Radiographic Assessment

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RECOMMENDATIONS

Awake, Asymptomatic Patient

Level 1

- In the awake, asymptomatic patient who is without neck pain or tenderness, who has a normal neurological examination, is without an injury detracting from an accurate evaluation, and who is able to complete a functional range of motion examination; radiographic evaluation of the cervical spine is not recommended.
- Discontinuance of cervical immobilization for these patients is recommended without cervical spinal imaging.

Awake, Symptomatic Patient

Level I

- In the awake, symptomatic patient, high-quality computed tomography (CT) imaging of the cervical spine is recommended.
- If high-quality CT imaging is available, routine 3-view cervical spine radiographs are not recommended.
- If high-quality CT imaging is not available, a 3-view cervical spine series (anteroposterior, lateral, and odontoid views) is recommended. This should be supplemented with CT (when it becomes available) if necessary to further define areas that are suspicious or not well visualized on the plain cervical x-rays.

ABBREVIATIONS: CCR, Canadian C-Spine Rule; **CCT,** cervical computed tomography; **CSR,** cervical spine radiographs; **EAST,** Eastern Association for the Surgery of Trauma; **NEXUS,** National Emergency X-Radiography Utilization Study Group; **NLC,** NEXUS low risk category; **NPV,** negative predictive value; **PPV,** positive predictive value

Level III

- In the awake patient with neck pain or tenderness and normal high-quality CT imaging or normal 3-view cervical spine series (with supplemental CT if indicated), the following recommendations should be considered:
  1. Continue cervical immobilization until asymptomatic,
  2. Discontinue cervical immobilization following normal and adequate dynamic flexion/extension radiographs,
  3. Discontinue cervical immobilization following a normal magnetic resonance imaging (MRI) obtained within 48 hours of injury (limited and conflicting Class II and Class III medical evidence), or,
  4. Discontinue cervical immobilization at the discretion of the treating physician.

Obtunded or Unevaluable Patient

Level I

- In the obtunded or unevaluable patient, high-quality CT imaging is recommended as the initial imaging modality of choice. If CT imaging is available, routine 3-view cervical spine radiographs are not recommended.
- If high-quality CT imaging is not available, a 3-view cervical spine series (anteroposterior, lateral, and odontoid views) is recommended. This should be supplemented with CT (when it becomes available) if necessary to further define areas that are suspicious or not well visualized on the plain cervical x-rays.

Level II

- In patients in whom there is a high clinical suspicion of injury yet have a normal high-

quality CT imaging study, it is recommended that the decisions for further patient management involve physicians trained in the diagnosis and management of spinal injuries.

Level III

- In the obtunded or unevaluable patient with a normal high-quality CT or normal 3-view cervical spine series, the following recommendations should be considered:
  1. Continue cervical immobilization until asymptomatic,
  2. Discontinue cervical immobilization following a normal MRI study obtained within 48 hours of injury, (limited and conflicting Class II and Class III medical evidence), or,
  3. Discontinue cervical immobilization at the discretion of the treating physician.

- In the obtunded or unevaluable patient with a normal high-quality CT, the routine use of dynamic imaging appears to be of marginal benefit and is not recommended.

RATIONALE

Spinal cord injury is a potentially devastating consequence of acute trauma and can occur with/be exacerbated by improper immobilization of an unstable cervical spinal injury. Immobilization of an injury victim's cervical spine following trauma is a universal standard practiced by Emergency Medical Services systems and is now based on pre-hospital clinical criteria. Immobilization of the potentially injured cervical spine is maintained until spinal column injury is ruled out by clinical assessment and/or radiographic survey. Radiographic study of the cervical spine of every trauma patient is costly and results in significant radiation exposure to a large number of patients, very few of whom will have a spinal column injury. Asymptomatic trauma patients, defined by rigid clinical criteria, require no radiographic assessment irrespective of the mechanism of potential injury.

Trauma patients who are symptomatic, that is complain of neck pain, have cervical spine tenderness, have symptoms or signs of a neurological deficit associated with the cervical spine, and trauma patients who cannot be assessed for symptoms or signs (those who are unconscious, uncooperative or incoherent, intoxicated, or who have associated traumatic injuries that distract from their assessment) require radiographic study of the cervical spine prior to the discontinuation of cervical spine immobilization. Many investigators have proposed strategies and imaging techniques to accomplish x-ray clearance of the cervical spine after trauma, particularly in the symptomatic or the obtunded patient.

In 2002, the guidelines author group of the Joint Section on Disorders of the Spine of the American Association of Neurological Surgeons (AANS) and the Congress of Neurological Surgeons (CNS) published 2 medical evidence-based guidelines on the topic of imaging the cervical spine following acute blunt trauma entitled, "Radiographic Assessment of the Cervical Spine in Asymptomatic Trauma Patients" and "Radiographic Assessment of the Cervical Spine in Symptomatic Trauma Patients."[1-2] The purpose of the current review is to build on that foundation, adding pertinent new evidence on these issues generated over the past decade.

SEARCH CRITERIA

A computerized search of the database of the National Library of Medicine (PubMed) between 1966 and 2011 was conducted using the search terms "spinal cord injury" or "spinal fractures" or "spinal injuries" and resulted in 30 238 references. A similar search was conducted with search terms "clearance" or "diagnosis" or "radiographs" that provided 23 005 577 citations. Combining these 2 searches using "and" gave 6399 references. The search was limited to the English language and human subjects. This resulted in 4942 citations. The titles and abstracts of these references were reviewed. Studies that investigated the diagnostic potential of an imaging technique to assess cervical trauma were selected. Additional articles were obtained from the bibliographies of selected manuscripts. Thirty-two manuscripts were identified that provided either direct or supporting medical evidence on the diagnostic potential of cervical spinal imaging modalities. In general, priority was given to large (greater than 100 patients) prospective studies, meta-analyses, and articles published since the previous iteration of this guideline. Fifteen articles addressing cervical spinal imaging in asymptomatic trauma patients, 25 references addressing imaging in symptomatic patients, and 20 references addressing imaging in the obtunded patient are summarized in Evidentiary Table format (Tables 3-5).

SCIENTIFIC FOUNDATION

In 2002, the guidelines author group of the Joint Section on Disorders of the Spine and Peripheral Nerves of the American Association of Neurological Surgeons and the Congress of Neurological Surgeons published 2 medical evidence-based guidelines on the topic of radiographic assessment of the cervical spine following acute trauma.[1,2] Based on 8 Class I medical evidence studies, diagnostic standards (Level I) were recommended at a high level of medical certainty that for asymptomatic patients, the "Radiographic assessment of the cervical spine is not recommended for trauma patients who are awake, alert, and not intoxicated, who are without neck pain or tenderness, and who do not have significant associated injuries that detract from their general evaluation." For all other patients (symptomatic) medical evidence-based diagnostic standards (Level I) recommendations were offered: "A 3-view cervical spine series (AP, lateral, and odontoid views) is recommended for the radiographic evaluation of the cervical spine in patients who are symptomatic after traumatic injury. This should be supplemented with CT to

further define areas that are suspicious or not well visualized on the plain cervical x-rays." Further, option or Level III recommendations based on Class III medical evidence were offered suggesting that "cervical spine immobilization in awake patients with neck pain or tenderness and normal cervical spine x-rays (including supplemental CT as necessary) be discontinued after either, (1) normal and adequate dynamic flexion/extension radiographs, or (2) a normal MRI study obtained within 48 hours of injury. For obtunded patients, Class III medical evidence supported the recommendation that "Cervical spine immobilization in obtunded patients with normal cervical spine x-rays (including supplemental CT as necessary) may be discontinued (1) after dynamic flexion/extension studies performed under fluoroscopic guidance, (2) after a normal MRI study is obtained within 48 hours of injury, or (3) at the discretion of the treating physician." These 3 clinical scenarios following trauma (asymptomatic, symptomatic, and the obtunded patient) are the focus of this update on the medical evidence on this important topic.

