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Magnetic resonance imaging evaluation of intervertebral disc injuries can predict kyphotic deformity after posterior fixation of unstable thoracolumbar spine injuries

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Abstract

The aim of the present study is to identify factors correlated with kyphotic deformity after thoracolumbar spine injuries. We performed a retrospective case–control study with data from thoracolumbar spine fracture patients who were treated with posterior spinal fixation. Patients with a follow-up period shorter than 6 months and who experienced low-energy trauma were excluded. Intervertebral disc injuries (IDIs) were graded from 0 to 3 upon admission in accordance with Sander's classification of traumatic intervertebral disc lesions. Vertebral wedge angles (VWAs) and local kyphosis angles (LKAs) were also measured. Patients were allocated to kyphosis and control groups if they had LKA correction losses of ≥10° and <10°, respectively. Forty-eight patients followed over a median period of 25 months were included. The median correction loss at the site of the injured vertebral body was 2.0°. The median LKA correction loss was 9.0°. Twenty-three and 25 patients were allocated to the kyphosis and control groups, respectively. Univariate analysis revealed that the median age was significantly lower in the kyphosis (35 years) than control group (56 years). The level of injury and IDI severity also significantly differed between groups, with a significantly greater proportion of more severe IDI cases in the kyphosis than control group. Finally, significantly more patients in kyphosis group underwent fusion (kyphosis, 19 vs control, 13) and implant removals (kyphosis, 19 vs control, 10). Multiple regression analysis revealed that IDI severity according to Sander's classification ($P=.005$; odds ratio, 5.263; 95% confidence interval [CI], 1.637–16.927) and implant removal ($P=.011$; odds ratio, 7.980; 95% CI, 1.603–39.728) were significantly associated with kyphotic deformity. IDI severity at initial magnetic resonance imaging (MRI) evaluation and implant removal are associated with kyphotic deformity after posterior fixation of thoracolumbar spine injuries. Thus, initial MRI evaluation of IDIs could be used to predict of recurrent kyphosis.

Abbreviations: IDI = intervertebral disc injury, LKA = local kyphosis angle, MRI = magnetic resonance imaging, VWA = vertebral wedge angle.

Keywords: intervertebral disc injury, kyphosis, kyphotic deformity, magnetic resonance imaging, posterior spinal fixation, thoracolumbar spine fracture

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1. Introduction

Surgical interventions for thoracolumbar spine fractures are usually indicated if injuries are highly unstable or complicated with neurological compromise.[1–3] Posterior spinal fixation using pedicle screws is a common intervention, because it is less invasive and provides adequate stability for most thoracolumbar spine injuries, including even those with a high grade of instability.[4] To aid surgeons in deciding whether patients with thoracolumbar injuries should be treated surgically, various classification systems, such as the load-sharing classification,[5] Arbeitsgemeinschaft für Osteosynthesefragen (AO) spine thoracolumbar spine classification (AOSTLC),[6] and thoracolumbar injury and classification score (TLICS),[7] can be used. While these systems classify fractures based on fracture patterns and patient neurological status, the severity of intervertebral disc injuries (IDIs) is not taken into account.

It is important to consider IDI severity, however, as thoracolumbar injuries are often associated with varying degrees of IDIs.[14,15] This can in turn lead to kyphotic deformity through processes such as intervertebral disc narrowing and vertebral body collapse.[8,11,14,16] Progressive intervertebral disc degeneration following injury has also been shown to affect kyphotic deformity over time.[11,14] It is therefore unsurprising that kyphotic deformity after thoracolumbar spine injuries has recently been a matter of discussion in the literature.[8–13]

To address this issue, Sander et al[17] proposed a method of classifying traumatic intervertebral disc lesions based on magnetic resonance imaging (MRI) findings. A high IDI grade was assumed to be correlated with severe disc degeneration resulting in kyphotic deformity, though this was not directly investigated. Thus, the primary hypothesis of the present study was that IDI severity upon initial MRI evaluation would be predictive of kyphotic deformity. We also aimed to identify other factors correlated with kyphotic deformity after thoracolumbar spine injuries.

2. Materials and methods

2.1. Patient characteristics

This study received approval from our institution's Ethical Committee. All procedures were performed in accordance with the ethical standards of this committee, as well as with the 1964 Helsinki Declaration and its later amendments.

