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REVIEW ARTICLE

Radiological protocol in spinal trauma: literature review and Spinal Cord Society position statement

P. K. Karthik Yelamarthy[1] · H. S. Chhabra[1] · Vedant Vaksha[1] · Yatish Agarwal[2] · Anita Agarwal[1] · Kalidutta Das[1] · Hans Joseph Erli[3] · Mihir Bapat[4] · Roop Singh[5] · Darshan Gautam[6] · Rushama Tandon[7] · G. Balamurali[8] · Sriram Rajan[9]

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Abstract

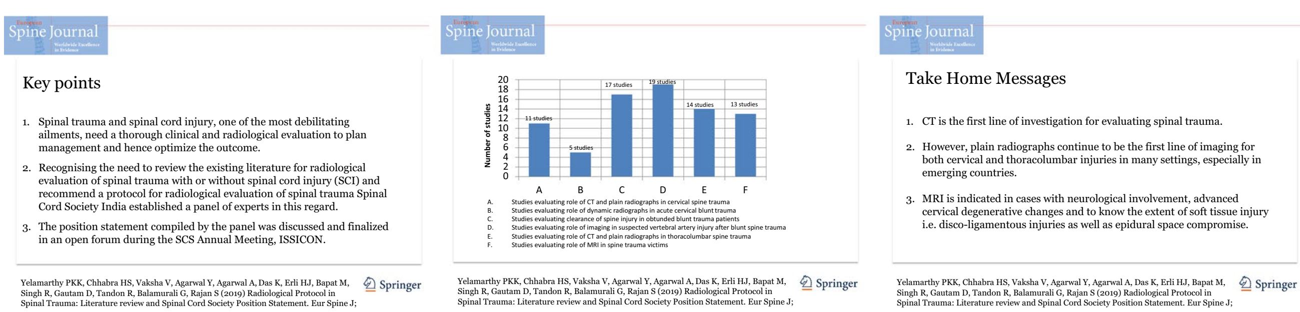
Purpose The Spinal Cord Society constituted a panel tasked with reviewing the literature on the radiological evaluation of spinal trauma with or without spinal cord injury and recommend a protocol. This position statement provides recommendations for the use of each modality, i.e., radiographs (X-rays), computed tomography (CT), magnetic resonance imaging (MRI), as well as vascular imaging, and makes suggestions on identifying or clearing spinal injury in trauma patients.

Methods PubMed was searched for the corresponding keywords from January 1, 1980, to August 1, 2017. A MEDLINE search was subsequently undertaken after applying MeSH filters. Appropriate cross-references were retrieved. Out of the 545 articles retrieved, 105 relevant papers that address the present topic were studied and the extracted content was circulated for further discussions. A draft position statement was compiled and circulated among the panel members via e-mail. The draft was modified by incorporating relevant suggestions to reach a consensus.

Results and conclusion For imaging cervical and thoracolumbar spine trauma patients, CT without contrast is generally considered to be the initial line of imaging and radiographs are required if CT is unavailable or unaffordable. CT screening in polytrauma cases is best done with a multidetector CT by utilizing the reformatted images obtained when scanning the chest, abdomen, and pelvis (CT-CAP). MRI is indicated in cases with neurological involvement and advanced cervical degenerative changes and to determine the extent of soft tissue injury, i.e., disco-ligamentous injuries as well as epidural space compromise. MRI is also usually performed when X-rays and CT are unable to correlate with patient symptomatology.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.



Keywords Cervical spine trauma · Thoracolumbar spine trauma · Spinal cord injury · X-rays · Computed tomography · Magnetic resonance imaging · Protocol · Position statement

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Extended author information available on the last page of the article

Introduction

Spine trauma and SCI can be one of the most debilitating ailments. It affects not only an individual's health but also creates an enormous burden on the family and society. Good clinical and radiological evaluations are important to plan management and thereby optimize the outcome. Plain radiographs have several limitations, including the non-visualization of low-contrast structures with an acceptable amount of radiation exposure. The introduction of CT was a major imaging advancement. CT is more sensitive to density variations than ordinary X-rays and is faster. Over the last decade, a massive shift has been observed in the imaging assessment of spine trauma. For suspected spinal injury, for example, the assessment has become more prompt and precise by shifting from X-rays to CT. Furthermore, the advent of MRI has helped provide better visualization of the spinal cord and soft tissue structures such as ligaments, disk, and blood vessels than was possible with CT or X-rays. Accessibility to diagnostic imaging is better in developed countries when compared to less and least developed countries. In these countries with large patient populations, low-cost diagnostic imaging modality such as X-rays is more frequently used compared to capital intensive equipment such as CT and MRI.

The Spinal Cord Society established a panel tasked with reviewing the current indications for radiological evaluation of spinal trauma and recommend a protocol for the radiological evaluation of spinal trauma in the current scenario. This panel consisted of various national and international experts from orthopedics, radiology, spine, and neurosciences. A coordinator for the panel was selected from the Indian Spinal Injuries Centre, New Delhi. The task of the coordinator was to compile the existing literature on radiological evaluation in spinal trauma and circulate the same along with a draft protocol among the panel members for their comments via e-mail. The draft was modified by incorporating the relevant suggestions and recirculated to reach a consensus. The final recommendations of the panel were subsequently discussed in an open forum during the annual meeting of the Spinal Cord Society (ISSICON) held in New Delhi, India.

This paper presents the assessment of data regarding the radiological evaluation of spine trauma. The current literature regarding the indications of various imaging modalities in spinal trauma is reviewed and critically analyzed. The paper puts forth the panel's recommendations for the radiological protocol in spinal trauma.

