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Multimodality Imaging Evaluation of Acute Spinal Trauma

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Abstract

Background: Acute spinal trauma is a common, potentially disabling emergency in which timely, accurate imaging is crucial to detect fractures, instability, and spinal cord injury (SCI) and to guide early management decisions.

Objectives: To evaluate imaging modalities in acute spinal trauma by characterizing the spectrum of radiological findings on plain radiographs, CT, and MRI, and to formulate an evidence-based imaging algorithm for their optimal utilization based on clinical presentation.

Methods: This single-center, hospital-based analytical cross-sectional study (18 months) enrolled 120 hemodynamically stable adults (18-60 years) with acute trauma and suspected spinal injury at Aarupadai Veedu Medical College and Hospital, Puducherry, using purposive consecutive sampling.

Results: The mean (SD) age was 39.8 (12.0) years. Males predominated (84/120, 70.0%), and 78/120 (65.0%) were from urban areas. At presentation, 66/120 (55.0%) had no neurological deficit, while 38/120 (31.7%) had incomplete, and 16/120 (13.3%) had complete deficits. Road traffic accidents (RTAs) were the leading mechanism (50/120, 41.7%), followed by falls from height (≥2 m) (40/120, 33.3%). Clinically, the thoracolumbar junction was the most frequently suspected level (34/120, 28.3%), closely followed by the cervical spine (32/120, 26.7%); RTAs were significantly associated with cervical involvement ($\chi^2 = 13.17$, $p = 0.001$). Imaging yield increased across modalities: X-ray detected acute abnormalities in 50/120 (41.7%) and was normal in 70/120 (58.3%), CT detected acute traumatic findings in 86/120 (71.7%), and MRI detected acute spinal injury in 90/120 (75.0%). Using MRI as the reference, X-ray identified 55/90 MRI-positive injuries (61.1% sensitivity) with 66.7% accuracy, whereas CT identified 86/90 MRI-positive injuries (95.6% sensitivity) with 95.0% accuracy ($p<0.001$ vs. X-ray). Cord involvement on MRI correlated strongly with neurological status ($\chi^2 = 72.4$, $p<0.001$), and unstable injuries were seen in 38/120 (31.7%); these had more complete deficits (12/38, 31.6%) than stable injuries (4/52, 7.7%).

Conclusion: Multimodality imaging demonstrated that CT markedly outperformed plain radiography for detecting acute spinal injury, while MRI provided definitive assessment of cord and ligamentous involvement, enabling more accurate injury characterization and stability-based triage in acute spinal trauma.

Categories: Trauma, Radiology
Keywords: acute spinal trauma, computed tomography, diagnostic accuracy, magnetic resonance imaging, multimodality imaging, plain radiography

Introduction

Acute spinal trauma is a major global health problem, with an estimated 250,000-500,000 new spinal cord injuries (SCI) occurring every year worldwide, and more than 15 million people living with the consequences of SCI [1,2]. In developing countries, the burden is more pronounced, with a pooled incidence of traumatic SCI around 22.6 per million per year and nearly 80% of cases occurring in young males, largely due to motor vehicle crashes (43%) and falls (34%) [3]. In India and other low- and middle-income settings, rapid urbanization, increasing vehicle density, and inadequate road safety measures contribute to a high and rising burden of spinal trauma, particularly from road traffic crashes and falls from height [4]. Beyond the risk of death at the scene or in the early post-trauma period, a critical concern is the progression from an initially incomplete SCI to a complete, disabling lesion if early recognition and stabilization are delayed. Timely and appropriate imaging plays a pivotal role in this context: it not only confirms or excludes spinal injury but also delineates the level, morphology, and stability of fractures; detects canal compromise and cord involvement; and guides decisions on immobilization, surgical decompression, and fixation [5]. Modern clinical decision rules such as the National Emergency X-Radiography Utilization Study (NEXUS) criteria and the Canadian C-Spine Rule (CCR) have been developed to identify patients at low risk of cervical spine injury who may safely avoid imaging, thereby helping to streamline resource use without compromising safety in busy emergency settings [5]. Nonetheless, in many low- and middle-income countries these rules are

inconsistently applied, and delayed or inadequate imaging remains an important contributor to missed or late diagnoses of unstable spinal injuries.

Conventional plain radiography has historically been the first-line screening tool for suspected spinal injury and remains the principal modality in many regions where access to CT is limited. It provides a rapid overview of spinal alignment and gross bony injury and can offer a specific diagnosis in characteristic fracture patterns, especially in resource-constrained emergency settings. However, its sensitivity for detecting clinically important cervical and thoracolumbar injuries is variable, and important fractures or instability, particularly at the cervicothoracic junction and posterior elements, may be missed [6-8]. The advent of multidetector computed tomography (MDCT) has transformed spinal trauma imaging by enabling fast acquisition with thin collimation, high-resolution multiplanar reformations, and three-dimensional reconstructions, substantially improving detection and characterization of vertebral and posterior element fractures, canal compromise, and overall injury morphology [9,10]. Current evidence-based guidelines therefore recommend non-contrast CT as the initial imaging modality in adults who meet clinical high-risk criteria for cervical or thoracolumbar trauma, reserving radiographs for situations where CT is unavailable or unaffordable [11,12]. Magnetic resonance imaging (MRI) complements CT by offering superior soft-tissue contrast and direct visualization of the spinal cord, intervertebral discs, ligaments, epidural space, and paraspinal soft tissues. MRI is particularly valuable in patients with neurological deficits, discordance between clinical findings and CT/radiography, or suspected disco-ligamentous injury or epidural hematoma, where it refines assessment of injury severity, stability, and prognosis [13]. MRI is particularly useful for detecting SCI without radiographic abnormality (SCIWORA) or with only subtle CT changes, a pattern more common in younger patients and in the cervical spine, where early recognition of cord edema, hemorrhage and disco-ligamentous disruption can influence timing and urgency of decompressive surgery. Despite these advances, there remains considerable variation between institutions in how and when plain radiographs, CT, and MRI are deployed in the initial work-up of spinal trauma, particularly in mixed-resource settings where availability of advanced imaging and specialist interpretation is uneven. Against this background, the aim of the present study was to comprehensively evaluate imaging modalities in acute spinal trauma by characterizing the spectrum of radiological findings on plain radiographs, CT, and MRI and to formulate an evidence-based imaging algorithm for their optimal utilization based on clinical presentation.

