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ORIGINAL ARTICLE

The value of CT and MRI in the classification and surgical decision-making among spine surgeons in thoracolumbar spinal injuries

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Abstract
Purpose Although imaging has a major role in evaluation and management of thoracolumbar spinal trauma by spine surgeons, the exact role of computed tomography (CT) and magnetic resonance imaging (MRI) in addition to radiographs for fracture classification and surgical decision-making is unclear.
Methods Spine surgeons ($n = 41$) from around the world classified 30 thoracolumbar fractures. The cases were presented in a three-step approach: first plain radiographs, followed by CT and MRI images. Surgeons were asked to classify according to the AOSpine classification system and choose management in each of the three steps.
Results Surgeons correctly classified 43.4 % of fractures with plain radiographs alone; after, additionally, evaluating CT and MRI images, this percentage increased by further 18.2 and 2.2 %, respectively. AO type A fractures were identified in 51.7 % of fractures with radiographs, while the number of type B fractures increased after CT and MRI. The number of type C fractures diagnosed was constant across the three steps. Agreement between radiographs and CT was fair for A-type ($k = 0.31$), poor for B-type ($k = 0.19$), but it was excellent between CT and MRI ($k > 0.87$). CT and MRI had similar sensitivity in identifying fracture subtypes except that MRI had a higher sensitivity (56.5 %) for B2 fractures ($p < 0.001$). The need for surgical fixation was deemed present in 72 % based on radiographs alone and increased to 81.7 % with CT images ($p < 0.0001$). The assessment for need of surgery did not change after an MRI ($p = 0.77$).
Conclusion For accurate classification, radiographs alone were insufficient except for C-type injuries. CT is mandatory for accurately classifying thoracolumbar fractures. Though MRI did confer a modest gain in sensitivity in B2 injuries, the study does not support the need for routine MRI in patients for classification, assessing instability or need for surgery.

Keywords Thoracolumbar · Trauma · Fracture · Classification · Computerized tomography · Radiograph · Magnetic resonance imaging · Survey

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Introduction

Fractures of the thoracolumbar region constitute a spectrum of injuries ranging from the simple bony apophyseal fractures without structural or neurologic implications to complex fracture dislocations. Overall, about 50 % of thoracolumbar injuries are unstable and can result in significant disability, deformity, and neurological deficit [1, 2]. Imaging of the thoracolumbar fractures is an important part in the management of spinal injuries, for diagnosis, classification, prognosis, and deciding upon the appropriate treatment. Fracture classification helps in assessing the stability of the injury and, thereby, the further management of the patient. Standard classification systems for thoracolumbar fractures are based on imaging features, such as fracture morphology, injury mechanism, neurological deficit, and injury to posterior ligamentous complex [3–7]. The recent AOSpine classification system has been developed based on imaging information acquired from computed tomography (CT) and clinical examination and found to have a good intra and inter observer reliability [8, 9].

Different imaging modalities, including the radiographs, CT scan, and magnetic resonance imaging (MRI) scan, are used to assess the severity of the injury, with each modality having advantages and limitations. There is considerable controversy regarding the best investigation for evaluating a particular patient [10–13]. A protocol, including radiographs, CT, and MRI, will provide complete information with regard to severity of bony disruption, identify injuries to the disk and ligaments, and document the extent of cord compression. However, this approach depends on imaging availability, interpretative expertise, rapidity of advanced imaging in the presence of challenging clinical scenarios, and the costs involved. CT and MRI scans alone or in combination are commonly performed at many trauma centers, but the exact advantages provided by these investigations are not clear. The aim of this study is to determine the adequacy and usefulness of radiographs, CT, and MRI in accurately classifying the fractures, assessing severity of bony injury and deciding on the treatment plan regarding surgical fixation.