Sources of data

A PubMed search was done for the keywords "cervical spine trauma, thoracolumbar spine trauma, spinal cord injury, X-rays, computed tomography, and magnetic resonance imaging" from January 1, 1980, to August 1, 2017. The search retrieved 22139 articles. Additionally, a MEDLINE search was undertaken for the same search terms after applying additional filters, such as MeSH major topic and MeSH term guidelines. Further appropriate cross-references were retrieved wherever necessary, and a total of 545 articles were retrieved. Out of the 545 articles, the titles, abstracts, and full texts (where required) of 105 relevant articles that address the present topic were studied (Supplemental Data, Table 1). The content was extracted from the relevant papers and presented/circulated for further discussions.

Literature review

Cervical spine trauma

Whom to image

Despite the universal accordance on the necessity of performing imaging for clearing blunt cervical spine (CS) trauma victims, optimal patient selection has remained debatable over the years [1]. The Canadian Cervical Spine rule (CCR) and National Emergency X-radiography Utilization Study (NEXUS) are the two established rules available to select candidates requiring imaging of the cervical spine. As per the NEXUS conducted by Hoffman et al. [2] (1998, p 463), cervical spine radiography is indicated for patients with trauma unless they meet all of the following criteria:

a. No posterior midline cervical spine tenderness
b. No evidence of intoxication
c. A normal level of alertness
d. No focal neurologic deficit
e. No painful distracting injuries

Stiell et al. [3] (2001, p. 1846) concluded in their study that "patients with age $\geq$ 65 year or dangerous mechanism of injury or paresthesia in extremities need to be evaluated and those patients who are ambulant and comfortably sitting in the emergency department after a simple rear-end collision and with preserved ability to actively rotate their neck or with delayed onset of neck pain but without corresponding midline tenderness can be cleared of cervical spine injury."As per a prospective cohort study, the sensitivity and specificity of CCR for selecting candidates for cervical spine imaging after blunt trauma are better than that of NEXUS low-risk criteria (NLC), and its use thereby reduces the rates of radiographic assessment [4].

Choice of imaging

Plain Radiographs Plain radiography provides a comprehensive overview of the extent and magnitude of injury and can provide a definitive and specific diagnosis of certain spinal injuries. Plain radiographs had for long been considered to be the standard first-line screening tool to analyze blunt trauma victims suspected to have spinal injuries. Plain film radiography is the principal imaging modality for evaluating blunt trauma victims across a majority of the world who do not have ready access to CT [5, 6].

CT versus plain radiographs

Studies comparing the use of CT and plain radiographs for cervical spine imaging are summarized in Table 1.

According to a retrospective study by Gale et al., plain cervical spine radiographs (CSR) are considered adequate for the complete evaluation of blunt cervical spine trauma only along with supplemental CT, and a dedicated CT of the cervical spine—if available—provides more precision and effectiveness in evaluating such injuries [7]. In one prospective analysis by Berne et al., the sensitivity of CSR and CT cervical spine (CTCS) in blunt trauma patients was 60% and 90%, respectively [8]. As per a study undertaken by Mathen et al., CTCS has more specificity and sensitivity when compared to plain radiographs in detecting acute cervical injuries and plain radiographs provided no extra clinically relevant information in such cases [9]. Diaz et al. in their prospective study observed that CTCS is the most specific and sensitive tool for the diagnosis of bony injuries

Table 1 Studies comparing the usage of CT and plain radiographs for cervical spine imaging

Sl.No	Author	Year of publication	Level of evidence	Conclusion/remarks
1	Gale et al. [7]	2005	Retrospective cohort study—level 3	Either complete CT or cervical spine X-rays with supplemental CT are required in blunt cervical trauma for cervical spine evaluation in blunt cervical trauma
2	Berne et al. [8]	1999	Prospective case series—level 4	CT is superior to plain radiographs for diagnosing cervical spine injuries
3	Mathen et al. [9]	2007	Prospective case series—level 4	CT outperformed plain radiography as a screening modality for the identification of acute cervical spine injury in trauma patients
4	Diaz et al. [10]	2005	Prospective case series—level 4	Helical CT is not only sensitive and specific but also cost-effective tool for screening cervical spine bony injuries. F and for ligamentous injuries, MRI is superior to CT
5	Diaz et al. [11]	2003	Prospective case series—level 4	CT is preferred over five-view radiographs in patients with altered mentation or distracting injuries
6	Holmes [12]	2005	Meta-analysis—level 3	CT outweighs plain radiographs in blunt trauma victims with a high risk of cervical spine injury and plain radiographs are preferred in less injured patients with less significant trauma with loweress risk of cervical spine injury
7	Blackmore et al. [13]	1999	Level 5	CT is the preferred screening modality in blunt trauma patients at high and moderate risk of cervical spine fracture
8	Daffner et al. [14]	2007	Level 5	MRI and CT have an important role in evaluating acute spine trauma. Dynamic radiographs are useful in late stages to document residual instability
9	Kortbeek et al. [15]	2008	Level 5	CT and MRI are the most useful modalities in acute blunt spine trauma imaging
10	Ackland [16]	2012	Level 5	Blunt cervical trauma victims need accurate clinico-radiological examination and radiographic screening with CT or five-view plain radiographs, if CT is unavailable. MRI is indicated in victims with neurological symptoms or advanced cervical degenerative disease
11	Vaccaro et al. [17]	2007	Level 3	CT and MRI have a crucial role in classifying the subaxial cervical injuries

