may be subtle,[53,182] but this is controversial.[173]

   Pathological studies have shown that cervical spine ligaments can be disrupted with and without vertebral fractures and rarely in isolation.[49] MRI showed disc injury in blunt trauma patients presenting to a neurosurgical unit with cervical injury in 23% overall and in 36% of cases with complete and 54% of incomplete cord lesions.[169] MRI showed that 47% of unstable cervical spine injuries (9/19) had herniated intervertebral discs.[160] Ligamentous, disc and soft tissue injury is often extensive, and account for 89% of post-traumatic cervical spine injuries in post-mortem series.[194] Benzel et al. used an ultra low field magnet to evaluate patients whose physical examination or plain radiography was equivocal. They found that 15.5% had both disc and ligamentous disruption, whilst 20% had isolated ligamentous abnormality.[17] Anterior longitudinal ligament (ALL) disruption, diagnosed on MRI, was associated with pre-vertebral soft tissue swelling in most (13/14) cases hospitalised following cervical injury.[191] Hence, in the absence of soft tissue swelling on plain radiographs, as may occur in rapid helicopter transfers may be a false negative for ALL disruption and occult fractures.

   The spinal ligaments can be assessed on MRI,[60,106,201,102,98,68,194] which is sensitive and has a high negative predictive value, but as yet a reported suboptimal specificity and positive predictive value.[211,201,216,102,68] Few studies have surgical follow up, but where available MRI diagnoses all the unstable ligamentous injuries, with some false positives and no false negatives,[211,216,4] but these papers predate Saiffuddin et al. He showed that disruption of the black stripe of ligaments is not a reliable sign of rupture, when taken in isolation.[181] On MRI the discontinuity of interspinous ligaments must be visualised and not simple haemorrhage alone are required to diagnose rupture.[216,181] It is likely that subsequent papers will show a higher specificity and positive predictive value, and is our experience of MRI.

2. MRI may show vertebral artery trauma, associated with facet or foramina transversaria fractures, whose effect otherwise may be incorrectly attributed to cerebral or cord injury.[119,54,70,153] Interruption to flow is surprisingly uncommon, in practice.
3. MRI is a good method, to diagnose traumatic meningoceles or CSF escaping from the neural foramen, after nerve root avulsions[35] or briachial plexus injury.[147,209,67]
4. To diagnose noncontiguous vertebral fractures. Plain films in tertiary spinal units find 15.2%,[85] but this is an underestimate as MRI has shown nearly double at (29%), on whole spine T2 fat suppressed MRI.[74] This implies that current imaging strategies do not fully evaluate noncontiguous injuries which are often unsuspected[162] and diagnosed late.[34] If MRI is indicated for focal neurology in a conscious patient, rapid MRI assessment of the whole spine is prudent,[162] even though the injuries are less significant clinically.
5. MRI allows accurate pre-operative cord assessment, surgical planning in unstable cervical spine injuries and prevents iatrogenic worsening of the neurological defect,[160,59,171,122,169,204] and is now mandatory.
6. MRI can evaluate complications and late symptoms after trauma such as cord atrophy (62%), myelomalacia (54%), minicystic degeneration (9%) or post-traumatic syrinx formation (22%).[219,210] Spinal injury patients are probably most cost effectively followed up with MRI.[188] MRI diffusion imaging may allow more confident differentiation between traumatic and metastatic vertebral collapse,[91] but in practical terms this is rarely an issue in this group.

Unconscious patient and MRI

When ventilated, multiple injury patients with obvious cervical spine injuries on plain radiographs and focal neurology are excluded, MRI finds a high incidence (25.6%) of significant ligamentous, disc or bony injury, and can be used to direct areas for CT, where up to 10.7% have previously unsuspected fractures.[44] When a good quality helical or multislice cervical CT is normal, MRI may find abnormalities and ligamentous injury in 10%.[103] Accurate diagnosis of cervical bony or ligamentous injuries allows appropriate management of the unconscious patient by nursing staff, obviates the need for log rolling and allows the early removal of collars, thus reduces the likelihood of pressure sores, deep vein thromboses and chest infections. With hard collars yet more complications become common after 72 h, including pressure sores, rash and difficult intravenous access.[3] In addition cervical immobilisation necessitates more attempts at intubation with more risks,[99] and delays tracheostomies.[3]