In 2009, the Eastern Association for the Surgery of Trauma (EAST) published an updated medical evidence review on the identification of cervical spinal injuries following trauma.[3] The authors utilize a 3-tiered system of medical evidence and linked their recommendations to the quality of the medical evidence reported in the world's literature. Fifty-two articles were selected for inclusion. The EAST author group concluded that Class I medical evidence indicates CT has become superior to plain radiography as the primary imaging modality of the cervical spine for acute trauma patients who required cervical imaging. A detailed review of the updated EAST recommendations suggest that the methodology used by the EAST author group is better suited to assess a therapeutic intervention, rather than to evaluate the validity and accuracy of a diagnostic test, which requires a different set of medical evidence criteria.[4,5] The current effort to update the medical evidence of these 2 guidelines consider radiographic imaging of the cervical spine in acute trauma patients to be a diagnostic test. Appropriate, distinct, and specific medical evidence grading criteria for a diagnostic test have been applied.

Since the original evidence-based medicine guideline produced on the issue of radiographic assessment of the asymptomatic patient in 2002, four clinical studies and a recent meta-analysis have been published. These citations provide Class I and Class II medical evidence in support of the original Level I recommendation that truly asymptomatic patients require no cervical spinal imaging after trauma.

In 2001, Stiell et al[6] published a study of 8924 awake blunt trauma patients treated in 10 large Canadian medical centers. The investigators evaluated 20 different standardized clinical findings in an attempt to create a valid decision-making rule sensitive for detecting acute cervical spinal injuries, therefore allowing the selective use of radiography in alert trauma patients. The reported incidence of a significant cervical spinal injury was 1.7%. The resultant Canadian C-Spine Rule (CCR) utilizes 3 questions: (1) presence of a high-risk factor that mandates radiography (ie: age 65 years or older, dangerous mechanism of injury, or paresthesias in extremities), (2) presence of a low-risk factor allowing safe assessment of range of motion (ie: simple rear-end motor vehicle collision, sitting position in ED, ambulatory at any time following injury, delayed onset of neck pain, or absence of midline C-spine tenderness), and (3) ability to actively rotate neck 45° to the left and right. Use of the CCR resulted in 100% sensitivity for a significant cervical spinal injury, (95% confidence interval [CI], 98%-100%) and 42.5% specificity (95% CI, 40%-44%).[6]

The largest series referenced in the previous version of this guideline was published by Hoffman et al[7] in 2000 and generated decision-making rules subsequently referred to as the NEXUS (National Emergency X-Radiography Utilization Study Group) criteria. This study involved the prospective study of 34 069 blunt trauma patients of which 4309 were asymptomatic. All patients underwent standard 3 view cervical spinal radiographs supplemented with CT as needed. Five criteria had to be met in order to be classified as having a low probability of injury: no midline cervical tenderness, no focal neurologic deficit, normal alertness, no intoxication, and no painful, distracting injury. These criteria correctly identified 810 of the 818 patients who had a cervical spinal injury (true positives), resulting in a sensitivity of 99.0%, a specificity of 12.9%, a negative predictive value (NPV) of 99.8% and a positive predictive value (PPV) of 2.7%. Only 2 patients were misclassified as unlikely to have an injury and had a clinically significant injury (false negatives) for a calculated sensitivity of 99.6%, a specificity of 12.9%, a NPV of 99.9% and a PPV of 1.9%. Only 1 of these 2 patients required surgical treatment for a C6 laminar fracture with delayed onset paresthesias. The other missed injury required no treatment.

In 2003, Stiell et al[8] conducted a prospective cohort study comparing the Canadian C-spine rule (CCR) vs the NEXUS criteria. Three hundred and ninety-four physicians evaluated 8283 patients prior to radiographic imaging, 169 of which had clinically significant cervical spinal injuries (2%). Application of the CCR resulted in 1 missed patient injury. Use of the NEXUS low risk criteria (NLC) resulted in 16 missed cervical spinal injuries, 4 of which were unstable. In this Class I medical evidence study, Stiell et al[8] found the CCR was statistically significantly more sensitive than the NEXUS criteria in the detection of a significant cervical spinal injury. Of interest, the application of the CCR rather than the NEXUS criteria would have resulted in significantly lower radiography rates (55.9% vs 66.6%, $P < .001$, see Table 1).

In 2010, Anderson et al[9] produced a meta-analysis of 14 Class I medical evidence studies published between 1966 and 2004.[6-8,10-20] The authors' inclusion criteria were: (1) a prospectively applied protocol; (2) reported outcomes to allow calculation of sensitivity, specificity, NPV, and PPV; and (3) follow-up to determine the status of potential missed injuries with minimum of a 2-week telephone call or a follow-up CT scan. The 3 senior authors each independently confirmed the validity of the included articles and independently verified each publication's analysis as well as extraction of true-positive, true-negative, false-

positive, and false-negative numbers. Original scale and log odds meta-analysis were performed. Sensitivity, specificity, PPV, and NPV were calculated using random effects methodology. The 14 studies that met these rigid inclusion criteria correctly identified the 3.7% of alert trauma patients who had confirmed cervical spinal injuries (PPV, 3.7%). They missed the 0.2% of patients who had acute injuries who should have had cervical radiography performed (NPV, 99.8%). The random effects model used in the meta-analysis resulted in a collective sensitivity of 0.981 (98.1%) and a specificity of 0.354. The authors concluded that the alert, asymptomatic patient without a neurologic deficit who can complete a functional range-of-motion examination and is free from other major distracting injury may safely be released from cervical spine immobilization without radiographic evaluation, with a sensitivity of 98.1% and a NPV of 99.8%. Additional supporting data is provided in Table 3.[77-81]

Awake Symptomatic Patient

In the previously produced 2002 guideline on the topic of Radiographic Assessment of the Symptomatic Patient, the author group concluded that a 3-view cervical spine series (AP, lateral, and odontoid views) was recommended for radiographic evaluation of the cervical spine in patients who are symptomatic after traumatic injury (Standard or Level I recommendation based on Class I medical evidence). Class I medical evidence suggests that those studies should be supplemented with CT as necessary, to define areas that are suspicious or not well-visualized on the plain cervical x-rays. These recommendations were based in part on a series of high quality articles considered to provide Class I medical evidence for diagnostic testing. The combined series of Berne et al,[21] Ajani et al,[22] Davis et al,[23] and MacDonald et al[24] included 1049 trauma patients evaluated with 3-film radiography. The sensitivity of the 3-film technique for fracture detection in these series ranged from 60% to 84%. The NPV ranged from 85% to 98%, increasing to 100% with the addition of dynamic studies. The current update on the topic of radiographic assessment of the symptomatic patient following acute trauma will focus on the increasing reliance on CT rather than plain radiography to assess the cervical spine (see Table 2 for comparison).

In 2005, Holmes and Akkinepalli[25] published a meta-analysis of studies comparing CT and plain radiographs in detecting cervical spinal injuries in patients predetermined to require imaging by clinical criteria. The authors included 7 studies, including 5 graded to provide Class III medical evidence and 2 to provide Class IV medical evidence on a 4-tiered evidence grading scale.[21,26-31] They failed to utilize an appropriate assessment scheme for a diagnostic test, and instead attempted to find randomized studies to provide Class I medical evidence. They did prioritize prospective data collection, an adequate study population, and the use of gold standards. The pooled sensitivity of plain radiographs for detecting cervical spinal injury in their analysis was 54% compared to 98% for CT. This study provides supporting Class III medical evidence that CT may be superior to plain radiographs to detect cervical spinal injury following trauma.

In 2009, Bailitz et al[32] published a prospective, comparative study of cervical spine radiographs (CSR) with cervical CT (CCT) to detect cervical spinal injury after trauma. The study assessed awake adult patients who had sustained blunt trauma who met 1 or more of the NEXUS criteria for spinal assessment following acute trauma. Three-view CSR and CCT were obtained in a standard protocol. Each CSR and CCT study was interpreted independently by a different blinded radiologist. Clinically significant injuries were defined as those requiring 1 or more of the following interventions: operative procedure, halo application, and/or rigid cervical collar. The entire data set included 1583 patients, but 78 patients (4.9%) were excluded due to lack of complete studies. The remaining 1505 patient data set contained 78 with a cervical spinal injury determined by 1 or both radiographic assessment methods. The sensitivity of CCT was 100% compared to 36% for CSR. The authors conclude that CT is significantly superior to plain film radiography for the initial evaluation of cervical spinal injuries following trauma and should be the imaging modality of choice. Their study provides Class I medical evidence for a diagnostic test.