of the cervical spine but not for ligamentous injuries [10]. Another prospective study by Diaz et al. [11] concluded CTCS to be better than five-view plain radiographs in evaluating hemodynamically stable patients, but with an abnormal mentation or a painful distracting injury. A meta-analysis by Holmes and Akkinepalli concluded that the sensitivity of CTCS in identifying cervical spine injuries is better than that of plain radiographs [12]. The study undertaken by Blackmore et al. [13] observed that CTCS was cost-effective when compared to plain films in evaluating medium- to high-risk patients with suspected cervical spine trauma. International guidelines suggest CTCS as the initial imaging tool for cases with a suspected injury to the cervical spine [14]. As per the ATLS and Spinal Cord Trauma guidelines, good quality radiographs of the cervical spine (anteroposterior, lateral, and odontoid view), if accurately interpreted along with axial CT of the suspicious area and the cervicothoracic junction (if no adequate visualization is available in the plain radiographs), can sensitively identify unstable cervical spine injuries [15]. The Victorian State Trauma System Cervical Spine Acute Care Guidelines suggest that radiographs are required only if CT is unavailable, in which case a minimum of three and preferably five high-quality plain radiographs (anteroposterior, lateral, odontoid, right, and left oblique views) with visualization of all the cervical vertebrae should be performed and ideally be reported by a radiologist [16]. Moreover, CT along with MRI cervical spine (MRICS) helps classify subaxial cervical spine injuries using the SLIC classification system [17].

Role of MRI As per a study by Geck et al., if an occult cervical injury is suspected in patients with negative plain radiographs, they should be investigated by MRI to detect soft tissue (disk and ligaments) injuries [18]. As per the Royal Australian College of General Practitioners (RACGP) guidelines, MRI is indicated to rule out discoligamentous injury in patients with neurological symptoms or advanced degenerative changes in the cervical spine [16].

Role of dynamic radiographs

Studies analyzing the use of dynamic radiographs after blunt cervical trauma are summarized in Table 2.

Insko et al. [19] in their retrospective review identified that dynamic radiographs of CS offer high sensitivity for ligamentous injuries after acute blunt cervical trauma only if there is adequate flexion and extension (greater than 30 degrees from the neutral cervical spine position). Eight percent of the trauma patients in the study group in one retrospective analysis by Lewis et al. displayed dynamic instability, among whom 36% had normal radiographs [20]. No neurological adverse effects of performing dynamic radiographs were observed. In another retrospective analysis by Brady et al. [21], 1.3% of the trauma patients in the study group with normal radiographs indicated instability on flexion/extension radiographs. However, none of them required surgical stabilization. A secondary analysis of the NEXUS cohort by Pollack et al. [22] concluded that dynamic radiographs have a minimal role in evaluating blunt trauma victims in the acute setting.

Table 2 Studies analyzing the role of dynamic radiographs after blunt Cervical trauma

Sl.No	Author	Year of publication	Level of evidence	Conclusion/remarks
1	Insko et al. [19]	2002	Prospective case series—level 4	There is limited diagnostic utility of dynamic radiographs due to limited flexion and extension motion on physical examination should make the usage of dynamic radiographs impossible, as they are of limited diagnostic utility
2	Lewis et al. [20]	1991	Retrospective Case series- Level 4	A larger prospective study is required to determine which patients warrant where dynamic cervical spine radiographs are warranted
3	Brady et al. [21]	1999	Retrospective Case series- Level 4	Blunt trauma victims with abnormal static cervical spine X-rays are more likely to have abnormal findings on dynamic X-rays
4	Pollack et al. [22]	2001	Prospective case series—Level 4	Dynamic radiographs add little to patient evaluation in acute blunt trauma. However, MRI or CT or delayed dynamic radiographs are depict a reasonable approach in specific clinical situations
5	Timothy et al. [23]	2013	Level 5	In an awake patient with neck pain and no neurological deficit but a normal CTCS with no neurological deficit, the cervical collar can be continued or may be removed after a negative MRI done within 72 h of injury or negative adequate dynamic radiographs. However, the role of MRI and dynamic radiographs in discontinuing the cervical spine immobilization is yet to be further determined by further high-quality prospective multi-centric controlled trials

Clearing Cervical Spine Injury in Alert Patients

As per the recommendations of Timothy et al. [23], "for awake and responsive patients with neck pain but no neurological deficit and normal CTCS, there are several management options but limited evidence. The cervical collar may be continued. Alternatively, it may be removed after a negative MRI performed within 72 h of injury or negative adequate dynamic radiographs or at the discretion of the doctor."

Table 3 Studies analyzing the clearance of spinal injury in obtunded blunt trauma patients

