# Imaging Evaluation of Adult Spinal Injuries: Emphasis on Multidetector CT in Cervical Spine Trauma[1]

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As computed tomography (CT) technology has evolved, multidetector CT has become an integral part of the initial assessment of many injured patients, and the spine is easily included in the total body screening performed in patients with severe blunt polytrauma. Despite all the advantages of multidetector CT, clearing the spine in which injury is suspected continues to be a daily challenge in clinical practice. The purpose of this review is to present the evidence and the controversies surrounding the practice of imaging in patients suspected of having spine injury. The discussion is centered on the increasing reliance on multidetector CT in the work-up of these patients but also considers the important contributions of clinical trials to select patient for appropriate imaging on the basis of risk and probability of injury. Available protocols, injury classification systems, and issues awaiting future research are addressed.



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**Learning Objectives:**
After reading the article and taking the test, the reader will be able to:

- Discuss current recommendations for evaluation of patients when cervical spine injury is suspected
- Explain the utility and limitations of the clinical prediction rules for evaluation of possible cervical spine injury
- Describe the biomechanics of selected cervical spine fractures and their appearance on CT

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The imaging assessment of trauma patients has undergone dramatic changes over the past several years. Specifically, when spine injury is suspected, there has been a shift from radiography to multidetector computed tomography (CT), which provides faster and more accurate evaluation of the spine.

During the early 1990s, discussions regarding spine imaging concentrated on how many radiographic views were needed for optimal assessment of the cervical spine, and CT was used as a problem-solving tool for inadequately shown segments of the spine, typically the craniocervical and cervicothoracic junctions. The increasing availability of first-generation volumetric CT brought new ways for faster imaging of trauma patients. Protocols were developed that were based on scanning the entire cervical spine, allowing for multiplanar display by using reformatted images from the axial data set. At first, reformations were of suboptimal quality and radiography was still deemed necessary, particularly for adequate evaluation of vertebral alignment and of transversely oriented fractures. Over the past decade, the development of multidetector CT has allowed faster volumetric acquisition with thin collimation and routine isotropic and multiplanar display, which has obviated routine radiography when multidetector CT is available. In the trauma setting, multidetector CT is used concurrently to assess other body regions, and the spine can easily be included as part of multisegment scan. Multidetector CT also allows generation of high-quality multiplanar two- and three-dimensional images for improved interpretation. Adequate thoracic and lumbar spine images can also be obtained from the chest and abdominal CT data (1). Multidetector CT provides a faster and more comprehensive display of spinal anatomy than does radiography, and, more important, it has shown a much higher sensitivity than radiography for fracture detection. In addition, multidetector CT introduces the opportunity for simultaneous assessment of the cervical region for vascular injuries if intravenous contrast material is used.

Despite all these advantages of multidetector CT, clearing the cervical spine in patients suspected of having an injury continues to be a daily challenge in clinical practice. Approximately 3 million patients per year with spinal trauma are cared for in emergency departments across the United Stated and Canada (2). Although the incidence of spine and cord injuries is low, cervical spine fractures may not be clinically obvious, and missing an injury can result in devastating consequences. This degree of uncertainty has introduced great variability in the imaging approach that allows one to adequately rule out cervical spine injury in trauma patients and has resulted in increasingly liberal utilization of imaging resources. It is estimated that $3.4 billion is spent in the United States to image the cervical spine (3). It is clear that even if multidetector CT is accepted as a valuable imaging resource, there should be no reason to perform multidetector CT in all trauma patients just because it is available, as this practice would result in inappropriate utilization with unjustifiable levels of radiation exposure and health care cost.

In light of these comments, the purpose of this review is to present the evidence and the controversies surrounding the practice of imaging in patients suspected of having a spine injury. Our discussion will be centered on the increasing reliance on multidetector CT in the work-up of these patients but will also consider the important contributions of clinical trials for selecting patients for appropriate imaging on the basis of risk and probability of injury. Available protocols, injury classification systems, and issues awaiting future research will be addressed.

### Essentials

- Multidetector CT has become an integral part of the initial assessment of many injured patients, and the spine is easily included in the total body screening performed in patients with severe blunt polytrauma.
- Application of the clinical prediction rules such as NEXUS and the Canadian Cervical Spine rule should dramatically decrease the rate of unnecessary imaging to clear the cervical spine.
- Despite all the evidence suggesting that the number of unstable cervical spine injuries in obtunded trauma patients that are potentially missed at multidetector CT should be extremely low, the need for cervical spine MR imaging in this patient population remains controversial.
- In elderly patients, compared with patients younger than 65 years, cervical spine fractures are more likely to be caused by low-energy mechanisms (eg, fall from standing height), and these injuries are more often missed.

## Clinical Clearance of the Cervical Spine

Cervical spine clearance after blunt trauma is defined as accurate confirmation of the absence of a cervical spine injury. First, one needs to consider those clinical factors that can be used as predictors of spinal fracture risk to optimize imaging strategies. Determining which blunt trauma patients need no imaging to rule out spine injury has been a subject of much interest over the years, particularly in view of the low yield of radiography in helping detect cervical spine fracture and/or dislocation, which is estimated between 1% and 5% in most series (4). The majority of publications consisted of uncontrolled case series until the arrival of two prospective observational cohort

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**Abbreviations:**
BCVI = blunt cerebrovascular injury
NEXUS = National Emergency X-Radiography Utilization Study

Potential conflicts of interest are listed at the end of this article.

multicenter trials: the National Emergency X-Radiography Utilization Study (NEXUS) (5) and the Canadian Cervical Spine rule (6). The two studies used different clinical criteria, but both provide robust evidence that has become widely accepted and used for identifying trauma patients who need not undergo spinal imaging.

The NEXUS decision tool comprises five simple criteria that make its application straightforward and consistent among referring physicians. It deems patients at low risk of cervical spine injury when there is absence of posterior midline cervical tenderness and of focal neurologic deficit when the patient is alert and not intoxicated or has a painful distracting injury. The CCS rule includes criteria for alert and stable trauma patients who are at risk for cervical injury and should undergo imaging. It identifies patients at low risk in whom it is safe to assess active range of motion of the cervical spine. It deems patients as cleared when they can turn their heads 45° in both directions. The CCS rule has been validated prospectively, and it performed better than the NEXUS criteria with higher sensitivity and specificity (7); however, the NEXUS criteria apply to all age groups, with good performance in the pediatric population, whereas the CCS rule applies only to patients aged 16–65 years. Debate continues about the advantages of one prediction rule over the other, but both sets of criteria have admittedly been shown to be powerful predictors of cervical spine injury, and their consistent application should substantially decrease the rate of unnecessary imaging to clear the cervical spine.