In 2007, Mathen et al[33] published a prospective Class I medical evidence study of 667 acute trauma patients including 60 patients with cervical spine injuries (9% of total) all evaluated with both cervical spine films and CT. CT had a sensitivity of 100% and a specificity of 99.5%. Plain films had a sensitivity of 45% and a specificity of 97.4%. Plain films missed 15 of 27 clinically significant cervical spinal injuries (55.5%). The authors concluded that CT is superior to plain spine films in the acute setting, and that plain films add no significant information to a high quality CT.

Griffen et al[28] in 2003 studied a series of 1199 acute trauma patients at risk for a cervical spinal injury who had both plain films and CT studies. There were 116 cervical spine injuries detected. All were identified by CT (sensitivity = 1.00, 100%; NPV = 1.00). Plain radiographs detected only 75 of the injuries (sensitivity = 0.64, 64%; NPV = 0.96). The authors summarized previous published studies comparing the sensitivity of CT to the sensitivity of plain films to detect cervical injury after blunt trauma.

Combining the patients from these series resulted in a total patient population of 3034. Ten percent were found to have cervical spinal injuries (309). The combined sensitivity of plain films was 53%. The combined sensitivity of CT was of 98%. This study and review provides Class I medical evidence on the superiority of CT for the assessment of cervical spinal injuries after trauma.

In 2001, Schenarts et al[30] published a large prospective series evaluating the role of cervical CT in their blunt trauma population. They reported on 2690 consecutive blunt trauma admissions. They applied the EAST recommendations to determine which patients should be studied radiographically to assess for potential cervical spinal injuries. This latter group consisted of 1356 patients who had experienced blunt trauma, many of whom were going to have CT studies performed on other body regions (ie, head injury, abdominal injury). All were assessed with 5-view cervical spine

x-rays. There were 70 cervical spine injuries detected (incidence 5.2%). CT detected 67 of the 70 injuries (sensitivity 96%). Five-view plain films detected 38 of the 70 injuries (sensitivity 54%). The authors concluded that the use of the EAST guidelines for clearance of the cervical spine correctly identified all injuries in their study population. They found CT was superior to plain films in the evaluation of acute cervical trauma.

Daffner et al[34] published a retrospective analysis of 5172 trauma admissions and identified 297 cervical fractures (5.4%). Of these, 245 were identified to have had both plain films and CT performed. CT identified 243 of the 245 fractures (sensitivity 0.992, 99.2%). Comparatively, plain films identified only 108 fractures (sensitivity 0.441, 44.1%). Their 2006 study is considered to provide Class III medical evidence due to the loss of subjects (17.5%) and its retrospective nature. Of note is that the 2 fractures missed on CT were readily identified on plain films. The authors recommended that lateral plain films be included with CT to assess for cervical spinal injury after trauma. Both fractures missed by CT involved the C2 spinous process; 1 was obscured by dental work and the other was in the plane of the scan. The Daffner et al study highlights the need for ensuring that the cervical imaging utilized to assess the cervical spine adequately visualizes the region of interest, regardless of the specific imaging modality employed, but fails to provide medical evidence for the utility of plain films to supplement CT in this setting.

In addition to CTs superior sensitivity in fracture detection, authors have reported on other advantages of CT over plain radiography in the acute trauma setting. Daffner et al[35,36] published a series of studies evaluating the efficiency of plain radiographs compared to CT, and found that the average time involved to obtain a cervical CT scan was 11 to 12 minutes, approximately half the time required to obtain a full radiographic series of the cervical spine. Blackmore et al[37] performed a cost-effectiveness analysis for high risk subjects and concluded that the higher short-term cost of CT would be offset by the increased sensitivity of CT for fracture detection, the shortened time required for the evaluation, and a decreased need for additional imaging.

Symptomatic Patient With Negative Initial Imaging.

The author group of the previous guideline published on this topic in 2002 recommended that cervical spinal immobilization could be discontinued in the awake but symptomatic patient with normal radiographic studies supplemented by thin section CT as indicated, following either normal flexion and extension radiographs or a normal MRI obtained within 48 hours of injury. Based on Class III medical evidence, the NPV of normal 3-view plain films supplemented with flexion and extension x-rays ranged from 93% to 100%,[23,24,38-41] and the NPV of an MRI obtained within 48 hours of injury ranged from 90% to 100%. Several studies evaluating cervical MRI in the acute trauma setting suggested that no significant injuries occurred in the setting of a normal MRI.[21,22,42-44] Isolated cases in which significant injuries were not detected by MRI have raised concerns and prompted additional study.[45,46]

Studies published since the previous guidelines have focused on the role of dynamic imaging and/or MRI in assessment of symptomatic trauma patients with negative initial radiographs or CT imaging, in an attempt to define which patients require continued spinal immobilization. The studies are varied in their comparison groups and in the level of medical evidence they provide. The report by Duane et al[47] provides Class II medical evidence that MRI is significantly more sensitive than dynamic films, but the Class III medical evidence study by Schuster et al[48] concludes that the routine use of MRI is of minimal benefit in detecting additional injury. Class II evidence published by Pollack et al[49] and Class III medical evidence offered by Insko et al[50] indicate that dynamic films are of limited benefit in detecting additional injuries when the clinical exam and CT imaging are normal.

In 2010, Duane et al[47] published the only investigation to date directly comparing dynamic imaging to MRI in this patient population. Their study evaluated 22 929 trauma patients, among whom 271 patients were studied with dynamic imaging, 49 of whom were also assessed with MRI. MRI identified 8 patients with ligamentous injury. Flexion and extension radiographs failed to identify any of the 8 ligamentous injuries identified on MRI. When comparing dynamic studies to MRI (these authors considered MRI to be the gold standard for ligamentous injuries), the sensitivity of dynamic films was 0.0%, the specificity was 98%, the PPV was 0%, and the NPV was 83%. Flexion and extension studies were incomplete in over 20.5% of the patients and ambiguous in another 9.2%. The authors concluded that due to the often incomplete or ambiguous results with dynamic imaging and the inability of flexion and extension radiographs to identify many potential ligamentous injuries, MRI be used in the relatively infrequent situation of a suspected cervical spinal ligamentous injury following trauma when the initial radiographs or CT images did not identify a fracture injury. This study offers a select few patients for comparison. The choice of MRI as the "gold standard" for ligamentous injury likely leads to a false endpoint. MRI has not been proven to represent the gold standard for ligamentous injury in the literature, and is associated with a high number of false-positive findings.

In 2005, Schuster et al[48] reported a prospective study examining the role of MRI in excluding significant injury in the symptomatic patient with a normal motor exam and a normal CT evaluation of the cervical spine following acute trauma. The study population included 2854 patients. Ninety-three patients had a normal admission motor examination yet persistent cervical spine pain. All underwent MRI examination and all were negative for a clinically significant injury. Seventeen patients had MRI studies that revealed pre-existing degenerative cervical spondylosis, and 6 had spinal canal stenosis secondary to ossification. The authors concluded that patients with a normal motor exam and normal CT of the cervical spine do not require MRI imaging in order to exclude a significant cervical spinal injury. The Class II medical evidence offered in this publication is in conflict with the Class II medical evidence provided by Duane et al[47] in 2010.

TABLE 1. Comparison of Canadian C-Spine Rule With the National Emergency X-Radiography Study Group Criteria for Low-Risk Criteria[a]

	Sensitivity	Specificity	
CCR	99.4%	45.1%	$P < .001$
NLC	90.7%	36.8%	$P < .001$

[a]CCR, Canadian C-Spine Rule, NLC, National Emergency X-Radiography Utilization Study Group low risk criteria.

Pollack et al[49] reported a large multicenter prospective study evaluating the role of dynamic plain films to supplement the standard 3-view radiographic evaluation of the cervical spine in the acute trauma setting. Twenty-one centers participating in the NEXUS project entered patients who had standard 3-view radiographs, as well as any other imaging deemed necessary by their physicians. Eight hundred and eighteen patients were diagnosed with a cervical spinal injury, of which 86 (10.5%) underwent dynamic imaging. Two patients (2.3%) had injuries detected only on dynamic imaging. The authors concluded that dynamic imaging added little to the acute evaluation of patients suspected to have sustained cervical spinal trauma. This study provides Class II medical evidence on this topic.