Materials And Methods

This was a single-center, hospital-based, analytical cross-sectional study conducted in the Department of Radiology, Aarupadai Veedu Medical College and Hospital, Puducherry, India, for a duration of 18 months between 08/06/2024 and 31/11/2025. The study was approved by the Institutional Human Ethics Committee (IHEC) with reference number AV/IHEC/01/2024/087, dated 07/06/2024. The participants were given the Participant Information Sheet (PIS) in their native language, and its contents were verbally explained to ensure their understanding and satisfaction. Eligible participants were adults aged 18-60 years of either gender who presented with a history of acute trauma and suspected spinal injury and who provided written informed consent to participate and to undergo comprehensive imaging evaluation with plain radiography (X-ray), CT, and MRI. Patients were excluded if they had contraindications to any imaging modality, including pregnancy (CT contraindication) and MRI-incompatible conditions such as metallic implants, dentures, cochlear implants, or claustrophobia, as well as if they were hemodynamically unstable.

The sample size for the present study was determined using a single-proportion approach based on the diagnostic performance of CT reported by Adarsh et al. (2021) [14], which documented a sensitivity of 55.1% for detecting spinal trauma. Using this anticipated proportion with a 95% confidence level and an absolute precision of 12%, a minimum sample size of 120 patients with acute spinal trauma was required. Participants were recruited using a nonprobability purposive (convenience) sampling method, with consecutive eligible patients referred to the Department of Radiology being enrolled. A detailed data collection form was then completed for every patient, including sociodemographic details, relevant clinical history, and findings from the physical and neurological examination. Any pre-existing spinal pathology or comorbid conditions that could influence imaging interpretation were also recorded. The patients subsequently underwent imaging of the clinically suspected spinal region with all three modalities: plain radiography, CT, and MRI. Plain X-ray imaging was performed first, using a Meditronics Diagnox 800-4032-II (Meditronics Manufacturing Co. Pvt. Ltd., India) system. Standard trauma views appropriate to the suspected level (anteroposterior and lateral views for cervical, thoracic, or lumbar spine, and open-mouth odontoid view when upper cervical injury was suspected) were obtained, with additional oblique or focused views taken as required based on clinical suspicion and initial findings. CT of the spine was then performed on a 16-slice Wipro GE Brivo CT-385 scanner (GE HealthCare, GE Hangwei Medical Systems Co., Ltd.). Contiguous axial sections covering the region of interest were acquired, typically with a thin slice thickness (approximately 1-3 mm), and reconstructed in sagittal and coronal planes using high-resolution bone and soft-tissue algorithms. An MRI was carried out on a 1.5 Tesla Philips Achieva DS MR (Philips Healthcare, Best, the Netherlands) system. Protocols included sagittal and axial T1-weighted, T2-weighted, and short tau inversion recovery (STIR) sequences of the suspected spinal segment, with additional sequences such as gradient-echo or diffusion-weighted imaging acquired when necessary to better characterize cord hemorrhage, edema, or ligamentous injury. When multilevel involvement was suspected, the field of view was extended to include adjacent segments (Figures *1*, *2*).