We retrospectively reviewed 48 consecutive patients (35 males and 13 females) with thoracolumbar spine injuries who underwent posterior fixation at our hospital between 2005 and 2016. Their mean age at time of surgery was 44.9 years (standard deviation [SD], 19.5 years; range, 14–79 years). All patients were followed up for more than 6 months, with a mean follow-up period of 32.7 months (SD, 24.1 months; range 6–117 months). Indications for surgical intervention were burst fractures with a kyphotic angle >15°, an anterior vertebral height of <50%, and spinal canal compromise of >50%, as well as neurological deficit, or highly unstable thoracolumbar spinal injuries represented as AOSTLC type B or C. Exclusion criteria included the presence of multiple contiguous or noncontiguous fractures, pathological fractures such as ankylosing spondylitis, tumors, inflammatory arthritis, and severely osteoporotic fractures.

2.2. Surgical technique for posterior spinal fixation

All surgical procedures were performed under controlled general anesthesia. Patients were placed in the prone position before initial postural reduction was carried out. The conventional posterior approach or percutaneous approach was then performed. Pedicle screws were inserted bilaterally at each of the 2 levels above and 2 levels below the fractured vertebra for thoracolumbar fractures, and at 1 level above and 1 below the fractured vertebra for lumbar fractures. Pedicle screws with the largest possible diameter were used. Kyphosis was corrected by ligamentotaxis, a technique whereby continuous longitudinal force (distraction) is applied and pedicle screw fixation is performed with or without posterior bone grafting.

2.3. Postoperative recovery

After surgery, all patients were allowed to sit up and walk on the second postoperative day while wearing a custom-molded thoracolumbosacral brace. Braces were applied to all patients and removed 12 weeks after surgery. Following brace removal, early lumbar range-of-motion exercises were performed as part of rehabilitation.

2.4. Clinical assessment

The TLICS, which assesses morphology, neurologic status, and posterior ligamentous integrity using a point system, was used to weight injury severity. Injury type was evaluated using the TLICS and AOSTLC, and neurological deficit was assessed using the American Spinal Injury Association (ASIA) Impairment Scale. Clinical results were also assessed using the 5-point Denis pain scale,[18] which includes both work and pain scales (Table 1). Lower scores on this scale represented better clinical outcomes. Other details that were documented included the location of injury (thoracic: T3–T10, thoracolumbar junction: T11–L2, or lumbar: L3–5), and whether patients underwent fusion (with posterior bone grafting) and implant removal.

Table 1

The clinical features and surgical outcomes.

Patients number	48
Year	44.9 (19.5)
Male/female	35/13
Follow-up period	32.7 (24.1)
AOSTLC	
A3	13
A4	6
B1	2
B2	18
B3	5
C	4
TLICS	5.1 (2.0)
ASIA impairment scale	
Preoperative	4.0 (1.3)
Final follow-up	4.4 (1.2)
Denis pain scale	2.4 (1.1)

AO = Arbeitsgemeinschaft für Osteosynthesefragen, AOSTLC = AO spine thoracolumbar spine classification, ASIA = American Spinal Injury Association, TLICS = thoracolumbar injury and classification score.

2.5. Radiological assessment

Vertebral fractures were evaluated using plain radiographs and computed tomography scans (Toshiba Aquilion 16; Toshiba Medical, Tochigi, Japan) with patients in the supine position. Plain radiographs were obtained preoperatively, at 3 and 6 months postoperation, and at final follow-up. Several parameters were measured using the Picture Archiving and Communication System (PACS). These included the local kyphosis angle (LKA), the angle between the superior endplate of the vertebra above the injured vertebra and the inferior endplate of the vertebra below the injured vertebra, as well as the vertebral wedge angle (VWA), the angle between the superior and inferior endplates of the fractured vertebra, which reflects kyphotic deformity (Fig. 1A). The height of the injured vertebral body was also measured in centimeters at anterior, middle, and posterior positions (referred to as anterior, middle, and posterior vertebral height, or AVH, MVH, and PVH, respectively) (Fig. 1B). Lastly, the anteroposterior (A/P) ratio was determined by calculating AVH as a percentage of PVH.