In 2002 Insko et al[50] published a retrospective review of 106 consecutive trauma patients in whom flexion and extension radiographs were obtained in the acute trauma setting. Nine patients were identified who had cervical spinal injuries. Only 74 patients (70%) had a range of flexion and extension felt to be adequate for diagnostic purposes. Five of the 74 patients with acceptable range of motion had cervical spinal injuries (6.75%). There were no missed ligamentous injuries in this group. Thirty-two of the flexion and extension examinations (30%) were inadequate because of limited motion. Four of the 32 patients with inadequate range of motion on dynamic x-rays were diagnosed with a significant injury either by CT or MRI (12.5%). The authors stressed the need for adequate and complete dynamic studies if they are to be used for diagnostic purposes. If adequate range of motion is not possible, they suggest MRI should be considered to assess for ligamentous injury.

Sanchez et al[51] instituted a single institution protocol to assess and image patients as indicated following trauma. They performed cervical helical CT imaging on patients who could not be cleared clinically. Patients with a neurological deficit underwent MRI, but patients with no focal deficit and a normal CT scan were cleared. Prospective data were collected on 2854 trauma patients. One hundred patients had cervical spine or spinal cord injuries, of which 99 were identified by their sequential protocol. The 1 missed patient had pre-existing syringomyelia. Fifteen percent of patients with neurological deficits of spinal cord origin had no imaging abnormality. The authors reported that their combination protocol of clinical exam, helical CT, and MRI had a sensitivity of 99% and a specificity of 100%. Their study provides a rational approach to the assessment for the potential of a cervical spinal injury following trauma, and provides Class II medical evidence. Additional supporting data is provided in Table 4.[82-85]

TABLE 2. Detection of Cervical Spinal Injury Following Blunt Trauma

Author Group	Sensitivity of Plain Films	Sensitivity of Computed Tomography
Nuñez et al[29]	37.5%	100%
Berne et al[21]	60%	90%
Schenarts et al[30]	54%	96%
Griffen et al[28]	64%	100%

Obtunded or Unevaluable Patient

The previous guideline author group recommended that in the obtunded or unevaluable patient who had normal radiographic studies of the cervical spine, cervical immobilization could be discontinued under the following conditions: normal dynamic imaging, normal MRI within 48 hours of injury, or at the discretion of the treating physician. These recommendations were based on Class III medical evidence provided in the literature through 2001 that indicated that in the obtunded patient with a normal 3-view x-ray series of the cervical spine supplemented with CT (as necessary), the incidence of a significant cervical spinal injury was less than 1%.[21] Flexion/extension studies could be performed under fluoroscopy safely, and could effectively rule out a significant ligamentous injury (reported NPV of over 99%).[23] A negative MRI within 48 hours of injury appeared to exclude the presence of a significant ligamentous injury. In selected patients, based upon normal radiographic imaging, the mechanism of injury, and clinical judgment, the cervical spine could be considered stable without further study.[39]

Of all the clinical issues associated with the radiographic assessment of the cervical spine, the issue of clearing the cervical spine in the obtunded or unevaluable patient has received the most attention and remains the issue of the greatest uncertainty. The role of CT as a replacement for plain radiographs has been the subject of active research in this select patient population, as has the role of dynamic imaging. The increasing use of MRI to exclude significant cervical ligamentous injury in the otherwise unevaluable patient has also been an active area of investigation. The following section will review the recent literature on plain films, CT, dynamic imaging, and MRI and their application to the obtunded/unexaminable acute trauma patient.

Plain Films and CT

In 2003, Diaz et al[27] published a prospective series of 1006 trauma patients with altered mental status evaluated with both plain films and CT imaging scanning. One hundred seventy-two cervical spinal injuries were identified. CT had a sensitivity of 97.4%, a specificity of 100%, a PPV of 100%, and a NPV of

TABLE 3. Evidentiary Table: Radiographic Assessment: Asymptomatic[a]

Citation	Description of Study	Evidence Class	Conclusions
Anderson,[9] *J Orthop Trauma,* 2010	Meta-analysis of 14 articles that addressed asymptomatic patients and discontinuance of cervical spine immobilization without radiographic evaluation.	I	Sensitivity 98.1%
	Inclusion criteria: prospective study, outcomes reported to allow calculation of sensitivity sensitivity, specificity, NPV, and PPV, and included clinical follow-up.		NPV 99.8%
			Alert, asymptomatic patient with no distracting injury, no neurologic deficit and able to complete a functional range-of-motion examination can safely have cervical spine immobilization precautions removed without radiographic evaluation
Duane,[77] *J Trauma,* 2007	Prospective study 534 blunt trauma patients comparing the reliability of the clinical examination (CE) with CT to identify cervical spine fracture.	II	The authors concluded that even with a normal Glasgow Coma Score, the CE alone does not provide sufficient sensitivity or NPV to exclude cervical spine fracture
			Downgraded to Class II medical evidence
			CE is not known to be reliable or valid. A smaller more restricted population involved in this study than other similar studies. This article stands alone in contrast to other larger studies addressing criteria for imaging in the asymptomatic patients.
Stiell,[8] *N Engl J Med,* 2003	Prospective study of 8283 alert stable trauma patients including 169 with cervical spine injuries comparing CCR and the NEXUS Low-Risk Criteria (NLC) in 9 Canadian emergency departments.	I	Sensitivity for injury: CCR 99.4%, NLC 90.7% ($P < 0.001$)
			Specificity for injury: CCR 45.1%, NLC 36.8%, $P < 0.001$.
			For alert stable trauma patients, the CCR is significantly more sensitive and specific than the NLC.
Stiell,[6] *JAMA,* 2001	Prospective cohort study of 8924 stable awake adult trauma patients including 151 with a cervical spine injury evaluating 20 standardized clinical findings prior to radiographic imaging to determine those findings most sensitive in identifying cervical spine fracture. This study defines the CCR.	II	The CCR is a highly sensitive decision rule for determining the need for imaging in suspected cervical spine trauma
			Class II because validation is not included in this study
Hoffman,[7] *N Engl J Med,* 2000	Prospective study of 34 069 patients including 4309 asymptomatic and 2 with clinically significant injuries.	I	NPV of 99.9%
			Radiographs not necessary in asymptomatic patients

(Continues)

TABLE 3. *Continued*

Citation	Description of Study	Evidence Class	Conclusions
Gonzalez,[12] *J Am Coll Surg,* 1999	Prospective diagnostic study of 2176 patients including 33 with a significant cervical spine injury evaluating the diagnostic potential of clinical exam and lateral radiography.	I	Clinical examination of the neck can reliably rule out significant cervical spine injury in the awake and alert blunt trauma patient
			Addition of lateral c-spine x-ray does not improve the sensitivity of clinical examination in the diagnosis of significant cervical spine injury
Roth,[18] *Arch Surg,* 1994	Prospective study of 682 patients admitted to ED with trauma; 96 were asymptomatic, none had injury.	I	NPV of asymptomatic exam: 100%
			PPV of symptomatic exam: 2.7
			Radiographs not necessary in asymptomatic patients
Hoffman,[13] *Ann Emerg Med,* 1992	Prospective study of 974 blunt trauma patients including 353 alert, asymptomatic patients.	I	NPV of asymptomatic exam: 100%
			PPV of symptomatic exam: 4.5%
			Asymptomatic patients do not require cervical spine films
Ross,[78] *Injury,* 1992	Prospective study of 410 patients	I	NPV: 100%
			PPV: 6.1%
	Including 196 asymptomatic patients.		Radiography not mandatory for asymptomatic patients
			Mechanism of injury is not a valuable predictor of injury
McNamara,[79] *J Emerg Med,* 1990	Retrospective review of 286 patients judged to be "high risk" by mechanism of injury:	III	NPV for asymptomatic exam was 100%
	• 178 were asymptomatic		PPV for symptomatic exam was 4.9%
	• 108 were symptomatic		CSR not necessary in asymptomatic patients
			Class III because many patients excluded
Bayless,[80] *Am J Emer Med,* 1989	Prospective study of 211 patients, including 122 alert asymptomatic patients.	I	NPV of asymptomatic exam: 100%
			PPV of symptomatic examination: 3%
			Asymptomatic patients do not require cervical spine films
Kreipke,[14] *J Trauma,* 1989	Prospective study of 860 patients including 324 asymptomatic.	I	NPV of asymptomatic exam: 100%
			PPV of symptomatic exam: 4%
			Radiographs not necessary in asymptomatic patients
Mirvis,[81] *Radiology,* 1988	Prospective study of 408 patients comparing radiographs and CT.	II	NPV of asymptomatic exam 99.3 to 100%
			PPV of symptomatic exam 12.6%
			Radiographs may not be unnecessary in asymptomatic patients
			Class II due to unclear "gold standard"
Neifeld,[15] *J Emerg Med,* 1988	Prospective study of 886 patients	I	NPV 100%
			PPV: 6.2%
	Including 244 asymptomatic patients.		Asymptomatic patients do not require radiographs
Roberge,[17] *J Trauma,* 1988	Prospective study of 467 trauma including 155 asymptomatic patients.	I	NPV of asymptomatic exam: 100%
			PPV of symptomatic exam: 2.5%
			Asymptomatic patients do not require radiographs