MRI, which uses magnetisation and no radiation, sounds like a good screening tool for bone, ligament and disc injury. However, MRI is unsuitable for unstable polytrauma, because of the difficulties in monitoring ventilated patients, in spite of the expensive specialised equipment. In addition, the scanner is often remote from the emergency department, necessitating further hazardous transfers and consequent delay. In a small study, Vaccaro et al.[203] found that routine MRI screening of both conscious and unconscious cases, was cost effective in America only where there was a neurological deficit. In this group MRI changed the management of 25%, or 4/55 cases however, more than half of the patients, 77 were excluded, making accurate analysis of the benefits of MRI impossible from their data. From the American College of Radiology (ACR) for unconscious patients with a normal CT and radiographs, MRI is now the investigation of choice for instability,[47] and on direct questioning at the International Skeletal Society in 2003, Dr. Daffner felt that less than 10% of unconscious polytrauma cases actually required MRI, and our experience is less than that.

The unconscious patient clinical perspective

Careful progressive evaluation of the cervical spine is needed, rather than a rush to clear it. All management needs clinical prioritisation by a multi-disciplinary team. Unstable patients need immediate life saving clinical intervention followed by appropriate timely spine imaging. There is little controversy about CTing the base of the skull to C3 at the same time as the brain CT, in unconscious patients. This practice is not widespread in the UK, but is to be recommended as long as the technique is good and reconstructions are available immediately, and the report is issued immediately. It is not appropriate to delay assessment of the reconstructions.

The current position

There is now a consensus forming on how to clear the cervical spine, and as randomised, controlled trials will probably never be allowed ethically, then the pragmatic approach will prevail. The British Trauma Society, acknowledging the uncertain evidence, in 2002 emphasised the clinical evaluation in conscious cases. We also recommended three management options in the unconscious patient (Fig. 6) where, in the first two, if radiographs and targeted CT scans are normal,[26] gentle in-line handling is permitted on the intensive care unit while the patient remains unconscious, or is deeply sedated allowing the hard collar to be taken off. The collar is replaced when the sedation is reduced and the patient is re-evaluated clinically when awake. This option is preferred if the patient is unlikely to remain unconscious for more than 24 h. The second option added MRI, accepting the logistic problems associated with transporting a ventilated trauma patient. The relatively high rate of false positive rate predated the paper by Suffiadin et al. who showed that in non-trauma ligaments may not normally be visible and that to diagnose rupture both ends of the torn ligament must be seen, not simply