Materials and methods

Thirty sets of images from patients with thoracolumbar spine trauma of varying severity were classified based on the AOSpine thoracolumbar injury classification system [8]. The classification is a morphologically based classification with three major types: type A—compression injury; type B—tension band injury; and type C—translational injury. All the patients had radiographs in two orthogonal views, CT images in the axial plane, coronal, and sagittal plane reconstructions, and MRI images in the axial, sagittal, and coronal planes. The fractures were first classified by two spine surgeons and a radiologist, experienced in AOSpine classification system. Whenever there was a disagreement on the fracture type, the case was settled by discussion. This provided the "reference standard" to compare and assess the results provided by the participants. The thirty cases for evaluation had a fair representation of the desired fracture subtypes except for A2 and B3 subtypes. Institutional review board approval from the institute of the principal investigator, from where the images were acquired, was sought before initiating the study.

A group of 41 volunteer AOSpine members with a minimum of 5 years experience in the field of spine surgery from different geographic areas participated in the study. Only spine surgeons were included as participants, since they are involved in the management of spinal injury patients. In particular, 14 surgeons were from Asia pacific region, 12 from Latin America, 7 from Middle East, 5 from Europe, 2 from North America, and 1 from Africa. A questionnaire was sent to the study participants through Survey Monkey (an online survey tool). The assessment of the images was performed in three steps. In the first step, all the participants were provided with a short clinical description together with anteroposterior (AP) and lateral radiographs of the patients and asked to answer questions regarding fracture classification, the type of treatment and the need for further investigations. After completing this first questionnaire, a set of axial, coronal, and sagittal CT images of the affected region was provided immediately, and the participants were asked to answer the same set of questions. Any change in the assessment of fracture classification, and the type of surgical treatment were documented by the participant. After completion of the second step, a set of MRI images, including axial and sagittal T1 and T2 images of the fracture, was provided in the last part of the survey. To evaluate the reproducibility of the classification among non-spine surgeons, three spinal radiologists were explained about the new AO classification and were sequentially provided with the radiographs, CT, and MRI images of the 30 patients in a stepwise manner. In each of the three steps, their ability to classify the fractures correctly was compared with the reference standard. The inter-observer agreement was good for the main A, B, or C fracture types ($\kappa = 0.61$, ranging from 0.54 to 0.66).

Descriptive statistics were performed to describe the distribution of number of fractures according to the classification system. A kappa statistic [14] was calculated for inter and intra observer reproducibility for the three different evaluations. The kappa coefficients were interpreted using the Landis and Koch [15] grading system: slight agreement (0.00–0.20), fair agreement (0.21–0.40), moderate agreement (0.41–0.60), and substantial agreement (0.61–0.80), and almost perfect (0.81–1.00).

Sensitivity and specificity estimates were calculated to compare assessments of all investigators against the reference standard by plain radiographs, CT, and MRI. The sensitivity is the fraction of positive cases that were correctly (according to the Reference Standards) classified by the investigators, whereas the specificity is the fraction of negative cases that were correctly classified by the investigators. McNemar test was used to determine treatment changes between radiographs and CT and subsequently between CT and MRI. Level of significance was set at $\alpha = 0.05$, and a p value lower than 0.05 indicates a significant change in evaluation. In the sensitivity/specificity analysis, the level of significance was corrected for multiple comparisons and set at $\alpha = 0.005$.

Results

Forty-one participants analyzed 30 cases amounting to a total of 1230 assessments. Among the fractures, the distribution based on AOSpine classification (the Reference Standard) was as follows, 6.7 % (2/30) for subtype A1, 20 % (6/30) for subtype A3, 13.3 % (4/30) for subtype A4, 20 % (6/30) for subtype B1, 20 % (6/30) for subtype B2, 20 % (6/30) for subtype C. After the three-step assessment by the participants, plain radiology was sufficient in 43.4 % of assessments to attain the correct classification. This improved significantly to 61.6 % when additional CT was available and to 63.8 % with MRI.

Fracture subtype assessment (Table 1)

On radiographs alone, 51.7 % of cases were classified as AOSpine type A fractures, 26.7 % were classified as type B fractures, and 21.6 % were classified as type C. With the addition of CT images, the numbers changed as follows, 43.0 % for AOSpine type A, 35.1 % for Type B fractures, and 21.8 % for type C fractures. This shows that more fractures initially classified as type A fractures were changed to type B fractures based on CT information. With MRI, the assessments changed to 41.7 % for type A, and 36.5 % for Type B fractures, while the diagnosis of type C fractures remained unchanged. In particular, after MRI, the AOSpine subgroup B2 was detected more frequently. Type C fractures were unique in that correct classification by radiographs alone was possible and CT or MRI did not add extra information.