TABLE 4. Evidentiary Table: Radiographic Assessment: Symptomatic[a]

Citation	Description of Study	Evidence Class	Conclusions
Duane,[47] *Am Surg,* 2010	22 929 trauma patients identifying 271 patients with dynamic imaging 49 of which were also imaged with MRI. Only study identified that directly compares dynamic imaging with MRI. Evaluated flexion/extension as a diagnostic test.	I	Sensitivity was 0.0%Specificity was 98% PPV was 0% NPV was 83%
	Gold standard for ligamentous injury was MRI.		MRI is more sensitive and specific than flexion/extension films for detecting ligamentous injury
	Flexion/extension films failed to identify any of the 8 ligamentous injuries.		Class III medical evidence. MRI not "gold standard," likely false endpoint
Bailitz,[32] *J Trauma* 2009	Prospective study of 1505 patients including 50 with clinically significant injuries comparing plain film with CT in blinded fashion. Blinded comparison of 3-view radiographs and cervical CT.	I	CT 100% sensitive
	NEXUS criteria used for initial diagnosis.		Plain films 36% sensitive ($P<0.05$)
			CT is significantly more sensitive than three view plain films for detecting clinical significant cervical spine injury
Mathen,[33] *J Trauma,* 2007	Prospective study of 667 trauma patients including 60 patients with cervical spine injuries comparing plain films and CT.	I	CT
			Sensitivity 100%
			Specificity 99.5%
			Plain films:
			Sensitivity 45%
			specificity 97.4%
			Plain films add no significant information to a high quality CT study
Daffner,[34] *Injury,* 2006	Retrospective cohort study of 5172 trauma admissions including 297 cervical fractures comparing plain films and CT.	II	Sensitivity:
			CT 99.2%
			Plain film 44.1%
			Lateral plain films can identify fractures not noted on CT
			Class II due to number of patients excluded and incomplete data
Holmes,[25] *J Trauma,* 2005	Meta-analysis of studies addressing 3-view radiographs and cervical CT.	Meta-analysis Class III	Sensitivity:
			CT 98%
			Plain films 52%
			CT more sensitive for detection of significant cervical spine injury
Sanchez,[51] *J Trauma,* 2005	Prospective study of 2854 trauma patients imaged per protocol with exam, CT and MRI.	II	Sensitivity was 99%
			Specificity was 100%
			Protocol of exam, CT and MRI has high sensitivity and specificity

(Continues)

TABLE 4. *Continued*

Citation	Description of Study	Evidence Class	Conclusions
Schuster,[48] *Arch Surg,* 2005	Prospective study of 2854 patients including 93 symptomatic with a normal exam comparing CT and MRI.	II	Patients with a normal motor exam and normal CT of the cervical spine do not require MRI imaging in order to exclude significant injury
			Class II as limited population and number excluded not stated
Griffen,[28] *J Trauma,* 2003	Prospective study comparing plain films and CT.	I	Sensitivity:
			CT 100%, Plain radiographs 64%
			NPV:
			CT100%, Plain films 96%.
			CT is superior to plain films
Insko,[50] J Trauma, 2002	Retrospective review of 106 patients evaluated with flexion/extension films	III	Flexion/extension films were of limited value due to inadequate motion on a significant number of studies
Schenarts,[30] *J Trauma,* 2001	Prospective study evaluating the role of cervical CT scanning in their trauma population.	I	Sensitivity:
			CT 96%, Plain films 54%
			CT was superior to plain films in the evaluation of early cervical trauma
Pollack,[49] *Ann Emerg Med,* 2001	Prospective study of 818 patients evaluating the role of dynamic plain films supplementing standard 3 view radiographic evaluation in the acute trauma setting.	II	Dynamic imaging adds little to the acute evaluation of cervical trauma
Berne,[21] *J Trauma,* 1999	Prospective study comparing plain films and CT.	I	Plain films:
			Sensitivity 60%, PPV of 100%, NPV of 85%
			CT:
			Sensitivity 90%, Specificity 100%, PPV of 100%, NPV of 95%
			CT more sensitive and more specific than plain films
Katzberg,[82] *Radiology,* 1999	Prospective study of 199 patients who underwent MRI in addition to standard radiographic study.	III	MRI detected injuries in a higher fraction of these patients than did conventional radiographs and CT
			Class III as no Gold Standard and inclusion criteria not clear
Klein,[44] *Spine,* 1999	Retrospective review of 32 patients with 75 known spine fractures evaluating MRI.	II	MRI not good for evaluating bony pathology
			Class II as a restricted population.
Tan,[83] *J Spinal Disord,* 1999	Retrospective review of 360 patients treated for blunt injury who underwent 3 view C-spine films supplemented with CT.	III	CT able to detect fractures missed by plain films
Ajani,[22] *Anaesth Intensive Care,* 1998	Prospective study of 100 consecutive patients evaluating 3-view radiographs.	I	PPV 45%
			NPV 98.9%
			Three-view radiographs have a high NPV
Emery,[43] *J Spinal Disord,* 1998	Prospective study of 37 patients with known spine injuries evaluated with MRI.	II	Sensitivity 89.5%
			PPV 100%

(Continues)

TABLE 4. ***Continued***

Citation	Description of Study	Evidence Class	Conclusions
			NPV 90%
			Class II as a restricted population
Davis,[23] *J Trauma,* 1995	Prospective study of 116 patients with GCS<13 and normal radiographs evaluated with flexion/extension views under fluoro evaluating plain films vs flexion/extension films as Gold standard for injury.	I	NPV 100%
			Flexion/extension films able to exclude significant injury
Borock,[84] *J Trauma,* 1991	Prospective study of 179 symptomatic patients with equivocal screening underwent CT to evaluate cervical spine.	II	PPV of 72%
			NPV of 97.6%
			Class II as questionable false endpoint
Cohn,[85] *J Trauma,* 1991	Prospective study of 60 patients prospectively studied with lateral film and full 5-view series.	II	Lateral view PPV 100%NPV 94%Sensitivity 57%
			Class II as questionable false endpoint
Lewis,[40] *Ann Emerg Med,* 1991	Retrospective review of 141 patients with flexion/extension films performed after 3-view series was normal.	II	Plain films vs flexion/extension vs plain films:
			Sensitivity 71% vs 99%, Specificity 89% vs 89%, NPV 93% vs 93%, PPV 67% vs 99%
MacDonald,[24] *J Trauma,* 1990	Prospective study of 775 patients with 3 views compared to Gold standard of all other studies performed and clinical outcome.	I	Three view series:
			Sensitivity: 83%
			Specificity: 97%
			PPV: 81%
			NPV: 98%
Freemyer,[86] *Ann Emerg Med,* 1989	Prospective study of symptomatic patients imaged with 5-view series compared to 3 with CT as Gold standard.	II	Three views adequate to visualize fractures in symptomatic patients
			Class II due to restricted population

99.7%. By comparison, plain cervical spine films had a sensitivity of 44.0%, a specificity of 100%, a PPV of 100%, and a NPV of 93.2%. Five-view plain films failed to identify 52% of the cervical spine fractures identified by CT imaging.