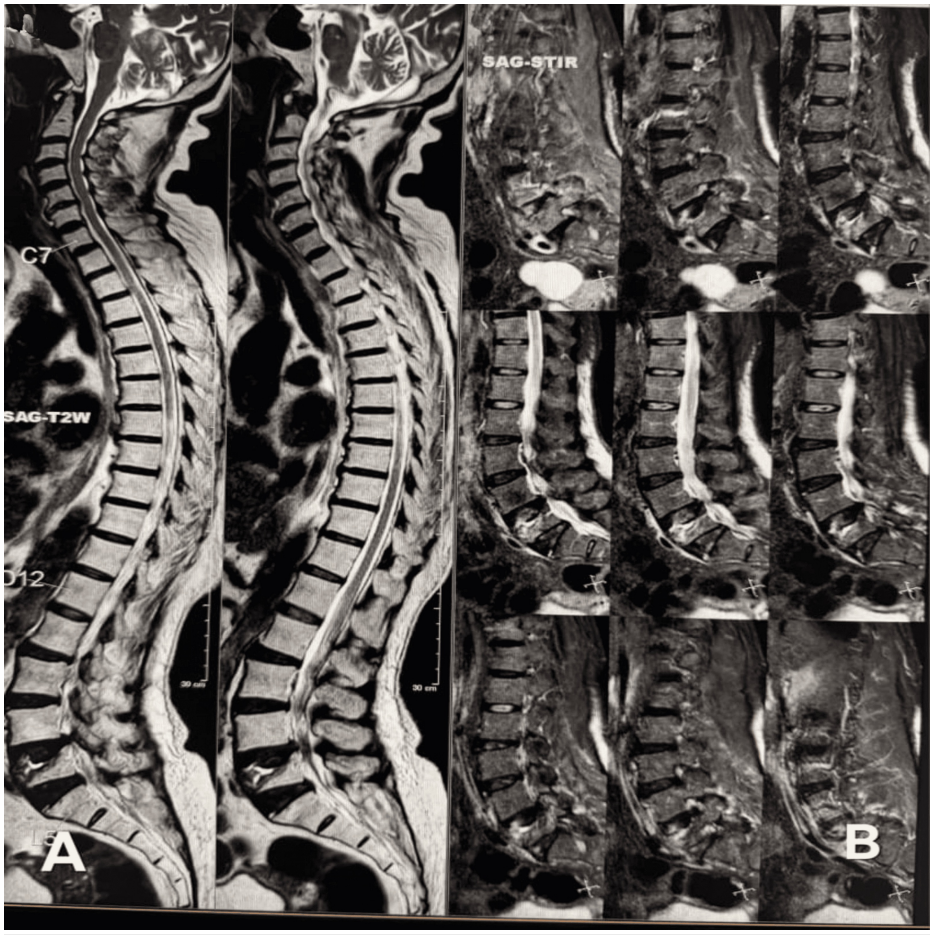


FIGURE 1: MRI findings

A: (T2 SAG) Wedge-shaped area of altered signal intensity (T2 hypointense) noted involving the L4 vertebral body with interspersed T2 hyperintense areas within. Reduction in the height of the vertebral body is noted with anterior wedge compression; posterior elements are intact, causing loss of 30-40% of body height. No evidence of a significant retropulsed segment impinging the cauda equina. B: (STIR SAG) Interspersed hyperintense areas are noted within the L4 vertebral body. A reduction in the height of the L4 vertebral body was noted with anterior wedge compression.

STIR: short tau inversion recovery; SAG: sagittal

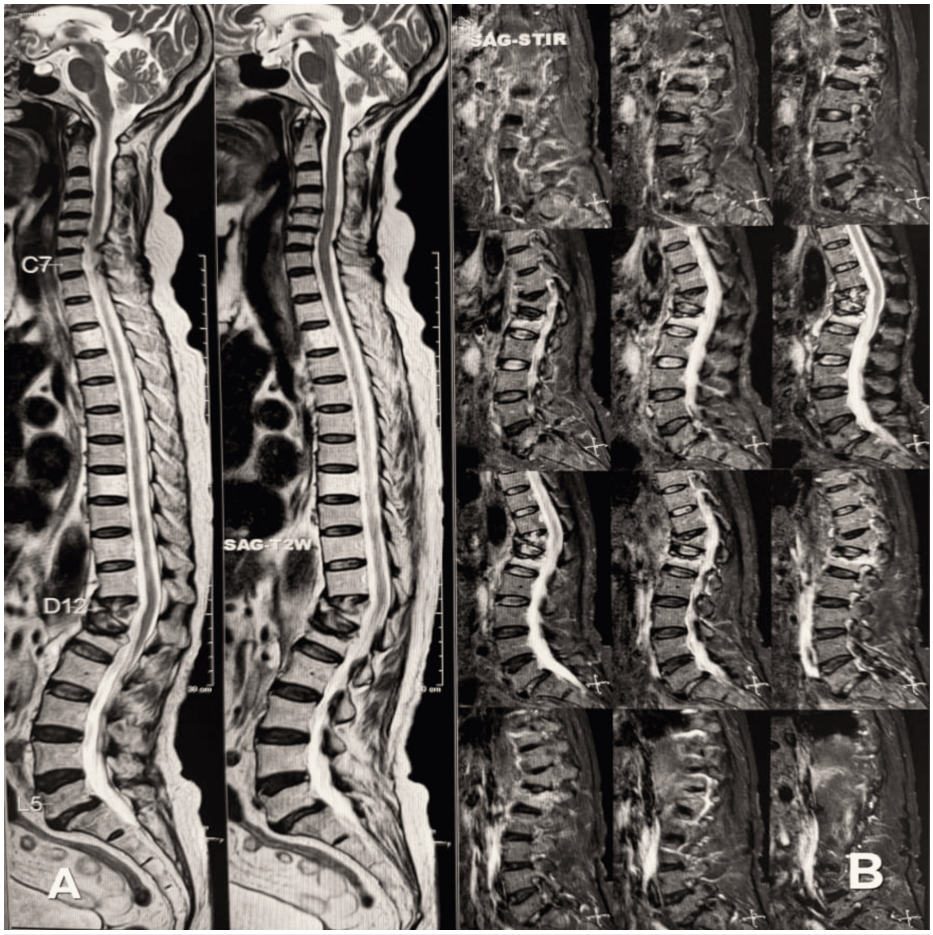


FIGURE 2: MRI findings

A: (T2 SAG) Anterior wedge compression fracture with altered T2 signal intensity of the L1 vertebral body with approximately 20–30% reduction in vertebral height. B: (STIR SAG) Extensive STIR hyperintense areas are noted involving the L1 vertebral body. It is further seen causing a focal kyphotic deformity. However, no abnormal cord signal intensity is noted.

STIR: short tau inversion recovery; SAG: sagittal

Statistical analysis was performed using IBM SPSS Statistics for Windows, Version 27 (Released 2019; IBM Corp., Armonk, New York, United States). Continuous variables were summarized as mean ± standard deviation (SD), while categorical variables were expressed as frequencies and percentages. The diagnostic performance of plain radiography and CT was evaluated using MRI as the reference standard, and sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall diagnostic accuracy were calculated for each modality. Associations between categorical variables were assessed using the chi-square test (or Fisher's exact test where appropriate), and differences in proportions of correctly detected injuries between X-ray and CT were also analyzed using chi-square tests. Agreement between the clinically suspected level and the MRI-confirmed level of spinal injury among patients with MRI-proven trauma was quantified using Cohen's kappa statistic with a corresponding p-value. All statistical tests were two-tailed, and a p-value < 0.05 was considered statistically significant.