Table 1 Number and percentage of fractures classified by the participants, according to the AO classification system in the three steps, using radiograph, computed tomography (CT), and magnetic resonance imaging (MRI)

AO type	After Radiograph $N = 1228$		After CT $N = 1229$		After MRI $N = 1229$	
	N	%	*N*	%	*N*	%
Type A	635	51.71	529	43.04	513	41.74
A1	161	13.11	77	6.27	76	6.18
A2	33	2.69	15	1.22	12	0.98
A3	315	25.65	235	19.12	237	19.28
A4	126	10.26	202	16.44	188	15.30
Type B	328	26.71	432	35.15	448	36.45
B1	126	10.26	145	11.80	137	11.15
B2	200	16.29	285	23.19	310	25.22
B3	2	0.16	2	0.16	1	0.08
Type C	265	21.58	268	21.81	268	21.81

Modality reproducibility of classification with each investigation

The results for intra-rater reproducibility for A and B subtypes are shown in Table 2. Agreement between radiographs and CT was fair for A-type ($K = 0.31$) and poor for B-type ($K = 0.19$), while excellent between CT and MRI (K for A-type = 0.93; K for B-type = 0.87). For A-type, the intra-rater kappa values ranged from −0.02 to 0.69 between radiographs and CT and from 0.43 to 1.00 between CT and MRI. For B-type, the intra-rater kappa values ranged from −0.24 to 0.74 between radiographs and CT and from 0.00 to 1.00 between CT and MRI.

Sensitivity and specificity for plain radiographs, CT, and MRI

Figure 1 shows the results of sensitivity and specificity analysis comparing the assessments of all investigators against the reference standard. After the first assessment with radiographs, the sensitivity estimates ranged from 22.0 to 89.8 % with less than 30 % sensitivity for A4, B1, and B2 fractures. The very low sensitivity indicates that investigators were able to correctly classify a fracture as an A4 injury in only 22 % of the cases based on plain radiographs. Sensitivity values at the ends of the spectrum of injuries for A1 and C (the extremes of injuries) were good at 61 and 89 %, respectively. After the second assessment with CT, the sensitivity improved for A3, A4, B1, and B2 injuries. With CT, the sensitivity estimates ranged from 38.2 to 94.7 %. These improvements were maintained after the third assessment with MRI. The specificity values were high ranging from 78.3 to 95.5 % for all the three modalities of investigation. CT and MRI evaluation had the same sensitivity and specificity with regard to the C classification. MRI showed a higher sensitivity [56.5 % (50.1–62.8 %)] in detecting B2 fractures when compared with CT [47.2 % (40.8–53.6 %) ($p < 0.001$)]. The addition of CT and radiographs increased the sensitivity to all classifications of fractures. The addition of MRI and CT did not improve the sensitivity or specificity in fractures except for B2 fractures.

Decision on fracture management

The percentage of patients assessed to need surgical fixation of the thoracolumbar fracture with plain radiographs was 72 %. This percentage increased significantly to 81.7 % with CT images ($p < .0001$). In the third part of the

Table 2 Mean kappa coefficients for the intra-rater reproducibility between radiographs versus CT, and CT versus MRI

A subtype		B subtype	
Radiographs versus CT	CT versus MRI	Radiographs versus CT	CT versus MRI
0.31	0.93	0.19	0.87