Widder et al[31] conducted a prospective blinded study in obtunded ventilated patients comparing the role of plain radiography and CT. In their 2004 report, the sensitivity of plain films in detecting cervical spinal injuries was 39% compared to 100% sensitivity of CT imaging.

In 2005, Brohi et al[52] reported on 437 unconscious intubated patients, including 61 with cervical spinal injuries, 31 of which were considered unstable (7%). The sensitivity of CT was 98.1%, with a specificity of 98.8%, and a NPV of 99.7%. CT detected all unstable injuries. In contrast, lateral cervical spine films detected only 14 unstable injuries and had a sensitivity of 53.3%.

Dynamic Imaging

The role of dynamic imaging in the obtunded patient remains controversial. In a recent study, Hennessey et al[53] in 2010 described a prospective study of consecutive trauma admissions over a 4-year period. Included in their analysis were 402 patients who underwent both CT and dynamic imaging of the cervical spine for suspected cervical spinal injuries. The authors identified 1 case (0.25%) that was negative on CT imaging yet positive on flexion and extension x-rays. Flexion and extension x-rays were used as the comparative gold standard. The reported sensitivity of CT was 99.75%. The authors concluded that routine flexion/extension studies were not necessary in the presence of normal CT imaging. The use of flexion/extension as a gold standard (likely false endpoint) and the lack of rigorously defined inclusion

TABLE 5. Evidentiary Table: Radiographic Assessment: Obtunded[a]

Citation	Description of Study	Evidence Class	Conclusions
Duane,[47] *Am Surg,* 2010	Retrospective review of 22x2009;929 blunt trauma patients who had both FE and MRI of the cervical spine performed.	II	MRI imaging should be used rather than flexion/extension radiographs to diagnose ligamentous injury. MRI should be used when there is high clinical suspicion of injury
			Class II as inclusion for imaging not defined
Hennessy,[53] *J Trauma,* 2010	Prospective study of 402 obtunded trauma patients comparing CT vs dynamic radiographs.	II	Sensitivity of CT 99.75%
			CT is more sensitive than flexion/extension films
	Only 1/402 (0.25%) missed fracture by CT that was detected by FE films.		Class II as inclusion criteria not clear
Menaker,[74] *Am Surg,* 2010	Retrospective review of 213 trauma patients evaluated with 40-slice CT vs MRI.	III	MRI changed clinical practice in 17.8% of all patients
	Determine how often MRI altered the management of patients with a negative CT.		MRI still required despite advancements in CT technology
Schoenfeld,[69] *J Trauma,* 2010	Meta-analysis of 11 studies considered Class I by authors including 1550 patients with a negative cervical CT scan subsequently imaged with MRI.	II	Reliance on CT imaging alone to "clear the cervical spine" after blunt trauma can lead to missed injuries
			The addition of MRI in evaluating patients who are obtunded, or unexaminable, despite a negative CT scan is recommended
	Q-statistic *P* value for heterogeneity was 0.99.		Class II as studies not all with same endpoints and variability in study design
Simon,[73] *J Trauma,* 2010	Retrospective study of 708 trauma patients undergoing CT scanning for cervical spine trauma including 91 patients with scans read as negative by radiologists and subsequently underwent MRI. The imaging was reviewed subsequently by 2 fellowship trained spine surgeons.	II for involving spine expertise in evaluation.	Excluding the presence of significant cervical injury in patients without the ability participate in a clinical examination is best determined by experts in spine trauma management
		III in support of MRI in algorithm.	A multidisciplinary, algorithmic approach generally yields the most consistent results. Reliance on a single imaging modality may lead to missed injurie
Schoenwaelder,[68] *Emerg Radiol,* 2009	Retrospective study in intubated trauma patients, evaluating the utility of MRI in intubated multitrauma patients with normal CT.	III	NPV 82% for discoligamentous injury and 100% for unstable injury
			A normal single-slice helical CT with sagittal reformats of the cervical spine in intubated trauma patients excludes unstable injuries
Muchow,[70] *J Trauma,* 2008	Meta-analysis of 5 Class I studies including 464 patients addressing the imaging of obtunded blunt trauma patients with negative radiographs or CT.	II	False negatives 0%
			NPV 100%
			PPV 94.2%
			Sensitivity 97.2%

(Continues)

TABLE 5. ***Continued***

Citation	Description of Study	Evidence Class	Conclusions
			Specificity 98.5%
			Negative MRI conclusively excludes cervical spine injury
			Class II as the studies reviewed not Class I and had variability in design and address a relatively restricted population
Tomycz,[67] *J Trauma,* 2008	Retrospective review of 690 patients with both CT and MRI of the cervical spine in a level I trauma center from January 2003 to December 2006 were retrospectively analyzed.	III	MRI is unlikely to identify a significant injury in the setting of a negative CT
Como,[61] *J Trauma,* 2007	Prospective evaluation of 115 CT negative trauma patients.	II	MRI did not add significantly to the evaluation
Mathen,[33] *J Trauma,* 2007	Prospective, unblinded, consecutive series of trauma patients requiring c-spine evaluation comparing plain radiographs to CT for cervical spine evaluation.	II	All clinically significant injuries were detected by CT. Plain films failed to identify 55.5% of clinically significant fractures
			CT is superior to plain radiography as a screening modality for the identification of acute traumatic cervical spine injury
Sarani,[64] *J Trauma,* 2007	Retrospective study of 254 adults includingIII 53 obtunded patients. All study patients underwent both CT and MRI scanning of the cervical spine.		A cervical spine MRI should be obtained in trauma patients who are either unexaminable or symptomatic with a normal CT scan
Stelfox,[66] *J Trauma* 2007	Prospective study of intubated trauma patients imaged with CT and either clinical examination or MRI to discontinue c-spine immobilization.	II	Discontinuation of c-spine precautions based on a normal CT decreases the duration of immobilization and is associated with fewer complications, fewer days of mechanical ventilation, and shorter hospital admissions
Adams,[60] *Am Surg,* 2006	Prospective evaluation of CT scanning in the blunt trauma patient.	II	CT:
			Sensitivity 94%
			Specificity 91%
			NPV 98%
			PPV 78%
			CT scanning identifies the presence of cervical injury with a high sensitivity
			Downgraded due to small size and unclear inclusion criteria
Stassen,[65] *J Trauma,* 2006	Retrospective review of 52 obtunded trauma patients having both cervical CT and MRI.	III	CT combined with MRI provides efficient evaluation for cervical spine injury. CT alone misses a statistically significant number of cervical spine injuries
Brohi,[52] *J Trauma,* 2005	Prospective study of 437 trauma patients including 61 patients with significant spine injury evaluating CT.	I	CT:
			Sensitivity of 98.1%, specificity of 98.8%
			NPV 99.7%
			CT excludes significant cervical spine trauma with a high sensitivity and specificity
Hogan,[62] *Radiology,* 2005	Retrospective study of CT and MRI in obtunded patients.	III	CT for ligamentous injury

(Continues)

TABLE 5. *Continued*

Citation	Description of Study	Evidence Class	Conclusions
			NPV 98.9% for and CT for unstable cervical spine injury
			NPV 100%
			A normal cervical CT scan in the obtunded blunt trauma patient can exclude an unstable cervical spine injury
Schuster,[48] *Arch Surg,* 2005	Prospectively collected registry data of 2854 trauma patients including 100 with cervical spine injuries with normal motor examination results and normal cervical spine helical CT scans	II	A normal exam and normal cervical CT excludes significant injury without additional imaging
Horn,[75] *J Neurosurg Spine,* 2004	Retrospective review of patients imaged with MRI compared with either plain films or CT.	III	MRI is not helpful in determining cervical stability and may lead to un-necessary testing
Diaz,[27] *J Trauma,* 2003	Prospective study of adults with altered mental status imaged with both CT and plain films.	I	CT:
			Sensitivity 97.4%
			Specificity 100%
			Prevalence of 11.5%
			PPV 100%
			NPV 99.7%
			Plain films:
			Sensitivity 44.0%
			Specificity 100%
			Prevalence 11.5%
			PPV 100%
			NPV 93.2%
			CT outperformed 5-view plain films in identifying cervical spine injury in obtunded patients
Albrecht,[71] *World J Surg,* 2001	Retrospective review of 150 obtunded patients evaluating the role of MRI to exclude significant cervical trauma.	III	MRI identified all significant cervical spine injuries

[a]CCR, Canadian C-Spine Rule; CT, computed tomography; MRI, magnetic resonance imaging; NEXUS, National Emergency X-Radiography Utilization Study Group; NLV, NEXUS low risk category; NPV, negative predictive value; PPV, positive predictive value.

criteria limit the evidence reported in this study to Class III medical evidence.