Results

Among the 120 patients, the mean age was 39.8 ± 12.0 years, with most aged 30-44 years (43.3%), and males predominated (70.0%); 65.0% were from urban areas (Table *1*). At presentation, 55.0% had no neurological deficit, while 31.7% had incomplete and 13.3% had complete deficits. Road traffic accidents (RTAs) were the most common mechanism of injury (41.7%), followed by falls from height ⩾2 m (33.3%). Clinically suspected involvement most often involved the thoracolumbar junction (28.3%) and cervical spine (26.7%). On X-ray, 58.3% were reported as normal, whereas CT detected acute traumatic findings in 71.7% (normal CT 28.3%), most commonly vertebral compression fractures (45.0%), posterior element fractures (25.0%), and subluxation/dislocation (20.0%), with 30.0% classified as unstable and a mean of 1.4 ± 0.7 vertebral levels involved. MRI identified acute injury in 75.0% (no acute abnormality in 25.0%), frequently demonstrating vertebral fractures (50.0%), posterior element fractures (37.5%), and ligamentous injury (30.0%), along with

cord edema (20.0%) and contusion/hemorrhage (12.5%); spinal canal compromise ⩾30% was seen in 25.0%, and the mean levels involved increased to 1.6 ± 0.8.

Variable	Category	Value
Age (years)	Mean ± SD	39.8 ± 12.0
Age group (years)	18–29	28 (23.3%)
	30–44	52 (43.3%)
	45–59	32 (26.7%)
	≥60	8 (6.7%)
Gender	Male	84 (70.0%)
	Female	36 (30.0%)
Residence	Urban	78 (65.0%)
	Rural	42 (35.0%)
Neurological status at presentation	No neurological deficit	66 (55.0%)
	Incomplete deficit	38 (31.7%)
	Complete deficit	16 (13.3%)
Mechanism of injury	Road traffic accident	50 (41.7%)
	Fall from height (≥2 m)	40 (33.3%)
	Fall from standing height/slip	16 (13.3%)
	Sports-related injury	6 (5.0%)
	Assault/others	8 (6.7%)
Clinically suspected spinal involvement	Cervical	32 (26.7%)
	Thoracic	20 (16.7%)
	Thoracolumbar junction	34 (28.3%)
	Lumbar	22 (18.3%)
	Multiple	12 (10.0%)
	Normal study (no acute abnormality)	70 (58.3%)
	Any acute abnormality detected	50 (41.7%)

Radiographic (X-ray) findings	Vertebral body compression fracture	24 (20.0%)
	Burst fracture	8 (6.7%)
	Posterior element fracture (pedicle/lamina/facet/spinous)	16 (13.3%)
	Subluxation/dislocation	10 (8.3%)
	Malalignment without obvious fracture (step-off/kyphosis)	12 (10.0%)
	Reduced disc height/interspinous widening suggestive of ligamentous injury	10 (8.3%)
	Prevertebral soft-tissue swelling	18 (15.0%)
Number of vertebral levels involved on X-ray (per patient)	Mean ± SD	1.2 ± 0.5
CT findings	Normal CT (no acute traumatic abnormality)	34 (28.3%)
	Any acute traumatic finding	86 (71.7%)
	Vertebral body compression fracture	54 (45.0%)
	Burst fracture	20 (16.7%)
	Chance fracture/flexion-distraction injury	6 (5.0%)
	Posterior element fracture (pedicle/lamina/facet/spinous)	30 (25.0%)
	Subluxation/dislocation	24 (20.0%)
	Retropulsed fragment causing spinal canal narrowing	22 (18.3%)
	Paravertebral/epidural hematoma suspected	16 (13.3%)
	Traumatic disc herniation	18 (15.0%)
	Injury pattern classified as unstable on CT	36 (30.0%)
Number of vertebral levels involved on CT (per patient)	Mean ± SD	1.4 ± 0.7
	No acute traumatic abnormality	30 (25.0%)
	Any acute spinal injury detected	90 (75.0%)
	Vertebral body fracture	60 (50.0%)
	Burst fracture	22 (18.3%)
	Posterior element fracture (pedicle/lamina/facet/spinous)	45 (37.5%)
	Ligamentous injury (ALL/PLL/posterior ligamentous complex)	36 (30.0%)

MRI findings	Traumatic disc herniation/prolapse	28 (23.3%)
	Extradural/epidural hematoma	20 (16.7%)
	Spinal cord edema	24 (20.0%)
	Spinal cord contusion/hemorrhage	15 (12.5%)
	Spinal cord transection	3 (2.5%)
	Spinal canal compromise ≥30%	30 (25.0%)
	Multilevel involvement (≥2 contiguous vertebrae)	26 (21.7%)
Number of vertebral levels involved on MRI (per patient)	Mean ± SD	1.6 ± 0.8

TABLE 1: Baseline demographic and clinical profile of patients with acute spinal trauma and summary of radiographic, CT, and MRI findings (N = 120)

Clinically suspected levels of spinal involvement varied significantly by mechanism of injury ($\chi^2 = 13.17$, $p = 0.001$) (Table 2). RTAs most frequently raised suspicion of cervical injury (22 patients; 18.3%), with fewer cases involving the thoracolumbar junction (10; 8.3%) and thoracic spine (8; 6.7%). In contrast, falls from height ⩾2 m were more commonly associated with suspected thoracolumbar junction involvement (18; 15.0%), along with notable multilevel suspicion (6; 5.0%). Falls from standing height/slip most often suggested lumbar involvement (7; 5.8%). Overall, the analysis indicated that RTAs were disproportionately associated with cervical-level involvement compared with other mechanisms and suspected levels.