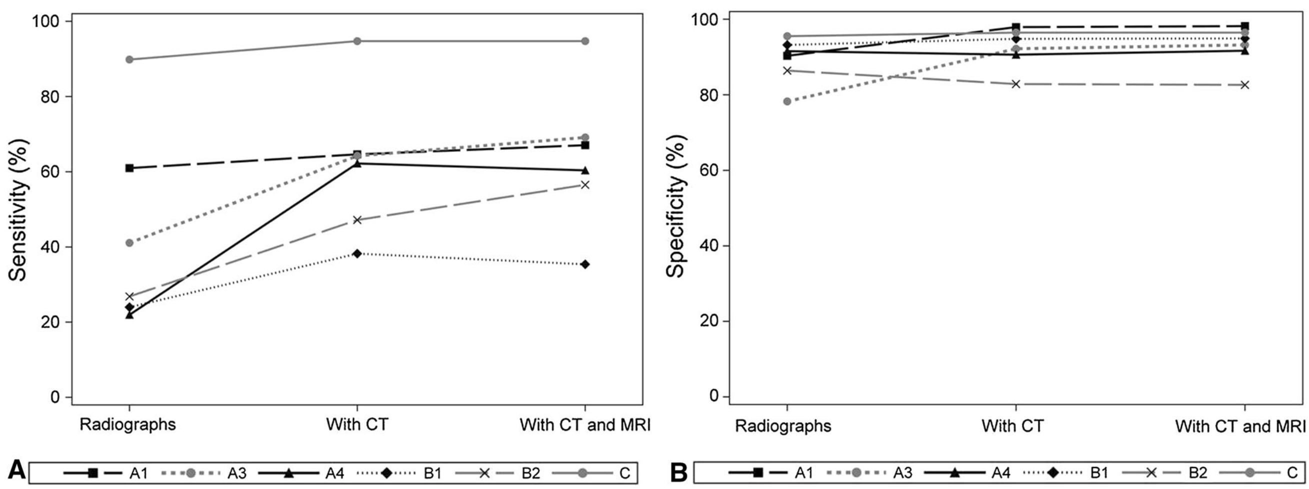

Fig. 1 Sensitivity and specificity of radiographs, CT, and MRI in fracture classification. **a** The sensitivity plot shows that for A1- and C-type injuries could be diagnosed with high sensitivity. For the other subtypes, sensitivity values change depending on the imaging modality and the subtype studied. **b** The specificity plot shows that in general, all three imaging modalities had good specificity in diagnosing the fracture subtypes

assessment with MRI, this percentage did not change ($p = 0.77$) (Table 3).

Discussion

In the management of spinal trauma, surgeons rely heavily on radiologic findings for classification, and for making management decisions regarding the need and type of surgery. Plain radiographs have been the first line of investigation, as they are universally available, portable, and relatively quick and cheap and are commonly part of a formal initial trauma survey. Assessment of the AP and lateral films can provide important clues regarding the nature of injury, injury to one or both spinal columns, the possible classification and the need for advanced imaging. CT and MRI are frequently performed for better delineation of posterior vertebral body wall fractures, canal compromise, and occult fractures of the posterior column and status of the spinal cord. There is, however, considerable variation in practice preferences of indications for ordering a CT and MRI in patients. The policy of 'all for all' would provide the most accurate assessment of both bony and soft tissue injuries, and may result in avoiding missed injuries and better medico-legal protection for the surgeon. However, this approach also inevitably increases imaging costs and constitute an additional drain on health resources [16]. Difficulties exist associated with obtaining an MRI in the acute trauma setting, such as in polytrauma patients, presence of metallic external mobilizers, and when monitoring of vital parameters is important [17]. This study was set up with the intention of obtaining more clarity on the potential benefits and added value of CT and MRI in various types of thoracolumbar fractures.

Table 3 Evaluation of surgery by radiographs and CT ($N = 1230$ assessments)

Surgery	Radiographs		CT		MRI	
	n	%	*n*	%	*n*	%
No	344	28	225	18.3	227	18.5
Yes	886	72	1005	81.7	1003	81.5