In 2007, Duane et al (8) prospectively evaluated 534 blunt trauma patients, comparing the clinical examination findings with the results of CT of the cervical spine. The results were not consistent with the above recommendations. Using history and physical examination findings, they failed to identify 12 of 52 patients with cervical spine fractures. Furthermore, in the subset of alert patients with a Glasgow Coma Scale score of 15 who had a nondistracting injury or were intoxicated, 17 had fractures, and seven of them had negative findings at clinical examination. These results require further investigation before we deviate from the currently accepted multicenter guidelines. In fact, the findings of Duane et al were not validated in a meta-analyses recently published by Anderson et al (4), whose goal was to identify those blunt trauma patients who can be safely cleared from cervical spine injury without radiographic examination. Using studies with prospectively applied protocols and reported outcomes, these authors extracted the statistics and, by applying random-effects methods, concluded that an alert asymptomatic patient without a distracting injury or neurologic deficit who is able to complete a functional range of motion can be confidently cleared from the cervical collar without imaging. The authors calculated a sensitivity of 98.1% and a negative predictive value of 99.8% for protocols that safely cleared the cervical spine in this patient population. Of note, the occult injuries in their study analysis resulted from protocols in which a functional examination or the presence of distracting injury was not used as criteria.

Prior to the publication of the NEXUS and the Canadian Cervical Spine criteria, Blackmore et al (9) had also investigated multiple clinical factors to determine the probability of cervical spine fracture. Using odds ratios and composite predictors with a simplified stepwise logistic model, the authors developed a clinical prediction rule and concluded that the cause of injury, the patient's age, and the presence of severe head injury or neurologic deficit were important predictors of cervical spine fracture.

## Selection of Imaging Modality: Radiography and CT

Patients who do not meet the criteria proposed by the clinical prediction rules should undergo imaging. This applies to patients with pain, a neurologic deficit, a distracting injury, altered mental status, or obtundation or who fulfill a high probability of fracture according to mechanistic criteria.

In the past, a three-view radiographic screening examination with additional "swimmer's" or oblique views, as well as limited CT of the poorly visualized segments of the spine, was common practice. The limitations of radiography have been long recognized, particularly in the subset of patients with the highest probability of fracture. Cervical radiography can be technically demanding in these patients, who are typically on a trauma board, who may have concurrent severe injuries, and who may be uncooperative. Moreover, a substantial number of studies have shown the superior performance of CT over radiography. In 1994, Nunez et al (10) published a report on a prospective series of 800 patients suspected of having multisystem injuries and reported a sensitivity of 98.5% for CT, as compared with 43% for radiography, in this high-risk population. Furthermore, they initially proposed screening these patients with CT of the entire cervical spine at the time of the CT examinations of other body areas. The same authors noted that up to a third of fractures missed at radiography were either clinically unimportant or unstable (11) and claimed a reduction in trauma work-up time when using CT, with improved patient disposition from the trauma bay (10,12). This concept was supported in additional publications by Daffner (13,14) that addressed the time efficiency of CT base protocols.

Griffin et al (15) concluded that there was no role for screening with radiography in a cohort of 1199 patients with altered mental status, posterior neck tenderness, and neurologic deficit. In a prospective study of 1006 patients with 72 injuries, Diaz et al (16) reported a 52.3% missed fracture rate for radiography, and a 17.5% miss rate was found for unstable cervical spine fractures. In that study, Diaz et al included patients with either altered mental status or distracting injury. Authors of additional publications in the trauma literature, with smaller patient populations and different selection criteria (17–19), also concluded that there was a clear sensitivity of CT over radiography.

Finally, in a meta-analysis, Holmes et al (20) compared radiography and CT and found that CT clearly outperforms radiography in injury detection, with a pooled sensitivity of 98% for CT and 52% for radiography in patients at high risk for injury, but concluded that there was insufficient evidence that CT should replace radiography in patients at low risk for cervical injury.

## Cost-effectiveness and Risk Stratification

Based on the premise that patients at risk for spine fracture constitute a rather heterogeneous group, Blackmore et al (21) assessed the cost-effectiveness of imaging as a function of the probability of injury. They stratified patients into different levels of probability on the basis of clinical findings at the time of admission to the emergency department. The cost-effectiveness analysis showed that in trauma patients at a risk higher than 10% for spine fracture, CT was the preferred imaging method in terms of both cost saving and paralysis prevention. CT was also considered a dominant strategy in patients with moderate probability of fracture (4%–10%), but, in patients in the low-probability rank (<4%), CT was not cost-effective and radiography was a preferred strategy.

Conversely, a recent report by Bailitz et al (22) provided further evidence that CT should replace radiography in patients at high, moderate, or low risk for blunt cervical spine injury. A surprisingly low sensitivity of 25% was encountered in this study for patients at low risk; in that study, however, risk stratification was not performed at admission, which precluded an adequate estimation of the predictive values for radiography and CT. Furthermore in that study, the low-risk patients were underrepresented in the total patient population.

In a publication by Daffner and Hackney (23), the prediction rules that endorse radiography for low-risk patients were considered obsolete, given the apparent underestimation of the performance of CT systems based on older technology and thick-section imaging. The current American College of Radiology appropriateness criteria state that the use of radiography in patients suspected of having a cervical spine injury should rather be reserved for adult patients when multidetector CT is not readily available, indicating that radiography should not be considered a substitute for CT.

## Radiation and Overutilization

Despite these recommendations by the American College of Radiology and all the evidence supporting the superiority of CT, the associated radiation exposure and the increasing cost of health care still suggest the need for further optimization of the indications for CT in those patients at low risk of cervical spine injury, in whom prediction criteria deemed imaging necessary. Radiation from CT is usually considered a nonhomogeneous dose distribution, and organ dose is the preferred metric for radiation risk estimation. There is direct epidemiologic evidence that the organ dose delivered during a common CT study of two or three body parts (30–90 mSv) results in increased risk of cancer (24). Rybicki et al (25) quantified the increasing thyroid radiation when CT of the entire cervical spine was performed with single-detector helical CT and found a 14-fold increase over the radiographic trauma series (26 mGy for CT vs 1.8 mGy for radiography). Chan et al (26) found the estimated absorbed dose by the thyroid to be 75.6 mGy when a 16–detector row scanner is used with no dose modulation.