In 2006, Padayachee et al[54] published a prospective analysis of 276 obtunded patients who were assessed with CSR, CT, and flexion/extension studies. The authors reported that flexion/extension studies had 94% (260/276) true negatives, 2.2% (6/276) false positives, and 0.4% (1/276) false negative results, with no true positives. In 9 patients, the dynamic films were deemed inadequate upon review. The authors concluded that in this prospective cervical spine clearance protocol for unconscious traumatic brain injury patients, flexion/extension studies under fluoroscopy failed to identify any patient with a significant cervical injury that was not already identified either by plain radiographs or high-definition CT.

Spiteri et al[55] published a retrospective review of 839 trauma patients for unstable cervical spine injuries and any cases missed by CT but identified by dynamic imaging. The authors identified 87 patients with unstable cervical spinal injuries. CT imaging missed 2 injuries (sensitivity 97%, specificity 100%). Flexion and extension films identified 1 case of atlanto-occipital dislocation missed on CT (sensitivity 98.8%, specificity 100%). No injuries or neurological worsening were attributable to dynamic imaging. The authors concluded that dynamic imaging is safe but adds little if anything to plain radiographs and/or CT of the cervical spine in the assessment of acute traumatic injury.

Freedman et al[56] studied all unconscious patients admitted over a 1-year period who failed to clear cognitively within 48 hours. In 2005 they reported on 123 patients who had normal 3-view cervical radiographs who subsequently underwent passive

dynamic imaging when they were able to participate. Final injury status at follow-up served as the gold standard. Dynamic imaging resulted in a 57% false negative rate (missed 4 of 7 injuries). None suffered an adverse neurologic outcome as a result of dynamic imaging. The authors concluded that passive flexion and extension imaging fails to provide adequate sensitivity for detecting occult cervical spinal injuries.

Griffiths et al[57] retrospectively reviewed 447 trauma patients examined with flexion and extension x-rays in evaluation for cervical spinal injuries. The outcome of interest was worsened neurological deficit as a result of the dynamic imaging procedure. There were no cases identified of neurological worsening following forced flexion and extension imaging. Of 447 patients evaluated with dynamic imaging, 29 were identified who had cervical spinal abnormalities, either fracture or ligamentous injury. In 80% of the patients with injuries (23 of 29), no change in diagnosis was made following forced flexion and extension studies. In 6 patients (20%), an alteration in diagnosis was made based on positive dynamic studies. Of the 497 dynamic imaging studies, 285 (59%) were found to be inadequate either due to inadequate motion (31%) or inadequate visualization (40%).

In 2004, Bolinger et al[58] reported a retrospective study of 56 consecutive comatose head-injured patients. All patients had 3-view radiographs and CT imaging performed and reviewed by the attending neurosurgeon and a radiologist. If these studies were felt to be normal, flexion/extension fluoroscopic studies were performed. In only 4% of the cases were the studies felt to be adequate to visualize the full cervical spine. Clinical outcome served as the gold standard. Occult instability was identified in 1 patient with a Type II odontoid fracture, and significant instability at C6-7 was identified in 1 patient despite normal dynamic films. The authors concluded that flexion and extension fluoroscopy was almost always inadequate for visualizing the lower cervical spine in obtunded patients.

Davis et al[59] evaluated the efficacy of flexion/extension studies under fluoroscopy in obtunded patients who had normal cervical spine plain films. Over a 7-year period, 301 patients were evaluated. Ligamentous injury was identified in 2 patients (0.7%). There were 297 true negative, 2 true positive, 1 false negative, and 1 false positive examinations. One patient was rendered quadriplegic by the dynamic evaluation. This study does not provide evidence to support the routine use of dynamic fluoroscopy in assessing the cervical spine in the obtunded patient and demonstrates the rare, but devastating complications that may occur with dynamic imaging.

MRI

In 2010, Schoenfeld et al[27,33,48,60-69] performed and reported a meta-analysis of 11 studies comparing CT alone to CT plus MRI in identifying occult cervical spine injuries following acute trauma. The authors attempted to address the question: Does adding MRI provide useful information that alters treatment when a CT scan of the cervical spine reveals no evidence of injury? The study included 1550 patients with a negative cervical CT study who were subsequently imaged with MRI. Abnormalities were detected by MRI in 182 patients (12%). Ligamentous injuries were found in 47% of the patients and bony abnormalities in 2% of patients. Significantly, MRI identified an injury that altered management in 96 patients (6%). Twelve patients (1%) required surgical stabilization and 84 patients (5%) required immobilization for injuries identified on MRI but not on CT imaging. The Q-statistic *P* value for heterogeneity was 0.99, supporting the validity of the study. The pooled sensitivity of MRI for detecting a clinically significant injury was 1.00 (100%) (95% CI = 95-100). The pooled specificity was 0.94 (94%) (95% CI = 93-95). The pooled NPV for MRI was 1.00 (100%) (95% CI = 95-100). There were no false negatives in any of the studies included in their meta-analysis. The pooled false-positive rate was 0.06 (6%) (95% CI = 1-11). The likelihood ratio of a clinically significant injury in the setting of a positive MRI was 17 (95% CI = 13.8-20.8). The authors advocate the use of MRI to evaluate patients who are obtunded or unexaminable despite a negative CT study of the cervical spine. Their report provides Class II medical evidence on this issue. The authors' meta-analysis included 6 retrospective studies. Study designs varied and had different criteria. There is no imaging gold standard for cervical spinal instability, or for ligamentous injury; therefore, several studies the authors included likely had false endpoints.

An earlier meta-analysis was published by Muchow et al[70] in 2008, and included studies by Albrecht et al,[71] Benzel et al,[42] D'Alise et al, Keiper et al,[72] and Schuster et al.[48] The authors considered these 5 studies to provide Class I medical evidence in the assessment of MRI in the setting of negative plain films or CT of the cervical spine following trauma. The authors used the following inclusion criteria: minimum 30 patients with clinically suspicious or unevaluable cervical spines, clinical follow-up as the gold standard, data reported to allow the collection of true positives, true negatives, false positives, and false negatives, MRI obtained within 72 hours of injury, and plain radiographs that disclosed nothing abnormal of the cervical spine with or without a CT scan that disclosed nothing abnormal. The pooled sensitivity, specificity, positive, and NPV of MRI were calculated from a log odds meta-analysis. The total number of patients in the combined studies was 464. The NPV of MRI was 100%. There were no false negatives in any of the 5 studies included in the analysis. The pooled sensitivity of MRI in these studies was 97.2% (95% CI 89.5, 99.3), the specificity was 98.5% (95% CI 91.8, 99.7), and the PPV was 94.2% (95% CI 75.0, 98.9). Ninety-seven injuries (20.9%) were identified on MRI that were not diagnosed by either plain film or CT imaging. The authors concluded that a normal MRI study in the setting of normal CSR or a normal CT study excludes cervical spinal injury and establishes MRI as a gold standard for excluding a significant cervical spinal injury in a clinically suspicious or unevaluable acute trauma victim. This analysis by Muchow et al[70] provides Class II medical evidence in support of the role of MRI in the evaluation of the obtunded or unevaluable patient who has negative plain radiography or CT imaging of the cervical spine. Their review was limited by differences in the imaging protocols, the combination of

negative plain films or CT as a portion of the entry criteria, difficulty ensuring similarity of the patient population across the 5 studies, the inclusion of a primarily pediatric study,[72] and extrapolating the overall results to an adult evidence-based review.