Mechanism of injury	Clinically suspected spinal involvement, n (%)				
	Cervical	Thoracic	Thoracolumbar junction (T10–L2)	Lumbar	Multiple levels
Road traffic accident	22 (18.3)	8 (6.7)	10 (8.3)	6 (5.0)	4 (3.3)
Fall from height (≥2 m)	4 (3.3)	6 (5.0)	18 (15.0)	6 (5.0)	6 (5.0)
Fall from standing height/slip	2 (1.7)	2 (1.7)	3 (2.5)	7 (5.8)	2 (1.7)
Sports-related injury	3 (2.5)	1 (0.8)	1 (0.8)	1 (0.8)	0 (0.0)
Assault/others	1 (0.8)	3 (2.5)	2 (1.7)	2 (1.7)	0 (0.0)

TABLE 2: Mechanism of injury and anatomical level of clinically suspected spinal involvement (N = 120)

Chi-square analysis demonstrated a statistically significant association between road traffic accidents and cervical-level involvement compared with other mechanisms and levels ($\chi^2 = 13.17$, $p = 0.001$).

Using MRI as the reference standard (90/120 with acute injury; 30/120 without), plain radiography detected acute spinal injury with 61.1% sensitivity and 83.3% specificity (PPV 91.7%, NPV 41.7%, accuracy 66.7%), yielding 55 true positives (TPs), 35 false negatives (FNs), five false positives (FPs), and 25 true negatives (TNs) (Table 3). In comparison, CT demonstrated markedly better performance, with 95.6% sensitivity and 93.3% specificity (PPV 97.7%, NPV 87.5%, accuracy 95.0%; 86 TP, 4 FN, 2 FP, 28 TN), and its higher detection of acute injury versus X-ray was statistically significant ($p < 0.001$). For specific injury patterns (MRI reference), X-ray showed moderate sensitivity but high specificity for vertebral body fractures (sensitivity 70.0%, specificity 90.0%) and lower sensitivity for posterior element fractures (44.4% vs 93.3%), while it performed poorly for spinal canal compromise ⩾30% (sensitivity 33.3%, specificity 96.7%). CT showed excellent diagnostic performance across all injury types, with sensitivity/specificity of 93.3%/95.0% for

vertebral body fractures, 88.9%/94.7% for posterior element fractures, and 86.7%/97.8% for canal compromise ⩾30%, with overall accuracies exceeding 90%; the superiority of CT over X-ray for osseous and canal compromise injuries was significant ($p < 0.001$) (Table 4).

Modality	n				%				
	TP	FN	FP	TN	Sensitivity	Specificity	PPV	NPV	Accuracy
X-ray	55	35	5	25	61.1	83.3	91.7	41.7	66.7
CT	86	4	2	28	95.6	93.3	97.7	87.5	95.0
MRI	90	0	0	30	100.0	100.0	100.0	100.0	100.0

TABLE 3: Comparison of X-ray, CT, and MRI findings with the reference standard (MRI) for detection of any acute spinal injury (N = 120)

MRI was considered the reference standard for confirming the presence or absence of acute spinal injury; its diagnostic indices are therefore 100%. In comparison, CT showed significantly higher detection of acute spinal injury than plain radiography ($p < 0.001$, chi-square test ($\chi^2 = 37.01$) for the difference in proportions).

TP: true positive; FN: false negative; FP: false positive; TN: true negative; PPV: positive predictive value; NPV: negative predictive value

Type of injury	n				%				
	TP	FN	FP	TN	Sensitivity	Specificity	PPV	NPV	Accuracy
Plain radiography (X-ray)									
Vertebral body fracture	42	18	6	54	70.0	90.0	87.5	75.0	80.0
Posterior element fracture	20	25	5	70	44.4	93.3	80.0	73.7	75.0
Spinal canal compromise (≥30%)	10	20	3	87	33.3	96.7	76.9	81.3	80.8
Computed tomography									
Vertebral body fracture	56	4	3	57	93.3	95.0	94.9	93.4	94.2
Posterior element fracture	40	5	4	71	88.9	94.7	90.9	93.4	92.5
Spinal canal compromise (≥30%)	26	4	2	88	86.7	97.8	92.9	95.7	95.0

TABLE 4: Diagnostic performance of X-ray and CT in detecting vertebral, posterior element, and spinal canal injuries using MRI as reference standard (N = 120)

Plain radiography demonstrated moderate sensitivity but high specificity for vertebral and posterior element fractures, and poor sensitivity for detecting significant spinal canal compromise. CT showed excellent sensitivity and specificity across all injury types, with diagnostic accuracy exceeding 90% for vertebral and posterior element fractures and for significant spinal canal compromise. The superiority of CT over X-ray in detecting osseous and canal compromise injuries was statistically significant ($p < 0.001$ for differences in sensitivity by chi-square test).

TP: true positive; FN: false negative; FP: false positive; TN: true negative; PPV: positive predictive value; NPV: negative predictive value

Among the 90 patients with MRI-proven spinal injury, clinical localization matched the MRI-confirmed level exactly in 58 cases (64.4%), was within one vertebral level in 22 (24.4%), and was discrepant by more than one level in 10 (11.1%), indicating moderate overall agreement (Cohen's $\kappa = 0.58$, $p < 0.001$) and a tendency for clinical assessment to underestimate multilevel involvement. MRI-based cord findings also correlated strongly with neurological status at presentation ($\chi^2 = 72.4$, $p < 0.001$): among those without neurological deficit (n = 66), 90.9% had no cord involvement and 9.1% had cord edema only, whereas incomplete deficits (n = 38) were commonly associated with cord edema (42.1%) or contusion/hemorrhage (26.3%). Complete deficits (n = 16) predominantly showed cord contusion/hemorrhage (68.8%) or transection (18.8%). On multimodality imaging, 30 patients (25.0%) had no MRI-detected injury, 52 (43.3%) had stable injuries, and 38 (31.7%) had unstable injuries; unstable injuries constituted 42.2% of MRI-confirmed injuries and were associated with a much higher proportion of complete neurological deficits than stable injuries (31.6% vs

7.7%; $\chi^2 = 18.9$, $p < 0.001$), along with greater multilevel involvement (mean injured levels 2.4 ± 0.6 vs 1.3 ± 0.5) (Table 5).