Overall, radiation exposure from CT can be reduced by using automated exposure-control options based on the patient's size. Prioritizing the different dose-reduction strategies is a challenge for the radiologist, and different dose-reduction solutions have been developed by CT manufacturers. Mulkens et al (27) showed that the use of tube current modulation with low tube voltage settings can substantially reduce radiation dose, as compared with standard fixed voltage settings, while preserving adequate image quality. The other options to minimize the radiation dose are to decrease the number of CT studies that are ordered or to replace CT with alternatives that involve lower radiation exposure. To this end, the more rigorous, consistent, and widespread application of the NEXUS criteria coupled with the use of radiography in patients at low risk for injury may help reduce a substantial number of negative CT examinations in this patient population.

Recent work (28) in which the ordering patterns of emergency department physicians were analyzed and the use of the NEXUS criteria was assessed could further decrease the utilization of CT imaging determined that if clinicians strictly adhere to the NEXUS prediction rules, more than 20% of the patients in their series would have been spared an unnecessary examination. In a recent publication, Larson et al (29) further support the need for evidence-based decision models that can establish the probability of patient benefit from CT at the time of decision making in the emergency department. Identifying national trends, they found that the use of CT in emergency departments in the United States has increased exponentially during their study period (1995–2007) and that CT-associated radiation exposure in the emergency department setting has likely increased even more rapidly than the number of CT examinations performed.

## The Obtunded Patient

Unrecognized cervical spine injuries in obtunded trauma patients have the potential for neurologic deterioration, paralysis, or even death (30,31). Unnecessary prolonged spinal immobilization limits central venous access and may cause various complications, including respiratory deterioration, pressure ulceration, and venous thrombosis (32–34). Furthermore, prolonged immobilization is associated with increased health care cost (31,35).

Several studies (34,36–38) have provided evidence suggesting that the number of unstable cervical spine injuries in obtunded patients with negative multidetector CT examination results is exceedingly low. In a retrospective study of 366 obtunded blunt trauma patients who had undergone cervical spine magnetic resonance (MR) imaging after negative findings from multidetector CT, Hogan et al (37) reported negative predictive values of 98.9% (362 of 366 patients) for ligament injury and 100% for unstable cervical spine. Harris et al (31) found that in only one of 367 patients examined did initial CT fail to help identify an injury, for a false-negative rate of 0.3%. That patient was effectively treated nonsurgically. In a prospective study by Como et al (34), 115 obtunded blunt trauma patients with negative multidetector CT results underwent cervical spine MR imaging for clearance. Among this study group, six patients (5.2%) had acute injuries, none of which required any change in management or intervention. In a prospective study of 402 patients by Hennessy et al (36), one injury was missed at CT but was identified at retrospective review of the images, for a sensitivity of 99.75%.

Conversely, Menaker et al (39), in a retrospective study of 203 patients who were evaluated with MR imaging with unreliable clinical examination findings and negative multidetector CT findings, suggested that negative results from cervical spine CT are not sufficient for cervical spine clearance in this patient population. Eighteen patients had abnormal findings on MR images, two of whom required surgical repair and 14 of whom required extended collar immobilization.

Despite all the evidence suggesting that the number of unstable cervical spine injuries in obtunded trauma patients potentially missed when multidetector CT is used should be extremely low; the need for cervical spine MR imaging in this patient population remains controversial.

## Role of MR Imaging

Under certain clinical conditions, MR imaging can add vital information and influence clinical and surgical care. Specifically when there is clinical evidence of progressive neurologic deficits, MR imaging is indicated regardless of the multidetector CT findings. An incomplete neurologic deficit could also be an indication to perform MR imaging. Patients with severe pain may also require further evaluation with MR. MR imaging can, for example, help determine the presence of a traumatic disk herniation or an expanding extramedullary hematoma, both of which may escape detection on CT images. In both circumstances, compression of adjacent neural structures (spinal cord or cervical nerve roots) may indicate the need for urgent surgical decompression, which may reverse or halt the progressive neurologic deficit(s). The issue of when to use MR imaging for traumatic spine injury is complicated by the potential medical, social, economic, and medicolegal consequences of missed injuries and should be elucidated in future larger prospective multi-institutional studies. Whether such a study becomes a reality due to funding and administrative issues is problematic, so at present the finding of an indication of worsening clinical neurologic status may suggest the need to obtain an urgent MR study.

## Imaging Elderly Patients Suspected of Having Spinal Trauma

Injury patterns in elderly patients differ from those in younger patients because of a combination of altered biomechanics resulting from degenerative changes and osteopenia (40). In elderly patients, as compared with patients younger than 65 years, cervical spine fractures are more likely to be caused by low-energy mechanisms such as a fall from standing height, and these injuries are more often missed (Fig 1). In addition, the predominance of degenerative changes in the lower cervical spine makes the upper cervical spine the more mobile portion, thus explaining the higher proportion of injuries in this segment in the elderly population (41–45).

In 2005, Bub et al (46) developed a clinical prediction rule to determine the risk of cervical spine fracture in blunt trauma patients aged 65 years or older. Their results were similar to those from a previously reported prediction rule developed for the general adult population. The most important predictors of injury were neurologic deficit, head injury, and high-energy mechanism of injury. However, the authors acknowledged that the probability of cervical spine fracture in the elderly is more difficult to predict than that in other adults, because fractures caused by low-energy mechanisms occur more commonly (9,46).

**Figure 1**

**Figure 1:** Sagittal midline CT reformatted image in an 85-year-old man who presented with central cord injury after a fall from standing demonstrates a hyperextension injury with anterior widening of the C4-5 disk space (solid arrow) and prevertebral soft-tissue swelling (open arrow). Note also multilevel cervical spondylosis and canal stenosis. Subaxial Cervical Spine Injury Classification (SLIC) score was 8 (surgical: injury morphology, 3 points; disruption of discoligamentous complex, 2 points; incomplete cord injury, 3 points).

## Protocol for 64-Detector CT

### Dedicated Cervical Spine Multidetector CT

Dedicated cervical spine multidetector CT is the technique used at our institution to evaluate blunt trauma patients suspected of having cervical spine injury who do not have an indication for

**Table 1**

**Multidetector CT Protocols**

| Parameter | Dedicated Cervical Spine | Whole Body |
|---|---|---|
| Collimation (mm)* | 0.6 | 0.6 |
| Rotation time (sec) | 0.5 | 0.5 |
| Anatomic coverage | Above foramen magnum to T2 | Above frontal sinus to symphysis pubis |
| Voltage (kV) | 120 | 120 |
| Current | Automatic modulation | Automatic modulation |
| Pitch | 0.7 | 0.7 |
| Imaging and reconstruction planes† | Axial (2.0); coronal and sagittal (1.5); three-dimensional | Axial (2.0 for neck to 3.0 for whole body), coronal and sagittal (1.5 for neck to 2.0 for whole body), three-dimensional |
| Contrast agent | | |
| Iodine concentration (mg/dL) | None | 350 |
| Injection rate | Not applicable | 4 mL/sec for 15 sec, then 3 mL/sec |
| First bolus volume (mL) | Not applicable | 100 |
| Second (saline) bolus volume (mL) | Not applicable | 40 |
| Timing technique | Not applicable | Bolus tracking |
| Region of interest | Not applicable | Ascending aorta |

*Used for both 64- and 128-section scanning.