In 2010, Simon et al[73] published a detailed analysis of 708 consecutively admitted trauma patients and identified a subset of 91 patients who had cervical CT imaging interpreted as negative who subsequently were evaluated with cervical MRI imaging. The collective images of these 91 patients were independently re-evaluated by 2 fellowship-trained spine surgeons. Both surgeons agreed that the images of 76 of 91 patients (84%) were adequate to determine the potential for a cervical spinal injury. Both agreed that the images of 7 of the 91 patients (8%) were inadequate (95% CI, 2.3-13.1). Total Observer agreement was 91% (kappa, 0.59). The calculated sensitivity of CT in this study was 77.3%. The specificity of CT for a cervical spinal injury was 91.5% with a NPV of 92.0%. The addition of MRI to CT imaging improved the probability of identifying a significant cervical spinal injury by approximately 8%. When clinicians skilled in the interpretation of cervical spinal imaging and the management of patients with cervical spinal injuries were directly involved in the assessment of obtunded, high risk patients following trauma, fewer injuries were missed compared to an initial single read of the acute images by less experienced clinicians. This study provides Class II medical evidence in support of the involvement of physicians trained in the diagnosis and management of spinal injuries in the assessment of obtunded or unevaluable patients following acute trauma in whom there is a high clinical suspicion of cervical spinal injury yet have a normal high-quality CT imaging study.

Menaker et al[74] offered a retrospective analysis of 213 patients who had negative CT on a high quality 40 slice CT who had a subsequent MRI. 24% of these patients had an abnormal MRI study (52 of 213). Fifteen (7%) underwent surgery, 23 (11%) were treated with cervical immobilization, and 14 (6.5%) had immobilization collars removed. In total, 8.3% of obtunded patients and 25.6% of symptomatic patients with normal CT studies had a change in management based on MRI findings (combined 17.8%). This 2010 publication is problematic in design and provides, at best, Class III medical evidence on the value of MRI in the acute setting following trauma, but does highlight the increased sensitivity of MRI in detecting cervical spinal injuries.

In 2006, Stassen et al[65] reported a retrospective analysis of 52 patients studied in a 1-year trauma protocol utilizing CT and MRI. Thirty-one patients (60%) had both a negative CT and MRI. The authors identified that of 44 patients with a negative CT, 13 (30%) had evidence of a potential ligamentous injury on MRI. Eight patients with positive CT findings also had positive MRI findings. There were no missed cervical spine injuries identified by clinical follow-up. The authors concluded that cervical CT, when used in combination with MRI, provides an efficient method for identifying cervical spine injuries following trauma. CT imaging alone, they added, misses a statistically significant number of acute cervical spinal injuries. Their study provides Class III medical evidence on this subject.

Horn et al[75] in 2004 described a retrospective series of 6328 trauma patients that included a subset of 314 trauma victims that were imaged with a cervical MRI for 1 of the following indications: neurological deficit, fracture, neck pain, and/or indeterminate clinical examination. Based on clinical follow-up, there were 65 patients identified with unstable cervical spinal injuries. In this group, plain films, CT, and MRI were all abnormal. There were 143 patients who had abnormal CT or plain films. Of these, 13 had normal MRI studies. Six of the 13 had dynamic films. All were interpreted as normal. One hundred and sixty-six of the 314 patients had normal CT or cervical plain films. Of these, 70 had abnormal MRI findings. Twenty-three of the 70 had dynamic studies performed as well; they were all normal. The authors concluded that MRI is sensitive to soft tissue image abnormalities but may add little in the detection of a significant cervical spinal injury in the circumstance of either normal plain films or CT study. Study design, lack of follow-up, and the lack of clear comparison groups limit the medical evidence in their report to Class III.

In 2002, Ghanta et al[76] published a retrospective review of 124 consecutive patients who underwent 3-view plain films (3VPF), a full CT survey (CTS), and MRI of the cervical spine. The study included 51 obtunded patients with normal plain films. Thirty-six of these 51 patients had normal CT and MRI studies. The authors determined that 22% of obtunded patients with normal cervical plain films and CTS had an abnormal MRI. Six percent of these injuries were potentially unstable. The authors concluded that plain films and CT imaging appear effective in detecting bony injury among obtunded patients, but may not be sensitive enough for cervical ligamentous injuries and significant disc herniations.

SUMMARY

Awake Asymptomatic Patient

Class I medical evidence was previously reported on this topic. The current updated review identified additional Class I evidence supporting a Level I recommendation that in the awake, asymptomatic patient who is without neck pain or tenderness, is neurologically intact without an injury detracting from an accurate evaluation, and who is able to complete a functional range of motion examination, radiographic evaluation of the cervical spine is not recommended. The discontinuance of cervical immobilization in this patient population is recommended.

Awake Symptomatic Patient

Class I medical evidence was previously reported on this topic. This current updated review identified additional Class I medical evidence that alters the previous Level I recommendation. High-quality CT imaging of the cervical spine in the symptomatic trauma patient has been proven to be more accurate than CSR with higher sensitivity and specificity for injury following blunt trauma. If high-quality CT is available, 3-view CSR are not necessary. If high quality CT is not available, a 3-view cervical spine series (anteroposterior, lateral, and odontoid views) remains a Level I recommendation.

The question of "what to do?" if anything for the awake patient with neck pain or tenderness and normal high-quality CT or 3-view CSR remains less clear. Only lower level medical evidence is available to guide treatment decisions for these patients. The current literature offers less robust medical evidence in support of the 3 following strategies in the awake but symptomatic patient: (1) continue cervical immobilization until asymptomatic, (2) discontinue cervical immobilization following either normal and adequate dynamic flexion/extension radiographs, or a normal MRI study obtained within 48 hours of injury, or (3) discontinue immobilization at the discretion of the treating physician. Several studies favor the use of MRI (Level II) over dynamic radiographs (Level III) in further study of these patients, but may not be feasible or indicated in all situations.

Obtunded or Unevaluable Patient

A large number of studies have been produced since the previous guideline publication on imaging the obtunded or unevaluable patient in order to clear the cervical spine without the benefit of the clinical examination. The current Level I recommendation, based on Class I medical evidence, is that high-quality CT imaging is recommended as the initial imaging study of choice. If high-quality CT imaging is available, routine 3-view CSR are not necessary, similar to the Level I recommendations in the other categories. If high-quality CT is not available, a 3-view cervical spine series (anteroposterior, lateral, and odontoid views) is recommended. The plain cervical spine x-ray studies should be supplemented with CT (when it becomes available) if necessary, to further define areas that are suspicious or not well-visualized on the plain cervical x-rays.

The most controversial issue in the obtunded/unevaluable patient group is the recommendation on the discontinuation of immobilization. The current recommendation is that in the obtunded or unevaluable patient who has normal high-quality CT imaging or a normal 3-view cervical spine series, 1 of the following strategies be considered: (1) continue cervical immobilization until asymptomatic, (2) discontinue cervical immobilization following a normal MRI study obtained within 48 hours of injury, or (3) discontinue immobilization at the discretion of the treating physician. MRI appears to be the imaging modality of choice in this situation based on limited and conflicting Class II and Class III medical evidence. Class III medical evidence suggests that the routine use of dynamic imaging is of marginal benefit and is not recommended. Class II medical evidence suggests that the decisions for the subsequent patient management of the obtunded/unevaluable patient including whether or not to obtain an MRI study on individual patients involve physicians trained in the diagnosis and management of spinal injuries.

KEY ISSUES FOR FUTURE INVESTIGATION

The issue of discontinuing cervical spinal immobilization after blunt trauma remains the area of most controversy in both the symptomatic patient with negative initial imaging, and in the obtunded or unevaluable patient with normal cervical spinal imaging. Numerous publications have addressed this issue and several have provided Class II and Class III medical evidence on this topic. Although a challenge, it appears that this issue could be addressed in a multicenter randomized trial. An appropriately designed and conducted prospective multicenter trial has the potential to define the optimum methodology to accurately exclude a significant cervical spinal injury in these patients prior to discontinuing immobilization. While limited and conflicting medical evidence suggests that MRI is recommended to further study these patients, this has yet to be definitely proven. The question of whether there is any role for dynamic imaging in this setting should be determined.

Disclosure

The other authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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