A strongpoint of this study is the involvement of 41 surgeons distributed worldwide assessing 30 thoracolumbar fractures representing the spectrum of severity of injuries. The study was designed to obtain specific advantages of CT over plain radiographs and MRI over CT by providing the data sequentially to the surgeons. The AOSpine classification system was chosen as it represents the most comprehensive pathomorphological classification to date [8, 9, 18–20]. In many centers around the world, plain radiographs remain the primary imaging modality for spine trauma. In this study, plain radiology alone was sufficient to attain the correct classification in 43.4 % of cases. The ability of plain radiographs to allow accurate classification varied between the different subgroups of the classification. In grossly unstable injuries, such as type C injuries, and mild fractures, such as type A1 and A0 injuries, radiographs provided adequate information. Type C fractures were classified correctly with radiographs alone with 90 % sensitivity and 95.5 % specificity. This was not improved significantly by either the CT or MRI, questioning the need for advanced investigation in C fractures without neurologic involvement. Plain radiographs were, however, found to have a poor sensitivity and specificity in other categories of injuries namely A3, A4, B1, and B2 injuries. Identification of these injuries depends specifically on the findings of a posterior wall or posterior column osseoligamentous injuries. Additional CT imaging improved the sensitivity of classification by 18.2 %. This was mainly due to the identification of additional fractures of the posterior wall, fractures of the posterior column, and separation of spinous process suggesting ligamentous injuries. This indicates that plain radiographs alone are insufficient and a CT is essential for accurate classification of fractures. An addition of an MRI improved the sensitivity by only 2.2 % and was limited in improving the diagnosis of B2 injuries by identification of PLC injuries (Fig. 2).

Our results also demonstrated the value of CT in the assessment for need for surgical stabilization by spine surgeons. CT provides better spatial resolution and ability to visualize the bone three dimensionally in axial, sagittal, and coronal views enabling better detection and delineation of fractures. In one study [21], it was observed that 25 % of burst fractures were misdiagnosed as compression fractures if radiographs alone are evaluated. Hauser et al. prospectively studied 222 patients with thoracolumbar injuries, and observed that conventional radiographs as compared with CT scan had sensitivity of 58 versus 97 %, specificity 93 versus 99 %, positive predictive value 64 versus 97 %, negative predictive value 92 versus 99 %, respectively [22]. In this study, participants identified more fractures as type A fractures—52 % as compared with 40 % in the reference standard based on radiographs alone. However, after provision of CT images, this percentage decreased to 43 % as some of these fractures were classified as B-type injuries. The finer details provided by the CT scan in terms of posterior vertebral wall fractures, sagittal split fractures, horizontal split of the spinous process, and lamina fractures enabled the participants to reclassify the fractures closer to the reference standards.

Interestingly in our study, the value of MRI was restricted to increase the sensitivity of diagnosis of B2 injuries. However, this finding must be considered carefully, as it may be subject to the regional bias of the study. Only two respondents were from North America, and in North America, there is a clear difference in the treatment algorithm for A4 fractures and B2 (with A4) fractures. Comparatively in regions, such as South America and Europe, there is little difference in the treatment algorithm between these two fractures [19]. The value of MRI in the diagnosis and management of fractures has been studied before. Pizones et al. conducted a prospective study of 33 patients to analyze the usefulness of MRI in fracture diagnosis, and its influence on the treatment decision [23]. They observed that while only 41 fractures were initially