† Coronal, sagittal, and three-dimensional are reconstructions. Numbers in parentheses are section thickness in millimeters.

contrast material–enhanced chest and/or abdominopelvic CT. This technique involves scanning the entire cervical spine without intravenous administration of contrast material by using automatic exposure control on a 64- or 128-detector CT scanner with 0.6-mm configuration. We use 2-mm axial section thickness with a 1-mm reconstruction interval, with routine 1.5-mm-thick coronal and sagittal reformations. The isotropic data set obtained with current-generation multidetector CT scanners allows the routine generation of multiplanar reformations and three-dimensional reconstructions that provide useful information for selection of the appropriate treatment and surgical planning. Optimal visualization may assist in treatment decision making by helping in the identification of cervical injuries in need of surgical stabilization (38,47). Three-dimensional reconstructions are generated by the interpreting radiologist at the picture archiving and communication system workstation by using incorporated (thin client) software (Table 1).

### Whole-Body Multidetector CT in Severe Blunt Polytrauma

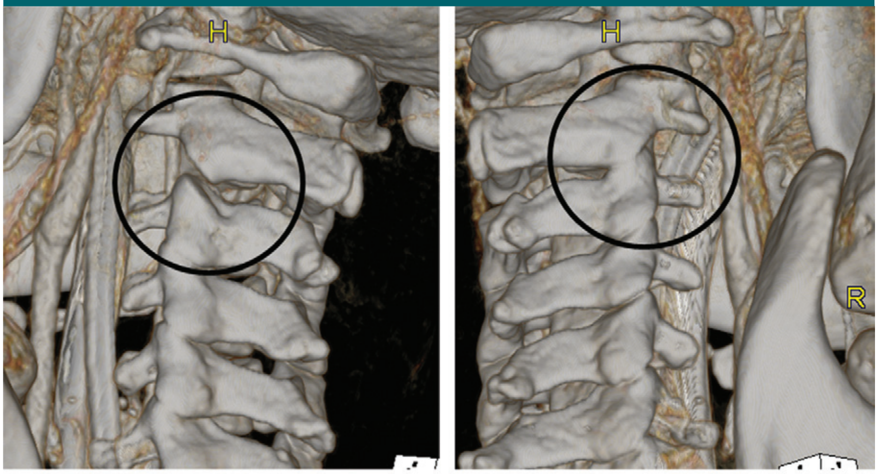
Whole-body multidetector CT is routinely used in patients with blunt polytrauma. This encompasses the cervical spine and contrast-enhanced body CT. The presence of intraarterial contrast material while scanning the neck allows simultaneous evaluation of the cervical spine and the carotid and vertebral arteries. An initial unenhanced examination of the head is obtained, followed by a single continuous acquisition from the circle of Willis to the symphysis pubis (48–50) (Table 1). The patient receives an intravenous injection of 100 mL of contrast agent (ioversol, Optiray [350 mg of iodine per millimeter]; Mallinckrodt Imaging, Hazelwood, Mo) at a rate of 4 mL/sec for 15 seconds, then at a rate of 3 mL/sec. This is followed immediately by a 40-mL 0.9% saline bolus at 4 mL/sec through an 18- or 20-gauge catheter located in an antecubital vein. We use an automated triggering device, with the region of interest placed in the ascending aorta.

## Biomechanics and Stability: Mechanisms of Injury

Currently, the commonly accepted classification system for predicting stability of the spine is the one described by Denis (51) in 1983—namely, the three-column system. Denis divided the spine into three columns: the anterior column, the middle column, and the posterior column. The anterior column comprises the anterior longitudinal ligament, the anterior two-thirds of both the vertebral body and the disk, and the anterior annulus fibrosus. The middle column is composed of the posterior one-third of the vertebral body and the posterior one-third of the disk, as well as the posterior longitudinal ligament (PLL). The posterior column is composed of the posterior vertebral elements: the ligamentum flavum, interspinous ligaments, and supraspinous ligaments. Stability of the spine can be predicted by the failure of two contiguous columns (51–55).

Stability of the spine may be defined as the ability to maintain normal alignment under normal loading and stress conditions. In evaluating stability of the cervical spine, four basic guidelines need to be assessed: namely, the anterior vertebral alignment, the posterior vertebral alignment, the spinolaminar line, and the spinous process line. In addition, there should be normal spacing of the facet joints, interspinous distances, and disk spaces. The facets should be parallel to each other, and the facet joint intervals should be relatively uni-

**Figure 2**




a. b.

**Figure 2:** Oblique sagittal volume-rendered CT images in a 29-year-old man involved in a motor vehicle collision. **(a)** Mild widening of the right C2-3 facet joint (circle) is shown. Compare with **(b)** the normal left facet joint (circle).

form (Fig 2). Disk spaces should also be symmetric, and there should not be widening or narrowing anteriorly or posteriorly (Fig 1). The interspinous or interlaminar distances should also demonstrate little variation. Vertebral body heights and their anteroposterior length, along with all osseous and soft tissues, should be assessed. By evaluating all these structures, the presence or absence of stability and the mechanism of injury may be determined. Each injury mechanism manifests a recognizable radiologic pattern, or what Daffner and colleagues (53,54) termed their radiologic "footprints."

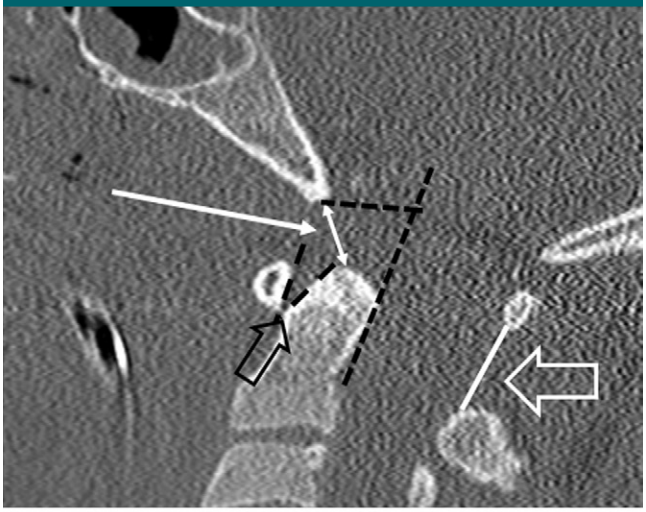
Injuries to the spine are caused by a variety of recognizable mechanisms. The four major patterns of injury are flexion, extension, rotational, and shearing. Each major mechanism may frequently be associated with other forces, making the injury pattern more complex. These include hyperflexion with rotation, hyperflexion with axial loading, hyperextension with rotation, distraction, lateral flexion, and rotation with flexion. These are all variations of the four major groups based on the vectors of the forces applied. A combination of mechanisms may also be recognizable, but a dominant force is usually apparent. Combinations of more than one spine injury are also reported in 10%–20% of cases, so careful inspection for other spine fractures is important (53–55).