Sl.No	Author	Year of publication	Level of evidence	Conclusion/remarks
1	Griffen et al. [24]	2003	Retrospective case series—level 4	CTCS should replace cervical spine radiographs in acute blunt trauma evaluation of cervical spine in awake or obtunded trauma victims
2	Brohi et al. [25]	2005	Retrospective case series—level 4	Helical CTCS allows rapid and safe evaluation of obtunded and intubated blunt trauma victim
3	Anglen et al. [26]	2002	Retrospective review—level 4	Dynamic radiographs are not cost-effective in the evaluation of acute cervical blunt trauma victim
4	Bolinger et al. [27]	2004	Prospective review—level 4	Dynamic radiographs are no longer an option in trauma center protocols in obtunded head injured victims
5	Davis et al. [28]	2001	Prospective case series—level 4	Dynamic radiographs are to be done only if static X-rays show no obvious injury in the entire extent of cervical spine including cervicothoracic junction. Otherwise plain radiographs with CT are recommended
6	Padayachee et al. [29]	2006	Retrospective study—level 4	Dynamic cervical spine radiographs have no role in the evaluation of obtunded blunt trauma victims
7	Stassen et al. [30]	2006	Retrospective study—level 4	CT with MRI is preferred over CT alone in obtunded blunt cervical trauma victims
8	Hogan et al. [31]	2005	Prospective case series—level 4	A normal CTCS in obtunded blunt trauma victim can safely exclude unstable cervical spine injuries
8	D'Alise et al. [32]	1999	Prospective Case series—level 4	MRI is safely and reliably excludes hidden cervical spine injury in obtunded patients
9	Albrecht et al. [33]	2001	Retrospective review—level 4	MRI is preferred over dynamic radiographs in evaluating obtunded blunt trauma victims
10	Horn et al. [34]	2004	Retrospective review—level 4	Though MRI is sensitive for detecting soft tissue injuries, it doesn't help in determining cervical instability if CTCS is normal. It and may lead to the unnecessary investigation when it is otherwise not unindicated
11	Ghanta et al. [35]	2002	Retrospective review—level 4	EAST guidelines for obtunded patients appear safe in detecting bony injury but may not be sensitive enough for unstable ligamentous injuries and significant disk herniations
12	Sarani et al. [36]	2007	Retrospective review—level 4	This study supports the practice of obtaining c-spine MRI is indicated in patients who are either unexaminable or symptomatic with the CTCS being normal
13	Schuster et al. [37]	2005	Prospective case series—level 4	Blunt trauma patients with normal motor examination results and normal CT results of the cervical spine do not require further radiologic examination for before clearing the cervical spine
14	Adams et al. [38]	2006	Retrospective review—level 4	MRI trauma protocol should be reserved for cases when initial CT scanning is suggestive of traumatic cervical injury
15	Como et al. [39]	2007	Prospective case series—level 4	MRI is not unnecessary in obtunded patients when CTCS is normal and This allows early removal of a cervical collar thereby, reducing health care costs and complications of cervical collars
16	Stelfox et al. [40]	2007	Prospective case series—level 4	A normal CTCS allows discontinuation of the cervical collar in obtunded blunt trauma victims thereby, reducing with fewer complications and reduced ICU stay
17	Plumb et al. [41]	2012	Level 5	Clinicians can either use MDCT alone or MDCT followed by MRI can to clear spinal injury in obtunded blunt trauma victims

Clearing spine injury in obtunded patients

Studies analyzing the clearance of spinal injury in obtunded blunt trauma patients are summarized in Table 3.

Griffen et al. [24] concluded that plain radiographs have no role in evaluating blunt trauma victims qualified for imaging using the CCR or NEXUS criteria. Their study evaluating such patient cohort showed that plain radiographs missed 35% of traumatic cervical spine injuries, but CTCS missed none of them. The study by Brohi et al. [25], which evaluated blunt trauma victims with poor Glasgow Coma Scale (GCS), showed that adequate lateral films had a sensitivity of 53.3% in identifying unstable cervical injuries and missed 45% of such injuries, but CTCS missed none of them. Though numerous studies analyzed the radiological workup of obtunded blunt trauma victims with a normal CTCS, a directive for evaluating such cases remains elusive. Many studies have been conducted to address the use of dynamic (lateral flexion and extension) radiographs in such patients, and as per the majority of them, dynamic radiographs had no role in clearing acute cervical spine injury in an obtunded blunt trauma victim [26–28]. Information provided by dynamic radiographs in evaluating such a patient cohort is not only cost ineffective and inadequate but is also dangerous [29]. MRI CS is more sensitive than CTCS in discerning spinal cord injury and soft tissue injuries and is thus recognized as the gold standard for diagnosing such injuries [30–34]. Nevertheless, the role of MRI CS in the workup of blunt trauma victims with negative CTCS is not evident in the literature and few studies consider it mandatory to use MRI. Moreover, few studies found that the significance of injuries identified by MRI CS in such patients is unclear while few other studies concluded that MRI is not necessary in such cases. In one retrospective analysis by Ghanta et al. [35], among the 51 obtunded blunt trauma victims who underwent CTCS and MRI CS, 10(20%) patients with a negative CTCS had an abnormal MRI among which 3(6%) were potentially unstable. Sarani et al. [36] also recommended MRI CS in candidates with negative CTCS examination. Eleven percent of their study group of blunt trauma victims with normal CTCS had soft tissue injuries detected on MRI CS. However, none of them required surgery and were treated conservatively. Moreover, D'Alise et al. [32] concluded that MRI CS obtained within 72 h should be used to clear obtunded patients with negative CTCS. Numerous studies have also suggested getting rid of cervical collar immobilization in obtunded blunt trauma victims with normal MRI CS obtained after a negative CTCS examination [30, 33, 34]. However, as per a study by Stassen et al. in patients with normal CTCS and injuries diagnosed with MRI CS, the stability of injuries has not been addressed. Among the 52 obtunded blunt trauma victims evaluated by CTCS and MRI CS, 30% with negative CTCS had an abnormal MRI CS [30]. Moreover, several other small study series have failed to show the significance of positive findings in the MRI CS of patients with a negative CTCS [37, 38]. However, the study conducted by Hogan et al. [31] with the largest cohort of patients with negative CTCS ($n=366$) evaluated with MRI CS showed that CTCS had 98.9% negative predictive value (362/366 patients) for soft tissue (ligaments) injury that increased to 100% for unstable CS injury. Another study of obtunded blunt trauma patients by Como et al. [39] concluded that MRI CS is unnecessary for evaluating such patients with no positive findings on CTCS. Only six out of the 115 obtunded patients with negative CTCS showed positive findings on MRI CS, and none of them required CS immobilization. In the prospective analysis of intubated polytrauma patients by Stelfox et al. [40] during the initial part of the study, either a negative clinical examination or a normal MRI CS was used along with a negative CTCS for the discontinuation of cervical immobilization. During the last year of their study, the authors used only a normal CTCS to terminate CS immobilization. They identified that their modified protocol reduced the complication rate, length of ICU stay, and mechanical ventilation in such patient cohort. However, as per a study by Helen Ackland [16], it is acceptable for practitioners to clear obtunded blunt trauma victims for suspected spine injury using MDCT alone or MDCT followed by MRI, with unclear superiority among the approaches. As per the recommendations of Timothy et al. [23],"In an obtunded patient cervical spine immobilization can be discontinued after a normal CT read by an experienced radiologist or after patient is asymptomatic or following a normal MRI obtained within 48 h of injury or at the discretion of the treating physician." Plumb et al. [41], in their review to clear cervical and TLS injury in obtunded blunt trauma victims, concluded that "Given the variability of screening performance it remains acceptable for clinicians to clear the spine of obtunded blunt trauma patients using MDCT alone or MDCT followed by MRI, with implications to either approach."