Injury category (multimodality imaging)	n (%)			
	Total	No neurological deficit	Incomplete deficit	Complete deficit
No MRI-detected spinal injury	30 (25.0)	30 (100.0)	0 (0.0)	0 (0.0)
Stable spinal injury	52 (43.3)	30 (57.7)	18 (34.6)	4 (7.7)
Unstable spinal injury	38 (31.7)	6 (15.8)	20 (52.6)	12 (31.6)

TABLE 5: Distribution of stable versus unstable spinal injuries based on multimodality imaging findings and baseline neurological status (N = 120)

Unstable injuries accounted for 31.7% of all patients and 42.2% of those with MRI-confirmed spinal injury. The proportion of complete neurological deficits was markedly higher in the unstable group (31.6%) compared with the stable injury group (7.7%), a difference that was statistically significant ($\chi^2 = 18.9$, $p < 0.001$). The mean number of injured vertebral levels was higher in unstable than in stable injuries (2.4 ± 0.6 vs 1.3 ± 0.5, respectively).

Discussion

In the present study, acute spinal trauma predominantly affected adults in their most economically productive years, with a mean age of 39.8 ± 12.0 years and the largest proportion in the 30-44-year group (43.3%). This age distribution is consistent with global and LMIC patterns noted by Kim et al. (2025), Izzy et al. (2024), and Selassie et al. (2015), in which traumatic spine and spinal cord injuries disproportionately involve young and middle-aged adults due to occupational exposure and high-risk travel, thereby amplifying socioeconomic impact through long-term disability and loss of productivity [15-17]. The male predominance (70.0%) also aligns with the widely reported epidemiology of traumatic spinal injuries, often attributed to greater exposure of men to high-energy mechanisms such as road traffic crashes, falls at work, and interpersonal violence, in corroboration with Biswas et al. (2022) and Fanslow et al. (2025) [18,19]. Urban residence constituted 65.0% in this cohort, which may reflect referral patterns to a tertiary center, higher traffic density, and greater emergency access in urban settings, as noted by Glennie et al. (2017) [20]; importantly, this reinforces the need for rapid, protocol-driven imaging pathways in busy emergency departments where early triage decisions directly influence neurological outcomes.

More than half of patients (55.0%) presented without neurological deficit, while 31.7% had incomplete and 13.3% had complete deficits. Clinically, this spectrum is crucial because neurological impairment is a key determinant of both imaging escalation and management urgency; patients with deficits require prompt identification of cord compression, epidural hematoma, unstable injury patterns, and disco-ligamentous disruption that may mandate urgent decompression or stabilization, as noted by Singh et al. (2015) and Aarabi et al. (2017) [21,22]. Tins et al. (2017) and Parizel et al. (2010) emphasize that imaging strategies in suspected spinal trauma must be driven not only by mechanism and pain/tenderness but also by neurological findings, altered sensorium, and distracting injuries, because clinical examination alone can be unreliable and may miss clinically significant injuries [23,24].

RTAs were the most common mechanism (41.7%), followed by falls from height ⩾2 m (33.3%). Kanna et al. (2022) added that this distribution is typical of high-energy trauma settings, where abrupt deceleration, rollover forces, and axial loading produce predictable injury patterns across spinal regions [25]. In our cohort, clinically suspected involvement clustered at the thoracolumbar junction (28.3%) and cervical spine (26.7%). Biomechanically, the thoracolumbar junction (T10-L2) is vulnerable because it represents a transition from the relatively rigid thoracic cage to the more mobile lumbar spine, concentrating stress during axial compression and flexion-distraction injuries, as noted by Charles & Steib (2015) [26]. The cervical spine, particularly in RTAs, is susceptible to complex translational/rotational forces and flexion-extension loading, which can result in fracture-dislocation, facet injury, and ligamentous disruption even when initial plain radiographs appear normal [27]. The significant association between RTA and cervical-level involvement ($\chi^2 = 13.17$, $p = 0.001$) is clinically meaningful because cervical trauma carries a higher risk of catastrophic neurological compromise and airway/respiratory complications, demanding rapid clearance protocols. Falls from height showed predominant thoracolumbar junction involvement, consistent with axial loading and burst/flexion-distraction patterns as noted by Gamanagatti et al. (2015) [28], which frequently require CT for accurate morphology and stability assessment.

Plain radiographs were normal in 58.3% of patients, with acute abnormalities detected in 41.7%. Although radiographs can rapidly demonstrate gross malalignment and compression fractures, their diagnostic limitations are well established, especially for posterior element fractures, cervicothoracic junction injuries, and subtle instability [29]. This limitation is reflected in our diagnostic indices using MRI as the reference;

X-ray sensitivity for 'any acute spinal injury' was 61.1%, with a particularly poor NPV of 41.7%, indicating that a negative radiograph could not reliably exclude injury. These findings are consistent with systematic evidence from Holmes & Akkinepalli (2005) showing substantially lower sensitivity of plain radiography compared with CT for cervical spine injury screening [30]. In injury-type analyses, radiography showed moderate sensitivity for vertebral body fractures (70.0%) but low sensitivity for posterior element fractures (44.4%) and significant canal compromise ≥30% (33.3%). Posterior element injuries and canal compromise are precisely the lesions that influence stability and surgical decision-making [31]; therefore, under-detection on X-ray can delay appropriate immobilization or referral. This supports guideline-consistent practice in which radiographs are reserved for low-risk scenarios or settings where CT is unavailable, rather than being used as a definitive rule-out test in high-risk trauma [11,29].