A shearing injury is the result either of a force applied in one direction while another force acts in an opposite direction or of a force applied at one level while the torso above or below the applied energy remains fixed. In the spine, these injuries most commonly occur at the craniocervical junction and near the thoracolumbar junction. Craniocervical dissociation injuries result from direct trauma to the skull, such as when the skull strikes the dashboard of a car while the body is moving in a forward direction, thus creating a shearing force at the craniocervical junction. There are three recognized types of craniocervical dissociation. All craniocervical dissociation injuries involve a distractive force to some degree. In type 1 injuries, the initial force is directed in a posterior-to-anterior direction, resulting in ligamentous disruption with anterior translation and distraction of the skull base in relation to C1. The type 1 injury is the most common; it is seen in approximately 65% of cases (56–59) (Fig 3). The type 2 injury results from a distractive force to the skull that results in cephalad separation of the craniocervical junction (Fig 4). The type 3 injury is uncommon; it is seen in 3% of cases and is considered the most serious type of injury. Type 3 injuries result from force applied in the anterior to posterior direction, causing posterior translation and distraction at the craniocervical junction. Although type 3 injuries may be devastating, there is increasing evidence that some of these injuries are survivable (59,60). Chang et al (58) described multidetector CT measurements that are helpful in establishing the diagnosis of craniocervical distraction injury (Fig 3).

Rotational injuries may occur near the skull base and near the thoracolumbar junction. Injuries at C1-2 may cause rotatory fixation or rotatory dislocation, where the lateral masses of C1 are locked over C2. At the thoracolumbar junction, rotational injuries cause severe disruption of the vertebral bodies with fracture dislocations of the posterior elements, including the transverse processes and ribs (54,55,60). These associated injuries can help distinguish this type of injury from burst fractures because, as the name implies, there are rotational and hyperflexion forces. Daffner and colleagues (53,54) have also described that the fracture fragments are oriented in a circular array, thus demonstrating the rotational vector of the force.

Occipital condylar fractures are frequently missed on standard radiographs. With the advent of multidetector CT, these fractures appear to be more common than previously thought. Three types have been described (57,61,62). Type 1 condylar fractures are the result of compression injuries of the occipital condyle. These demonstrate nondisplaced fractures of the condyle and are considered stable (Fig 5). Type 2 fractures of the occipital condyles are actually extensions of an occipital skull fracture; they may extend unilaterally or bilaterally into the basion and are also considered stable (Fig 6). Type 3 fractures, however, have a displaced bone fragment from the occipital condyle into the spinal canal due to avul-

**Figure 3**



a.

b.

c.

**Figure 3:** **(a)** Sagittal midline CT multiplanar reformatted image in a 35-year-old man who had been in a motor vehicle accident shows type 1 atlanto-occipital dissociation with a widened basion-dens Interval (arrow) and basion–posterior axial line interval (dashed lines—both intervals greater than 12 mm). Note the V sign, indicating the abnormal divergent nature of alignment of the anterior arch of C1 with the dens (black open arrow). The white open arrow shows an increased midline C1-2 spinolaminar distance (> 8 mm). Patient underwent occipitocervical fusion with interval reduction in the atlanto-occipital subluxation (not shown). **(b)** Sagittal CT reformatted image in a 28-year-old man with a type 1 craniocervical distraction injury resulting from a motorcycle crash demonstrates anterior condylar displacement (circle). **(c)** Sagittal CT multiplanar reformatted image obtained after occipitocervical fusion shows reestablishment of normal craniocervical relationships.

**Figure 4**

**Figure 4:** Coronal CT reformatted image in a 25-year-old man involved in a motor vehicle collision demonstrates an extreme example of atlanto-occipital dissociation with cephalad separation of the craniocervical junction (type 2 injury) (*).

**Figure 5**

**Figure 5:** Coronal CT reformatted image in a 48-year-old woman with nondisplaced type 1 fracture of right occipital condyle (arrow) resulting from a motor vehicle collision.

sion at the attachment of the alar ligament (Fig 7). Type 3 fractures are considered to be unstable fractures (60).

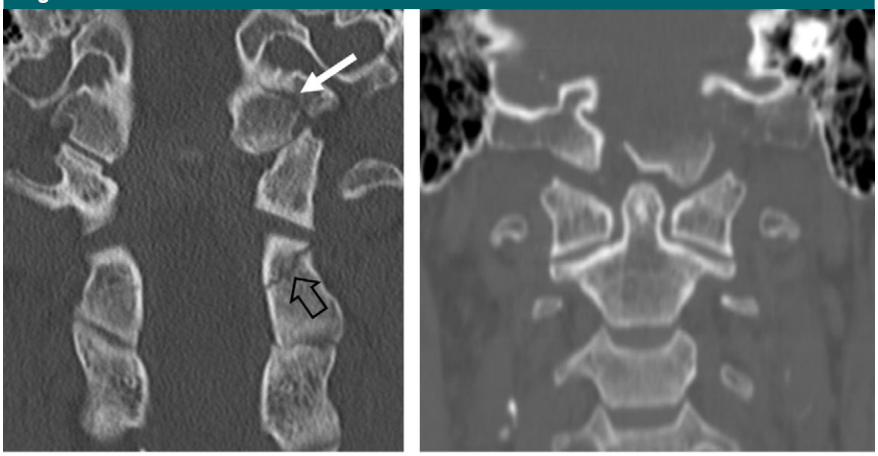
Fractures of the atlas (C1) may result from hyperextension injuries, as well as from pure axial loading injuries. Axial loading of the skull base on the axis can result from diving injuries or injuries resulting in direct loading of the

**Figure 6**

a. b.

**Figure 6:** **(a, b)** Coronal multiplanar CT images in a 52-year-old male pedestrian who was hit by a car show type 2 fracture of an occipital bone (arrow) extending into the left occipital condyle.