Vertebral artery imaging (VAI) in spine trauma

Studies analyzing the VAI in spine trauma patients are summarized in Table 4.

The prevalence of blunt cerebrovascular injury (BCVI) varies from 1 to 2.7% with a higher incidence in blunt polytrauma patients [42, 43]. Despite the relatively low incidence, BCVI can lead to catastrophic sequelae in the form of severe neurological deficit requiring long-term medical care [44]. Seat-belt injury to the anterior neck (aka cervical seat-belt sign), with a clinically normal examination and with no other risk factors, should not be the only criteria for imaging for BCVI [45, 46]. Cervical hyperextension/hyperflexion/rotational or direct blow injuries seem to be associated with BCVI. As per one

Table 4 Studies analyzing the role of imaging in VAI in spine trauma patients

Sl.No	Author	Year of publication	Level of evidence	Conclusions/remarks
1	Biffl et al. [42]	1998	Retrospective review—level 4	Screening for BCVI allows early identification thereby making anticoagulation possible. However, the role of endovascular stents for traumatic pseudoaneurysms is yet to be defined
2	Mutze et al. [43]	2005	Retrospective review—level 4	CTA is preferred over duplex Doppler USS to detect blunt Cerebrovascular injury
3	Cothren et al. [44]	2005	Prospective case series—level 4	High-risk patients for blunt carotid or vertebral artery injury should be subjected to screening with CTA to reduce the cost of long-term rehabilitation care
4	DiPerna et al. [45]	2002	Retrospective review—level 4	A cervical seat-belt sign should not serve as a sole indicator for evaluation of the carotid artery in the absence of other pertinent signs or symptoms
5	Rozycki et al. [46]	2002	Prospective study—level 4	The cervicothoracic seat-belt mark and an abnormal physical examination are an effective combination for screening off or cervicothoracic vascular injury
6	Kral et al. [47]	2002	Prospective case series—level 4	Blunt trauma victims with cervical dislocation or foramen transversarium stenosis should undergo early angiography to establish the diagnosis
7	Biffl et al. [48]	1999	Prospective case series—level 4	Patients sustaining high-risk injury mechanisms or patterns should be screened for BCVI especially in face of limited resources
8	Cothren et al. [49]	2003	Prospective case series—level 4	Blunt vertebral artery injury is associated with complex cervical spine fractures involving subluxation, extension into the foramen transversarium, or upper C1 to C3 fractures
9	Willinsky et al. [50]	2003	Prospective Case series—level 4	Age-related vascular disease accounted for the failure to lower the neurologic complication rate of cerebral angiography despite technological advances
10	Cogbill et al. [51]	1994	Retrospective review—level 4	Delayed neurologic symptoms may develop in a delayed fashion in blunt carotid artery trauma; however, a prior clinical suspicion and diagnostic evaluation testing are essential for diagnosis
11	Sturzenegger [52]	1993	Retrospective review—level 4	Even though the USS findings are not pathognomonic of blunt vertebral injury, it may confirm the clinical suspicion and help in decision making regarding anticoagulation treatment
12	Friedman [53]	1995	Prospective case series—level 4	Noninvasive assessment of the vertebral arteries by means of MR imaging should be an integral part of the evaluation of the acutely injured cervical spine
13	Weller [54]	1999	Prospective case series—level 4	Foramen transversarium fractures after blunt cervical trauma warrant flow-sensitive MRI
14	Bok et al. [55]	1996	Retrospective Case series—level 4	With modern methods of investigation and management, the prognosis of carotid and vertebral artery injury may be improved
15	Biffl et al. [56]	2002	Prospective case series—level 4	Routine follow-up arteriography is warranted in patients with grade I and II BCVIs. However, a prospective randomized trial will be necessary to identify the optimal treatment of BCVI
16	Levy et al. [57]	1994	Prospective case series—level 4	MR angiography is preferred for carotid artery dissection, and conventional arteriography is preferred for vertebral artery dissection
17	Eastman et al. [58]	2006	Prospective case series—level 4	CT angiography can be used to accurately screen at-risk patients for BCVI
18	Eastman et al. [59]	2009	Prospective case series —level 4	CT angiography reduces d the time to diagnose BCVI and hence thus reduces the time to initiate the anticoagulation therapy
19	Vertinsky et al. [60]	2008	Retrospective Case series—level 4	CT angiography is preferred for vertebral artery dissection. T and there i was no technique preference for carotid artery dissection