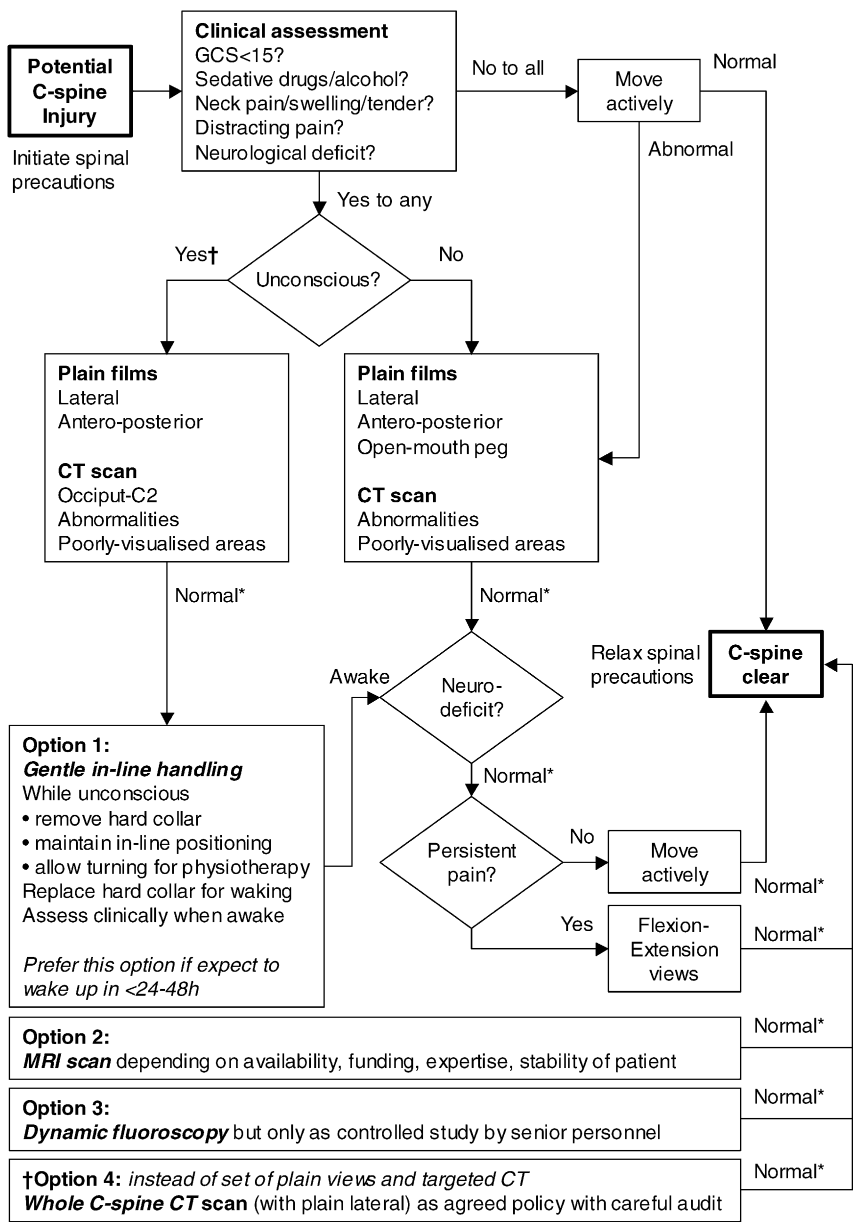


Figure 6 BTS 2002 cervical spine clearance algorithm.

the presence of haematoma/oedema.[181] In our institution I have also found these criteria of benefit as evidenced by the cases which subsequently went to surgery. The final option requires a thin-slice CT of the whole cervical spine together with a single lateral plain radiograph. A major advantage of this option is that it can be carried out conveniently before admission to the intensive care unit, at the same time as the head CT. This avoids the logistic difficulties associated with MRI and the potential risk of moving the neck to perform flexion–extension views. The last option, of dynamic fluoroscopy to clear the spine, cannot be supported.

The British Trauma Society recognised that the ideal protocol for a particular institution varies according to its status (University, DGH), location and case mix. It is wise for multidisciplinary agreement on one protocol in which the merits and risks are understood, accepted and audited.

More recently, in June 2003, NICE's Guidance on Head Injury (National Institute for Clinical Excellence, 2003)[143] reinforced the Royal College of Radiologists guidance to CT the brain down to C3 with orthogonal reconstructions set out in the 5th edition of "Making the best use of a department of radiology".[177] In 2003, the American College of Radiology reviewed practice and new guidance led by Richard H. Daffner of Allegheny General Hospital, Pittsburgh recommend for unconscious patients: an AP and lateral radiograph of the cervical spine, spiral CT of the entire cervical spine at the same time as the brain CT and use MRI for suspected ligamentous instability, if the radiographs and/or the CT were negative. He also warns caution in relation to the massive doses in relation to multislice CT even for the multiply injured patient, with CT now making up 40% of the total annual dose to the public from medical procedures.[42] The MS-CT with reconstructions remains incomplete until a report is issued, at which time the clinicians can act for the patients' best interest. In practice Dr. Daffner told the International Skeletal Society, August 2003 that this had resulted in an MRI in about 10% of cases.

Conclusions

Much has improved in recent years, both in decision-making and in the technology itself.[42,142] Conscious patients are no longer subjected to unnecessary investigation, just because spinal immobilisation has been applied by pre-hospital personnel in the field. Within the hospital, improved resolution and sensitivity of CT and MRI scanning have facilitated the definitive care of specific injuries.

This paper has inevitably focused on cervical spinal clearance in the unconscious patient. It is important to understand the balance between missing injuries, delaying diagnosis or risking secondary spinal cord damage and performing unnecessary, potentially harmful spinal precautions at unjustified cost. At the same time, the potential benefits and limitations of new imaging techniques were discussed. I strongly recommend that all unconscious patients undergoing brain CT should continue 2 mm slices reformatted at 1 mm, to incorporate the body of the axis (C2) with reconstructions in the other two planes. This document is intended to summarise the balancing demands of the clinical and radiological evaluation, to move the debate forward allowing multidisciplinary teams to evaluate and agree the best policy for their unit.

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