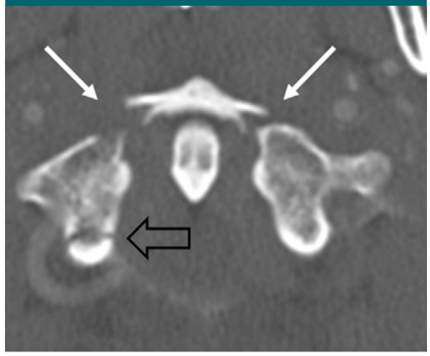
**Figure 7**



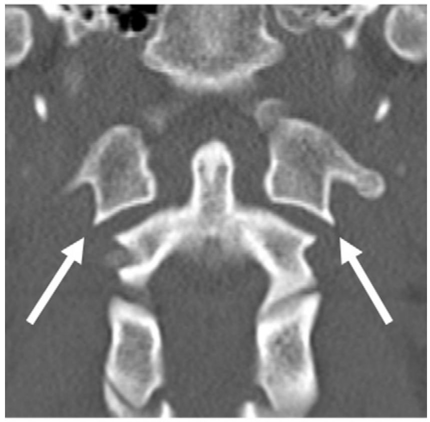
a. b.

**Figure 7:** **(a)** Multiplanar coronal CT reformatted image in a 27-year-old man involved in a motor vehicle collision shows a type 3 fracture with medial displacement of left occipital condyle (solid arrow). Nondisplaced fracture of left lateral mass of C2 (open arrow) is also shown. **(b)** Coronal CT reformatted image in a 46 year-old man involved in a motor vehicle collision shows type 3 fracture with severe displacement of left occipital condyle.

**Figure 8**



a.



b.

**Figure 8:** Jefferson fracture resulting from a diving accident in a 36-year-old man. **(a)** Axial CT image shows bilateral fractures of the anterior arch (solid arrows) and nondisplaced fracture of the lateral mass of C2 (open arrow). Patient also had bilateral posterior arch fractures (not shown). **(b)** Multiplanar coronal CT reformatted image shows lateral displacement of lateral masses of C1 relative to lateral margins of the axis (arrows).

skull on the cervical spine. This can result in fractures of the anterior arch of C1 at one or two locations, as well fractures of the posterior arch (Fig 8). Hyperextension injuries may result in compressive forces on the posterior arch that cause bilateral fractures of the posterior ring of C1. Avulsion fractures of the anterior arch can also occur with hyperextension at the attachments of the longus colli muscles or at the ligamentous attachments to the skull base.

The mechanism of injury of odontoid fractures is probably complex with multiple forces acting together. The Anderson-D'Alonzo classification system is the one most commonly used to describe dens fractures (55,60). A type I fracture is an avulsion of the tip. A type II fracture, the most common, is a transverse fracture through the base of the dens. A type III fracture extends into the body of C2 (Fig 9).

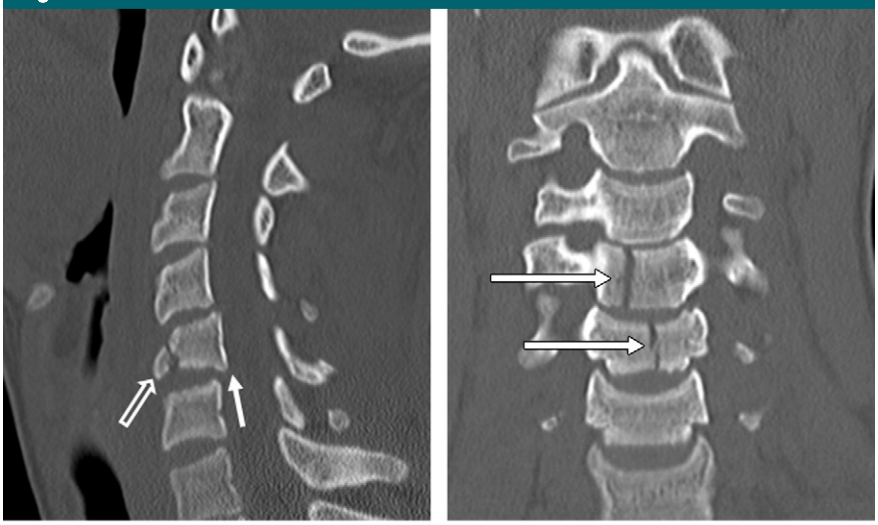
Hyperflexion injuries are the most common injuries to the spine; they are seen in 50%–60% of cases. In the thoracolumbar spine, these injuries are usually centered at the thoracolumbar junction, where the normal thoracic kyphosis is continuous with the lumbar lordosis. Injuries from hyperflexion mechanisms include hyperflexion sprains, a purely ligamentous injury, bilateral facet dislocations, anterior

**Figure 9**

a. b. c.

**Figure 9:** Dens fractures. **(a)** Rare type 1 odontoid fracture in a 20-year-old man involved in a motor vehicle collision. Coronal multiplanar CT reformatted image shows fracture (arrow) of tip of the dens secondary to avulsion of alar ligament. **(b)** Type 2 odontoid fracture in a 72-year-old woman after a fall. Coronal CT reformatted image shows fracture at base of odontoid above the plane of C2 lateral masses (arrow). **(c)** Type 3 odontoid fracture in a 26-year-old man involved in a diving accident. Coronal CT reformatted image fracture extending into body of C2 (arrow).

**Figure 10**



a. b.

**Figure 10:** Flexion teardrop fracture of C5 vertebral body in a 17-year-old girl involved in a motor vehicle collision. **(a)** Sagittal CT reformatted image shows anteriorly displaced fragment (open arrow) and retropulsion of C5 vertebral body (arrowhead). **(b)** Coronal CT reformatted image shows sagittal fractures through C4 and C5 vertebral bodies (arrows).

wedge compressions of the vertebral body, clay shovelers fractures, flexion teardrop fractures, and Chance-type fractures. The addition of a rotational component and posterior distraction with hyperflexion injuries can result in unilateral facet dislocations. Axial loading and accompanying hyperflexion will lead to burst fractures. Forces acting along the coronal plane—that is, a lateral flexion injury—give rise to occipital condylar fractures and odontoid fractures, as well as lateral compression of the vertebral bodies (53–55,60,63,64) (Fig 7).