analysis by Kral et al. [47], patients with cervical fracture/dislocation causing transverse foraminal stenosis should undergo early angiography to detect BCVI and start anticoagulation. A study by Biffl et al. [48] identified four independent predictors for blunt carotid artery injury and single predictor for blunt vertebral artery injury by screening 249 patients. The four independent predictors for blunt carotid artery injury as per this study include “(1) Glasgow Coma Scale (GCS) < 6; (2) diffuse axonal injury; (3) Le Fort II or III fracture and (4) petrous bone fracture.” The authors found a 41% risk of blunt carotid artery injury in the presence of any of the four predictors, but in the presence of all four independent predictors, however, they observed an increase in the risk to 93%. The presence of cervical spine fracture is considered the sole risk factor for blunt vertebral artery injury. However, one fifth of patients with BCVI when screened with the Biffl criteria had no independent risk factors. This indicated that comprehensive selection principles are required to avert false-negative injuries [48]. Cothren et al. [49] in a retrospective analysis of blunt vertebral artery injury victims concluded that complex cervical spine dislocations/fractures extending into foramen transversarium and C1 to C3 injuries had a high association with blunt vertebral artery injury. In another study by the same authors, involving a review of the screening of blunt trauma patients with digital four-vessel cerebral angiography using Biffl criteria with a modification to incorporate specific fracture patterns, authors identified the screening yield for BCVI to be 34% [44]. Even though digital subtraction angiography is the available gold standard to date, its invasiveness and non-availability make its routine use difficult among head and neck injury patients. Additionally, the complication rate of 2% with digital subtraction angiography remains a concern [50]. Other screening options include duplex ultrasonography, CT angiography, and MR angiography. Though duplex ultrasonography is noninvasive and readily accessible, its sensitivity is very low in assessing vertebral arteries due to the technical limitations of the presence of bony foramen, coexisting neck stiffness, and central intravenous lines. It has a sensitivity of approximately 38.5% (BCVI) to 86% (carotid injuries alone) in various studies [43, 51, 52]. Thus, duplex ultrasonography cannot be utilized for screening BCVI. When imaging BCVI, MR angiography showed mixed results and some studies reported less valuable results [53–57]. In acute trauma patients, MR angiography also has the disadvantage of longer scanning time and challenges regarding safety in the scanning environment. CT angiography has shown a sensitivity of 99% for BCVI [58]. Moreover, screening with CT angiography reduced the diagnostic time 12-fold and stroke rate because of BCVI injury fourfold [59]. In one retrospective analysis by Vertinsky et al. [60], the imaging features of the dissection of cervical arteries are more visualized by multidetector CT angiography than that of MR angiography.

Thoracic and lumbar spine trauma

Whom to image

Back pain with or without back tenderness or neurological deficit after trauma is a universally accepted indication for TLS imaging. In one report by Terregino et al. [61], the specificity of back pain and back tenderness for thoracolumbar imaging was 89% and 94%, respectively. The incidence of non-contiguous spinal injury is relatively high, and cervical fractures are usually found in association with TLS fractures [61–63]. Though back pain and tenderness are specific factors in imaging, several other factors hinder the evaluation of a blunt trauma victim. Several studies have shown that GCS influences back pain/back tenderness perception. In one study by Frankel et al., it was found that GCS ≤ 8 poses more risk of TLS fracture in victims sustaining blunt trauma [64]. Even a subtle decrease in consciousness can make a clinical assessment of the spine erratic in blunt trauma victims [63, 65–67]. Several studies have also shown that drug or alcohol intoxication affects the clinical assessment of the spine in blunt trauma victims [67, 68]. In addition to increasing the risk of TLS fractures, major orthopedic and non-orthopedic injuries also hinder the clinical examination of the spine. Various definitions of major injuries exist in different studies; they are considered as injuries with an abbreviated injury scale score ≥ 3 in one study [65] and as fractures involving pelvis/long bones/significant chest or abdominal trauma in another study [63, 67, 69, 70]. Painful and distracting injury elsewhere delays the clinical diagnosis of cervical spine fractures in one study [71]. Some other studies concluded that the clinical examination of the spine yields false-negative results in the setting of other major injuries [63, 65].

Choice of imaging

Plain Radiographs The same as discussed for cervical spine injuries is also applicable here.

CT versus plain radiographs

Studies comparing the use of CT and plain radiographs for thoracolumbar spine imaging are summarized in Table 5.

Few studies [72, 73] reported the advantages of CT imaging in reclassifying and surgically evaluating the spinal fractures identified on plain radiographs, which changed surgical decisions. CT imaging also reclassified the diagnosis of transverse process (TP) fractures [74, 75]. In a study by Rhee et al. [76], it was found that non-reconstructed CT abdomen/pelvis with 5–10 mm slice thickness missed 23.2% of lumbar fractures while plain radiographs missed 12.7% of such fractures. However, in the same study, it was found that none of the fractures were missed if both are integrated or if a dedicated CT of the lumbar spine has been used.