CT identified acute traumatic abnormalities in 71.7% of patients and outperformed radiography across injury categories. Using MRI as reference, CT achieved sensitivity of 95.6% and specificity of 93.3% for detecting 'any acute spinal injury,' with high PPV (97.7%), NPV (87.5%), and accuracy (95.0%). This strong performance is concordant with Dieckmeyer et al. (2023) and Phal et al. (2008), who found that multidetector CT, through thin-slice acquisition and multiplanar reconstructions, markedly improves detection of fractures, posterior element disruption, and canal narrowing compared with plain radiography [32,33]. In the systematic review comparing CT and radiography for cervical spine screening, pooled sensitivity was dramatically higher for CT than for radiographs, supporting CT as the preferred screening test in high-risk patients [30]. CT also enabled clinically actionable morphology: burst fractures (16.7%), subluxation/dislocation (20.0%), retropulsed fragments with canal narrowing (18.3%), and flexion-distraction injuries (5.0%). These patterns are central to stability determination and operative planning. Notably, 30.0% were classified as unstable on CT morphology, reinforcing that a substantial subset of patients require urgent specialist evaluation and that reliance on radiographs risks under-triage.

MRI detected acute spinal injury in 75.0% of patients and uniquely characterized ligamentous injury (30.0%), traumatic disc herniation (23.3%), epidural hematoma (16.7%), and intramedullary cord pathology (edema 20.0%; contusion/hemorrhage 12.5%; transection 2.5%). Kumar & Hayashi (2016) noted that the principal added value of MRI in trauma is its superior evaluation of the spinal cord, discs, ligaments (including posterior ligamentous complex), and epidural space, which directly affects stability grading and prognosis [34]. Evidence indicates that intramedullary hemorrhage and greater lesion extent on MRI correlate with more severe initial injury and poorer neurological recovery, while isolated edema tends to have a more favorable prognosis than hemorrhagic contusion or transection [21,22]. The observed increase in mean number of involved levels from X-ray (1.2 ± 0.5) to CT (1.4 ± 0.7) and MRI (1.6 ± 0.8) underscores how advanced imaging detects additional injury levels and soft-tissue extensions not appreciated on radiographs, supporting a multimodality strategy when clinical risk is high, or symptoms are discordant with initial imaging [11,29]. Among MRI-proven injuries (n=90), exact agreement between clinically suspected and MRI-confirmed level occurred in 64.4%, while 11.1% were discrepant by more than one vertebral level ($\kappa = 0.58$). This 'moderate' agreement suggests that clinical examination alone may mislocalize or underestimate multilevel trauma, particularly in polytrauma, altered sensorium, distracting injuries, or when pain is diffuse. This finding supports guideline-based imaging approaches that incorporate mechanism, examination reliability, and risk criteria rather than relying solely on perceived pain level to decide the imaging extent [11,29]. MRI cord findings demonstrated a strong stepwise relationship with baseline neurological status ($\chi^2 = 72.4$, $p < 0.001$). Patients without deficits predominantly had no cord involvement (90.9%), whereas incomplete deficits were commonly associated with cord edema (42.1%) or contusion/hemorrhage (26.3%), and complete deficits were dominated by contusion/hemorrhage (68.8%) or transection (18.8%). This pattern is biologically plausible and is consistent with Ulusoy et al. (2025), who found that intramedullary hemorrhage signifies more severe primary injury and is associated with worse neurological recovery compared with edema alone [35]. Clinically, additionally, these data justify MRI as the key escalation test in any neurological deficit or when CT/radiographs do not adequately explain symptoms, because MRI can identify surgically remediable causes (e.g., epidural hematoma, traumatic disc herniation, ligamentous disruption with instability) and provide prognostic stratification.

On multimodality assessment, unstable injuries comprised 31.7% of all patients and 42.2% of those with MRI-confirmed injury, and complete neurological deficits were significantly more frequent in unstable injuries than stable injuries (31.6% vs 7.7%). Stability frameworks in thoracolumbar trauma emphasize injury morphology, integrity of the posterior ligamentous complex, and neurological status as major determinants of operative need, which aligns with classification approaches such as thoracolumbar injury classification and severity score (TLICS) that integrate these domains for management decisions [36]. The higher mean number of involved levels in unstable injuries (2.4 ± 0.6) further supports comprehensive imaging to define the full extent before definitive stabilization, especially at transitional zones and in high-energy mechanisms.

Overall, the study findings support a tiered, clinically driven imaging algorithm in which high-risk patients or those with neurological symptoms undergo CT as the first-line modality for rapid osseous and canal assessment; plain radiography is reserved for low-risk scenarios or when CT is unavailable; and MRI is prioritized when neurological deficit exists, when CT-positive fractures raise concern for ligamentous instability, or when clinical-CT discordance persists. This approach is concordant with ACR Appropriateness Criteria® Suspected Spine Trauma, which advocates CT as the initial test in suspected spinal injury when

high-risk features are present, while using MRI selectively to assess cord and soft-tissue injury that changes stability assessment and management (Figure *3*) [37].