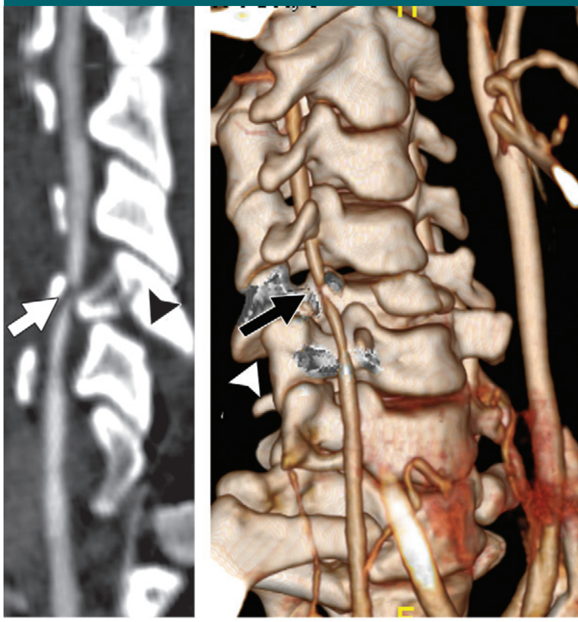
In general, hyperflexion injuries cause narrowing of the anterior disk space with distraction of the posterior ligament complex and the posterior disk space. Anterior translation of the vertebral body and posterior elements may also be present, distinguishing this injury from anterior subluxations caused by hyperextension injuries wherein the spinolaminar line is not usually displaced. The radiologic findings of hyperflexion injuries include widening of the interlaminar and interfacet spaces and compression fractures of anterior vertebral bodies, resulting in displaced fractures of the anterior inferior body (teardrop fracture) (Fig 10) and, if accompanied with axial loading such as that seen with direct force on the vertex of the head, can result in burst fractures of the vertebral body (Fig 11). Hyperflexion injuries disrupt the posterior ligament complex and cause widening of the interspinous, interlaminar spaces, as well as widening of the facet joints and disruption of the posterior column and middle columns (Fig 12). Bilateral facet dislocation is seen with severe hyperflexion and can result in severe neurologic injury (54,55,60,64).

Hyperextension injuries are more common in the cervical spine than in the thoracolumbar spine (Fig 1). They tend to widen the anterior disk space and may be associated with fracture dislocations of the facet joints and pedicles. Vertebral bodies can be dislocated posteriorly or anteriorly; however, anterior subluxations of the vertebral bodies result when there is failure of the middle column and posterior vertebral elements, the laminae

**Figure 11**

**Figure 11:** Burst-type fracture in a 65-year-old man after a fall from 15 feet (4.5 m). Sagittal CT reformatted image shows C7 fracture with retropulsion into spinal canal. Also note small fracture at anterosuperior aspect of T1 (arrow).

**Figure 12**



a. b.

**Figure 12:** Hyperflexion injury in a 17-year-old boy involved in a motorcycle crash. **(a)** Sagittal oblique CT curved reformatted image and **(b)** volume-rendered CT image show severe focal narrowing of right vertebral artery (arrow), indicating dissection (grade 2 injury) and bilateral C4-5 facet fracture-subluxation (arrowhead) (only the right side is shown).

and pillars. Traumatic spondylolisthesis of C2, known as *hanged man's fracture* is a group of injuries with variable mechanisms (Fig 13). Hanged man's fractures cause distraction anteriorly with fractures through the posterior arch or posterior vertebral body (atypical hanged man's fracture) or a combination of the two. Most of these fractures are due to hyperextension forces and are usually stable. Anterior or posterior subluxations may be seen with this type of fracture. When anterior subluxations occur with hyperextension injuries, the interlaminar line remains intact, as does the interspinous distance, distinguishing this injury from a hyperflexion injury wherein the posterior ligamentous structure and middle column are distracted.

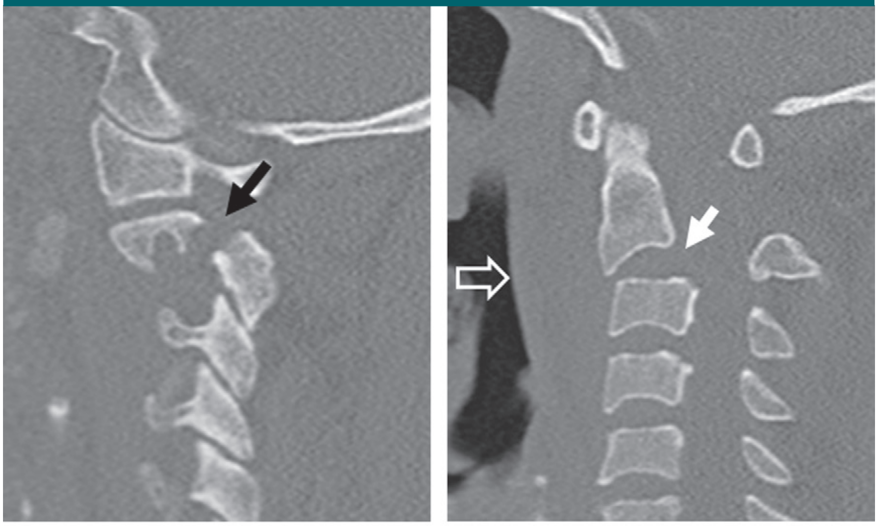
## The Subaxial Cervical Spine and Thoracolumbar Injury Classification

The majority of the classification systems currently in use in clinical practice are primarily descriptive and are based on presumed injury mechanisms (65,66). Several years ago, a new classification system was proposed by Vaccaro et al (67,68), who based the system on three injury characteristics for the thoracolumbar and, later, the subaxial cervical spine—the Thoracolumbar Injury Classification and Severity score (67) and the Subaxial Cervical Spine Injury Classification system (68). This new classification system puts greater focus on the posterior ligamentous complex and its integrity rather than on the middle column and takes into account the morphology of the injury and the clinical neurologic status of the patient, with each category being assigned points related to the severity of the findings (68–71). When combined, the clinical and radiologic findings generate a numeric score that can help predict the need for surgical intervention (Tables 2, 3). The authors reported the need for cervical spine surgical intervention in 76% of patients with a score of 7 (Fig 1). A thoracolumbar injury with a score higher than 4 would require intervention, that with a score less than 4 could be treated conservatively, and that with a score of 4 could be managed either way. This scoring system has been shown to be reliable and reproducible for all levels of experience (71). The injury morphology patterns assessed on imaging studies include compression, burst, distraction, and rotation and translation. The anatomic components of discoligamentous complex comprise the intervertebral disk and the anterior and posterior ligamentous structures. The neurologic status of the patient is the third component evaluated in this classification system; it includes nerve root injury and complete and partial spinal cord injury.