There is clear evidence for the routine performance of CT-CAP in any blunt trauma victim with a head injury. In one prospective study screening blunt trauma victims with suspected TLS injury using contrast-enhanced CT-CAP and

Table 5 Studies comparing the role of CT versus plain radiographs for thoracolumbar spine imaging

Sl.No	Author	Year of publication	Level of evidence	Conclusions/remarks
1	Handelberg et al. [72]	1981	Case reports—level 5	CT enabled an easy, fast, accurate and reliable diagnosis of thoracolumbar fractures to be made, circumventing dangerous manipulation of the blunt trauma victim
2	Keene et al. [73]	1982	Case series—level 4	CT should replace conventional polytomography as the initial study to augment plain X-rays in the assessment of thoracic and lumbar fractures
3	Krueger et al. [74]	1997	Prospective case series—level 4	CT should be is considered if there are transverse process fractures of the lumbar spine as it decreases the risk of missing an injury
4	Patten et al. [75]	2000	Prospective case series—level 4	There is a statistically significant association between lumbar transverse process fractures and abdominal injury
5	Rhee et al. [76]	2002	Retrospective review—level 4	Abdominopelvic CT and two view plain radiographs together reduce the risk of missing lumbar fractures after blunt trauma
6	Hauser et al. [77]	2003	Prospective case series—level 4	CT is preferable over plain radiographs for thoracic and lumbar spine blunt trauma
7	Gestring et al. [78]	2002	Prospective case series—level 4	CT is preferred over plain radiographs for detecting thoracic and lumbar spine fractures after blunt trauma
8	Sheridan et al. [79]	2003	Prospective case series—level 4	Reformatted images can be obtained from CT done for abdominal or thoracic visceral injury and this reduces time, exposure and expense associated with plain X-rays
9	Wintermark et al. [80]	2003	Prospective case series—level 4	MDCT is better than plain radiographs and can replace them in patients who sustained severe blunt trauma
10	Brandt et al. [81]	2004	Retrospective Case series—level 4	R the authors recommend using the reformatted images from CT are recommended for to evaluating the spine
11	Berry et al. [82]	2005	Retrospective case series—level 4	Chest–abdomen–pelvis CT obtained during routine trauma evaluation in high-risk patients is more sensitive than plain radiographs for detecting thoracolumbar spine injuries
12	Ptak et al. [83]	2003	Case series—level 4	A whole-body single-pass trauma protocol results in lower reduced radiation dose as when compared to that of segmented acquisition
13	Kim e al. [84]	2010	Prospective case series—level 4	Reformatted images obtained from visceral targeted CT are sufficient for screening thoracolumbar spinal injuries
14	Howes et al. [85]	2006	Level 5	Thoracolumbar spine screening is best done using reformatted images acquired when scanning the chest and abdomen of high-risk multi-trauma patients. However, if CT is not indicated, then plain X-rays serve as are the initial investigation required

plain radiographs, it was found that the sensitivity and specificity for plain radiographs were 58% and 99% and that of contrast-enhanced CT-CAP was 97% and 99%, respectively [77]. The superiority of CT imaging over plain radiographs in clearing TLS injury has been proved in several other studies [78–82]. Radiation dosage can be reduced when a single-pass whole-body MDCT imaging was used [83] or by reconstructing the images acquired from scanning other body regions, for instance, facial skeleton (from CT Brain) and spine (from CT of abdomen and pelvis) [80–82]. Furthermore, as per a retrospective study by Kim et al. [84], "both spine-targeted CT (TLS) images and visceral organ-targeted CT (abdominopelvic) images are comparable for evaluating TLS trauma." However, as per a literature review by Howes et al. [85], it was concluded that "TLS screening is best done using reformatted images acquired when scanning the chest and abdomen of high-risk multi-trauma patients but if computed tomography is not clinically indicated for investigation of other injuries then plain films are the first line investigation."

Role of MRI The concept of spinal cord injury without radiological abnormality (SCIWORA) exists since X-rays and MDCT cannot rule out SCI [86]. MRI is the ideal investigative tool for detecting soft tissue injuries (ligamentous and intervertebral disk), localizing spinal cord injury, assessing its severity, as well as the cause of neural compression and for diagnosing bone contusions missed by plain radiographs [38, 87–91]. The nature of spinal cord insult varies from spinal cord edema to cord transection. The cause for extrinsic neural compressions can be found, be it a bone fragment or a herniated disk fragment due to trauma [92]. MRI findings also predict neurological prognosis since the recovery is poor in spine trauma victims with intramedullary hemorrhage or transection of the spinal cord as compared to patients with spinal cord edema or cord contusion [93]. As per a study by Gray et al. [94], MRI especially has a role when X-rays and CT are unable to account for the patient's symptoms and also aids in ruling out epidural hematoma, traumatic disk herniation or SCI. An MRI, combined with CT scan, is useful in the classification of TLS injuries as per the TLICS classification system [95].

Non-contiguous injuries in spine trauma

The incidence of non-contiguous injury is around 20% in various studies [96–98], and these should be suspected in the presence of high-velocity injury or in the setting of spine fracture at any level. As per a series by Korres et al. [99], the most common combination of fractures included thoracic and lumbar spine (25%), followed by the cervical and thoracic spine (17%) and cervical and lumbar spine (10%). MRI screening of the whole spine is indicated to rule out such injuries [100, 101]. Furthermore, a thorough clinical examination of the spine and radiographs of other regions aids in screening for non-contiguous injuries [102].

Spinal Cord Society position statement

Based on the reviewed literature, the recommendations of the expert panel, and discussions in an open forum during its annual meeting, the Spinal Cord Society has issued a position statement that is given below (also available on www.scs-isic.com):

Radiological protocol in spinal trauma

Spinal trauma and spinal cord injury are one of the most catastrophic injuries that can burden humanity. It affects not only an individual's health but also creates an enormous burden on the family and society. Efficient clinical and radiological evaluations are important to plan management and henceforth optimize the outcome. The past decade has witnessed a substantial shift in the imaging assessment of spinal trauma patients. To save time as well as improve diagnostic capabilities, advanced imaging is increasingly being utilized, but it comes at a heavy financial burden. Guidelines have been brought out even in the past for the optimal utilization of resources with the maximum possible efficacy. The Spinal Cord Society's position statement is an endeavor to relook at the various guidelines in today's perspective, especially with regard to developing and underdeveloped countries, to come to a consensus protocol for daily use for not only spine physicians but also general orthopedic and trauma surgeons as well as general practitioners.