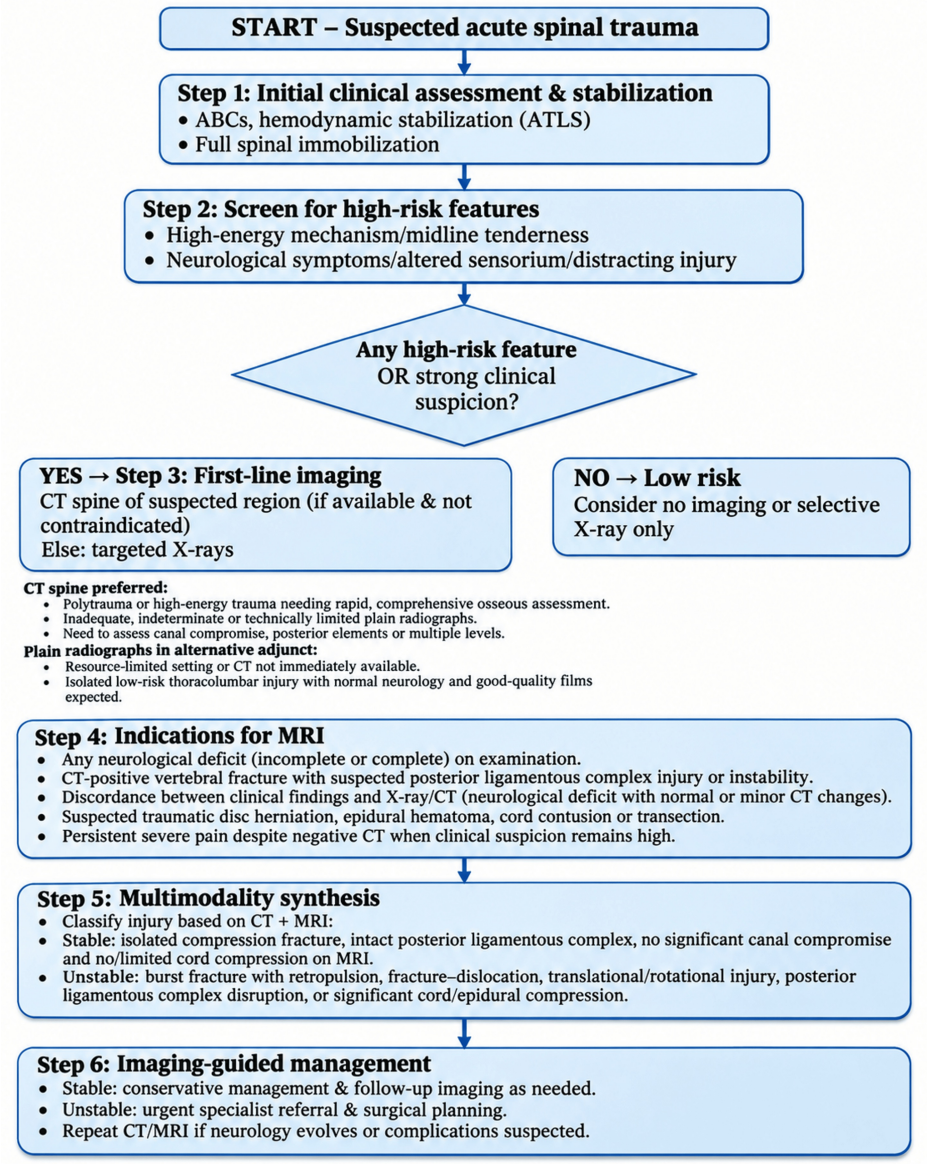


FIGURE 3: Algorithm for optimal utilization of imaging modalities

The figure was created by the authors using Microsoft PowerPoint (Microsoft Corporation, Redmond, Washington, United States).

ATLS: Advanced Trauma Life Support

The present study has several limitations. Being a single-center, hospital-based analytical cross-sectional study with purposive/convenient sampling, the findings may be affected by referral and selection bias and may not be fully generalizable to community settings or centers with different trauma patterns and imaging access. Because only hemodynamically stable adults (18-60 years) who consented and could undergo all three modalities were included, patients with severe polytrauma, unstable physiology, pediatric/elderly populations, and those with contraindications to CT/MRI were underrepresented, which may underestimate the spectrum and severity of spinal trauma. Imaging interpretation was performed by radiologists in routine clinical practice and may be subject to inter-observer variability. In addition, the study focused on diagnostic performance and imaging patterns at presentation; it did not incorporate surgical findings as an external gold standard, quantify radiation dose, assess time-to-imaging or workflow delays, or evaluate downstream outcomes such as management changes, neurological recovery, functional status, or cost-effectiveness, factors that would strengthen conclusions regarding optimal imaging algorithms in real-world trauma care.

Conclusions

In adults presenting with suspected acute spinal trauma, this study demonstrated that plain radiography had limited diagnostic utility and frequently missed clinically important injuries, particularly posterior element fractures and significant spinal canal compromise. CT provided rapid and highly accurate detection of acute traumatic abnormalities and significantly outperformed X-ray, supporting its use as the preferred first-line imaging modality in clinically high-risk patients. MRI remained indispensable for defining the full burden of injury and for characterizing disco-ligamentous and spinal cord pathology, with cord findings showing a strong graded relationship with neurological status and instability. Given only moderate agreement between clinical localization and MRI-confirmed levels and the substantial proportion of unstable, multilevel injuries, an imaging-led approach is essential. A pragmatic pathway is therefore recommended: CT as the primary screening tool for osseous and canal compromise, with targeted MRI for neurological deficits, suspected ligamentous instability, clinico-radiologic discordance, and suspected cord or epidural involvement to optimize triage, prognostication, and management planning.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Siddharthan Kumar, Prabhu C S , Shriram T

Acquisition, analysis, or interpretation of data: Siddharthan Kumar

Drafting of the manuscript: Siddharthan Kumar

Critical review of the manuscript for important intellectual content: Siddharthan Kumar, Prabhu C S , Shriram T

Supervision: Prabhu C S , Shriram T

Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. Aarupadai Veedu Medical College and Hospital, Puducherry, India issued approval AV/IHEC/01/2024/087, dated 07/06/2024. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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