## Multidetector CT Findings of Associated Blunt Cerebrovascular Injuries

Blunt carotid and vertebral arterial injuries, collectively known as blunt cerebrovascular injuries (BCVIs), are the result of nonpenetrating trauma to the neck. Motor vehicle accidents are the most common mechanism of injury, causing up to 80% of BCVIs. Other less frequent causes include falls, diving injuries, chiropractic manipulation, assault, and hanging (72–74). Symptomatic patients who present with focal neurologic deficit unexplained by neuroimaging findings may have a reported morbidity of up to 80% and associated mortality of up to 59% (75,76)). These injuries, however, are often initially asymptomatic for up to 72 hours (72,77). This has led to the implementation of aggressive screening programs to enable early detection and treatment of these injuries, before the development of a neurologic deficit (75). The need to identify a BCVI while the patient remains asymptomatic has been strengthened by the results of studies that have shown a significant improvement in neurologic outcome with early treatment with anticoagulation or antiplatelet agents (74–76). Moreover, screening and treatment of BCVI has been shown to be cost effective (77). Although previously thought to be extremely rare, the incidence of these injuries after the implementation of this liberal approach to screening is around 1% of patients with blunt trauma (76). Screening criteria for BCVI include skull base fractures (particularly those extending into the carotid canal), cervical spine fractures involving C1-3, foramen transversarium, and cervical subluxation or dislocations, LeFort II or III facial fractures, Glasgow Coma Scale score of less than 6, and/or severe chest injuries (77–84).

**Figure 13**



a. b.

c.

**Figure 13:** Hanged man's fracture in a 50-year-old man involved in a motor vehicle collision. **(a)** Parasagittal CT image of cervical spine shows bilateral fractures (arrow) through the pars interarticularis (only left side shown). **(b)** Midsagittal CT reformatted image shows slight anterior displacement and widening of posterior C2-3 disk space. Note anterior angulation related to combined flexion and extension forces, indicating unstable injury (solid arrow), and prevertebral soft-tissue edema (open arrow). **(c)** Volume-rendered CT sagittal image shows associated occlusion of left vertebral artery (open arrows; grade 4 injury) and fracture of the pars interarticularis (solid arrow).

Vertebral artery injuries associated with cervical spine fractures are most likely to occur in the foraminal (V2) segment, where the artery is immediately adjacent to osseous structures. Because of its location within the foramen transversarium, the vertebral artery is at risk for injury in cervical spine trauma. Vertebral artery injuries can occur as a result of direct trauma from bone fragments or from excessive stretch in fractures and dislocations (85). Vertebral artery injury is seen more frequently with multilevel foramina fractures and in patients with foramen transversarium fracture comminution (86). The reported incidence of vertebral artery injury in patients who sustain cervical spine trauma is between 17% and 46% (86–88). Approximately 70% of these injuries are associated with a cervical spine fracture (86,89,90).

The outcome in patients with vertebral artery injury is variable, ranging from no neurologic deficits to posterior circulation stroke and death. Neurologic deficits may be caused by several mechanisms, including vertebrobasilar insufficiency when both vertebral arteries are severely narrowed or occluded or when the dominant vertebral artery is injured. Thrombus formation at the injury site, with resultant distal embolization, may also cause neurologic sequelae. Emboli are more common in nonocclusive injuries such as dissection or pseudoaneurysm (86,91–94).

In the evaluation of BCVIs, conventional angiography has been the reference standard imaging modality, but it has limitations, including its invasive nature, cost, logistic constraints, and potential complications (94). Multidetector CT angiography is increasingly being used as screening modality in the evaluation of cerebrovascular injuries because of its widespread availability. CT angiography can easily be performed in the same setting as CT for other traumatic injuries and is emerging as an accurate, rapid, noninvasive diagnostic alternative in the initial evaluation of

**Table 2**

**The Thoracolumbar Injury Classification and Severity (TLICS) Score**

| Feature | No. of Points |
|---|---|
| Injury morphology | |
| Compression (eg, axial, lateral) | 1 |
| Burst | 2 |
| Translational or rotational (eg, unilateral, bilateral facet dislocation) | 3 |
| Distraction (flexion, extension) | 4 |
| Posterior ligamentous complex | |
| Suspected or indeterminate | 2 |
| Injured | 3 |
| Neurologic status | |
| Nerve root | 2 |
| Complete cord injury | 2 |
| Incomplete cord injury | 3 |
| Cauda equina | 3 |

Source.—Reference 67.

**Table 3**

**The Subaxial Cervical Injury Classification (SLIC) System**

| Feature | No. of Points |
|---|---|
| Injury morphology | |
| Compression | 1 |
| Burst | 2 |
| Distraction (eg, perch facet, hyperextension) | 3 |
| Rotational or translational (eg, severe flexion or compression injury, facet dislocation, teardrop) | 4 |
| Discoligamentous complex | |
| Indeterminate | 1 |
| Disrupted (eg, widening of anterior disk space, perch facet or dislocation, kyphotic deformity) | 2 |
| Neurologic status | |
| Root injury | 1 |
| Complete cord injury | 2 |
| Incomplete cord injury | 3 |

Source.—Reference 68.

patients who present to the emergency department with possible BCVIs (38,50,72–76,78,81,95–101). For these reasons, multidetector CT has been adopted as the screening modality of choice at many trauma centers (38, 50,51,73–75,81,83,98,100).

Owing to the presence of some conflicting results, results from the available studies do not definitively answer the question about the true accuracy of multidetector CT angiography (100–102); CT criteria for diagnosis of arterial injury include vessel irregularity, wall thickening secondary to mural hematoma, abrupt caliber change, raised intimal flap, intraluminal thrombus, pseudoaneurysm, occlusion, active extravasation, and early venous filling (arteriovenous fistula) (50,51,78,103–105) (Figs 12, 13).

Biffl et al (106,107) proposed a classification for blunt carotid artery injury that has gained great acceptance and has also been widely applied to blunt vertebral artery injury. In this classification, a grade 1 injury involves arterial wall irregularity or dissection or intramural hematoma causing luminal narrowing of less than 25%; a grade 2 injury, intraluminal thrombus, raised intimal flap, or dissection causing luminal narrowing of 25% or greater; a grade 3 injury, pseudoaneurysm formation; a grade 4 injury, vessel occlusion; and a grade 5 injury, vessel transection or arteriovenous fistula. In general, higher grades of injury are associated with increased risk of stroke, although for the vertebral circulation, grade 2 injuries more frequently cause ischemic events. The reported stroke rate in vertebral artery injury is 24% and does not increase with injury grade (88). The reported stroke incidence of stroke associated with blunt carotid injury is 3%, 11%, 33%, 44%, and 100%, for Grades 1–5, respectively (107,108).

## Conclusion

As CT technology has evolved, whole-body multidetector CT has become an integral part of the initial assessment of many injured patients. Cervical spine CT is easily included in the whole-body screening performed in patients with severe blunt polytrauma.

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