Cervical spine trauma

For stable alert patients, CCR is sensitive and specific when compared to NLC; hence, its use results in the decreased use of radiography [2–4]. In CCR low risk or NLC patients, cervical immobilization should be discontinued without the need for imaging. In awake patients who require imaging, computed tomography (CT) cervical spine without contrast is generally considered to be the first line of imaging [14]. Radiographs are required only if CT is unavailable; in this case, minimum three (anteroposterior, lateral, and odontoid views) and preferably five high-quality plain radiographs (anteroposterior, lateral, odontoid, right, and left oblique views) with visualization of all the cervical vertebrae should be performed and ideally be reported by a radiologist [16]. However, plain radiographs remain the mainstay for the evaluation of trauma patients worldwide who do not have ready access to CT [5, 6, 16]. MRI is indicated if there are neurological signs or symptoms or advanced cervical spondylotic changes since the latter is at high risk of sustaining a disco-ligamentous injury after trauma [16].

In an awake patient who requires imaging as per the CCR/NLC [23], immobilization can be discontinued "if no radiological abnormality is found and:

- after the patient is asymptomatic or
- following normal and adequate dynamic radiographs or
- following a normal MRI obtained within 48 h of injury or
- at the discretion of the treating physician."

In un-evaluable patients, a CT of the cervical spine without contrast should be performed. However, radiographs can be conducted if CT is not available or affordability is an issue and can further be followed by supplemental CT later. Plain radiographs especially remain the mainstay for evaluation of such patients in developing and underdeveloped countries where access to CT and affordability are prevalent issues [5, 6, 16].

In un-evaluable patients [23], cervical immobilization can be terminated "if no radiological abnormality is found and:-

- after the patient is asymptomatic or
- a normal CT read by an experienced radiologist or
- following a normal MRI obtained within 48 h of injury or
- at the discretion of the treating physician."

There is no role of dynamic radiographs in an obtunded blunt trauma victim.

Blunt cerebrovascular injury (BCVI) in adult patients has an incidence that varies from 1 to 2.7% with the higher incidence observed in patients with multiple injuries [42, 43]. Screening is recommended to rule out blunt vertebral artery injury in trauma victims satisfying the modified Denver screening criteria [103]. CT angiography is preferable to MR angiography for assessing the vertebral arteries in acute blunt trauma [104]. Though the gold standard to diagnose these injuries is digital subtraction angiography, the 2% complication rate associated with its use remains a concern [50].

Thoracic and lumbar spine trauma

Imaging of the TLS spine is required following blunt trauma if any of the following exist [100]:

- Back pain
- Midline tenderness
- Local signs of TLS injury
- Abnormal neurological signs
- Cervical spine fracture
- GCS < 15
- Major distracting injury
- Alcohol or drug intoxication

For TLS spine trauma, a CT scan is generally considered to be the first line of imaging unless it is unavailable or unaffordable. In such cases, plain imaging could be used [5, 14, 85]. In polytrauma cases, CT screening is best performed with a multidetector CT (MDCT) using reformatted imaging sequences procured when conducting CT-CAP [85]. The whole spine should still be screened [85, 105]. However, plain radiographs continue to be the first line of imaging in many settings and particularly so in developing and underdeveloped countries [5, 6, 16]. In an un-evaluable patient, CT scan with or without an MRI of the TLS region can be used to clear spine injury [41].

MRI in thoracic and lumbar trauma is indicated [94] in the following:

- in the presence of neurological deficit or radiculopathy
- when radiographs and CT cannot explain the patient's symptoms

CT myelography may be required if MRI is unavailable or contraindicated.

Non-contiguous injuries

Twenty percent of victims with vertebral column injuries have non-contiguous injuries and should generally be suspected and investigated for these in the setting of the high-velocity mechanism of injury and spine fracture at any level [97]. Thorough clinical examination of the spine along with radiographs of other regions or evaluation with reformatted MDCT/CT-CAP or sagittal MR screening of the whole spine aids in the unmasking of non-contiguous injuries [85, 102].

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Compliance with ethical standards

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Affiliations

P. K. Karthik Yelamarthy[1] · H. S. Chhabra[1] · Vedant Vaksha[1] · Yatish Agarwal[2] · Anita Agarwal[1] · Kalidutta Das[1] · Hans Joseph Erli[3] · Mihir Bapat[4] · Roop Singh[5] · Darshan Gautam[6] · Rushama Tandon[7] · G. Balamurali[8] · Sriram Rajan[9]

✉ H. S. Chhabra
drhschhabra@isiconline.org

1 Indian Spinal Injuries Centre, Sector C, Vasant Kunj, New Delhi, India

2 Department of Diagnostic Radiology and Imaging, Safdarjung Hospital and VM Medical College, New Delhi, India

3 Centre for Musculoskeletal Surgery, Vivantes Humboldt Hospital, Berlin, Germany

4 Kokilaben Dhirubhai Ambani Hospital and Medical Research Institute, Mumbai, India

5 PGIMS, Rohtak, India

6 Indian Spine and Bone Hospital, Kota, India

7 Northern Railway Central Hospital, New Delhi, India

8 Kauvery Spine Institute, Kauvery Hospital, Chennai, India

9 Diwan Chand Satyapal Aggarwal Imaging Research Centre, New Delhi, India