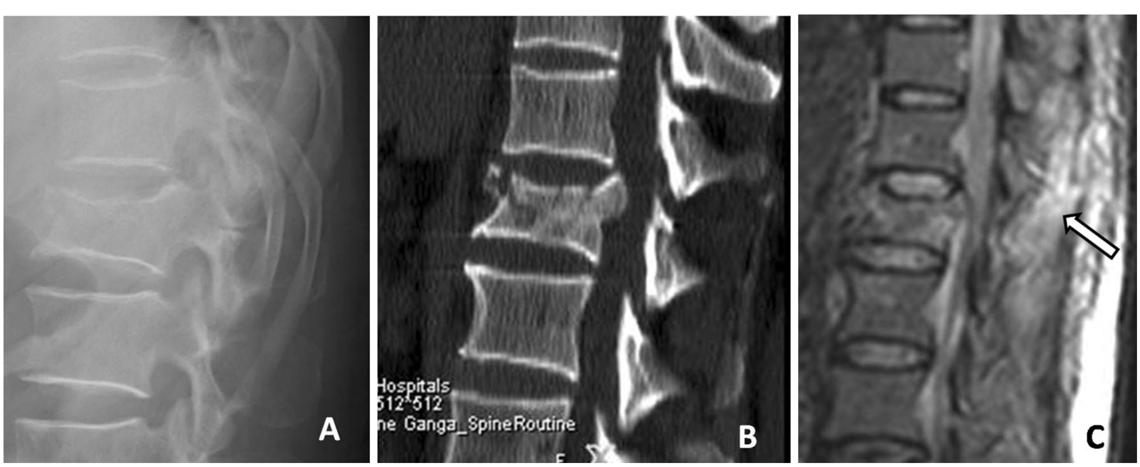

Fig. 2 Example of a patient with B2 injury reclassified after MRI scan. In this patient, based on radiographs (**a**) and sagittal CT (**b**), the fracture was classified as A3. Sagittal fat suppressed T2 MR image (**c**) demonstrated injury to the PLC, based on which the fracture was reclassified as B2 subtype

diagnosed using plain radiographs and CT scans, MRI diagnosed 50 fractures and 9 vertebral contusions. MRI modified the diagnosis in 40 % of patients by diagnosing 18 occult injuries, and the management plan changed in 16 % of patients. On the contrary, in our study, the intra-rater reproducibility between CT and MRI images was excellent indicating that MRI does not provide additional information over CT in diagnosing these injuries. The intra-rater reproducibility between radiographs and CT images was fair for A-type fractures, and poor for B-type fractures, which indicates that information from CT is mandatory to correctly diagnose and differentiate A and B injuries. Our sensitivity and specificity studies of imaging showed only low sensitivity with radiographs alone in A and B morphology injuries. With CT, this value improved. C-type injuries had high sensitivity and specificity with all the three modalities of investigation.

Having said this, the usefulness of MRI in the evaluation of spinal injuries is significant. In spinal injuries, MRI enables detailed and thorough assessment of the spinal cord, paraspinal soft tissues, integrity of the intervertebral disks, and ligamentous complexes. MRI is the only investigation, which permits direct visualization of the morphology of the injured cord parenchyma and the presence of any compression on the spinal cord. Furthermore, its ability to identify multi-level non-contiguous fractures is an added value in the management of spinal fractures [24]. Hence, MRI should clearly be considered in the evaluation of spinal trauma patients.

MRI showed a higher sensitivity (56.5 %) in detecting B2 fractures when compared with CT (47.2 %). The ability of MRI to detect posterior ligamentous complex injury would have enabled the participants in diagnosing more B2 injuries. In a prospective study of 34 patients, Lee et al. evaluated the patients by palpation of the interspinous gap, plain radiography, and MRI before surgery [25]. They observed that there was a significant relation between MRI interpretation and operative findings, better than clinical or radiographic assessment. Öner et al. studied MRI of 70 patients with spinal trauma for ligament injuries, and they observed a high incidence of injuries to the ALL, PLL, and the PLC, which were not detected by conventional imaging. In our study, participants were able to judge injury to PLC by CT itself in the majority of injuries [26], but MRI was beneficial in diagnosing B2 fractures.

This study has a few limitations. First, it is a study based on information acquired from imaging; if the patients were able to be examined, and a complete history obtained, it is possible that there would have been improved reliability. Also, this is a worldwide survey, and surgeons from different parts of the world may have different 'needs' with the different imaging types. Also, there is significant regional variability in the treatment of some fractures, and this may affect the surgeons' responses to the perceived stability and need for surgical treatment of each injury. This study did not involve any A2 and B3 fractures. Furthermore, spine surgeons, either orthopaedic or neurosurgeons, are involved in the management of spinal fractures, and hence, the study focused on the added value of CT and MRI in fracture classification and management by including only spine surgeons as assessors. However, being a study involving radiological images, the inclusion of radiologists could have been ideal except that variations in treatment decisions based on the three imaging modalities could not have been assessed.

Conclusion

For accurate classification based on the AOSpine thoracolumbar classification system, radiographs alone were insufficient except for C-type injuries. A CT was necessary for all other injuries improving the classification accuracy by further 18.2 %. In patients with normal neurology, MRI provides limited additional information in terms of assessment of fracture stability or management with the exception of helping to identify B2 fractures. When high-quality radiographs and CT are available, the need for further MR imaging should be limited to fractures in which there is a concern for a possible B-type injury.

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Compliance with ethical standards

Conflict of interest None.

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