For MRI assessment, scans were carried out preoperatively with patients in the prone position using a 1.5-T Sigma MRI unit (Symphony; Siemens Medical Solutions, Erlangen, Germany). Using MRI findings, IDIs were graded upon admission according to Sander's classification of traumatic intervertebral disc lesions.[17] IDIs were classified as grades 0 to 3 as follows: grade 0, uninjured intervertebral discs in their normal condition; grade 1, hyperintense appearance on T2-weighted MRI images, as compared to adjacent intervertebral discs without traumatic change; grade 2, decreased signal intensity with perifocal

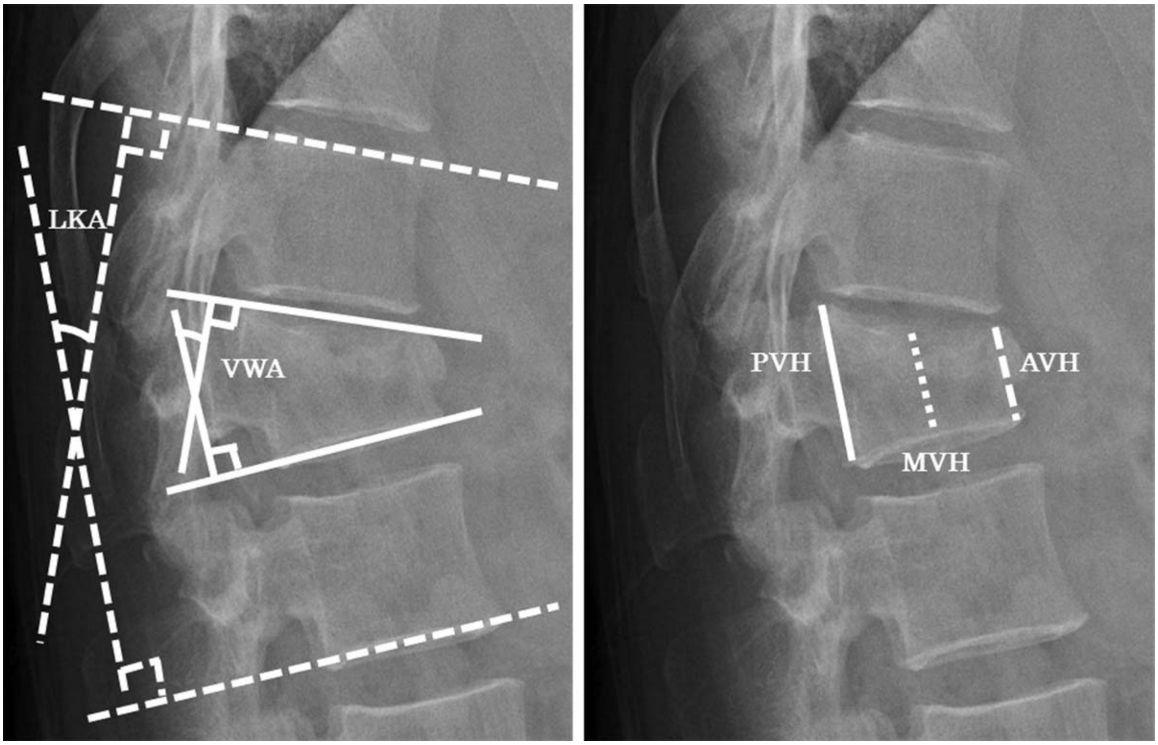

Figure 1. Measurement of radiological parameters on lateral radiographs. (A) Measurement of the local kyphosis angle (LKA) and vertebral wedge angle (VWA). The LKA was defined as the angle between the superior endplate of the vertebra above the injured vertebra and the inferior endplate of the vertebra below the injured vertebra. The VWA was defined as the angle between the superior endplate and the inferior endplate of the fractured vertebra, which reflects kyphotic deformity. (B) Measurement of anterior vertebral body height, middle vertebral body height, and posterior vertebral body height. The height of the injured vertebral body was measured in centimeters at anterior, middle, and posterior positions.

hyperintense appearance on T2-weighted images and isointense to isointense appearance on T1-weighted images; and grade 3, an infraction of the disc into the vertebral body, annular tears, or herniation into the endplate (Fig. 2).

Independent observers measured each parameter in consensus with a PACS viewer using electronic calipers on a PACS workstation. All radiographs and MRIs were evaluated by 2 of the present study authors (T.I. and N.N.) who were not involved in surgery. Intra- and interobserver agreement values were good to excellent for each parameter (Kappa >0.70).

2.6. Statistical analysis

All data are expressed as mean (SD). For comparisons between patients with and without kyphosis, the Mann–Whitney *U* test was used for continuous variables, and the chi-squared test or Fisher's *U* test was used for dichotomous variables. Multiple logistic regression analysis was then carried out to identify factors associated with kyphotic deformity. Independent variables were chosen based on statistical significance (forward selection method), which was set at $P<.05$. All analyses were performed using SPSS software (SPSS Inc., Chicago, IL).

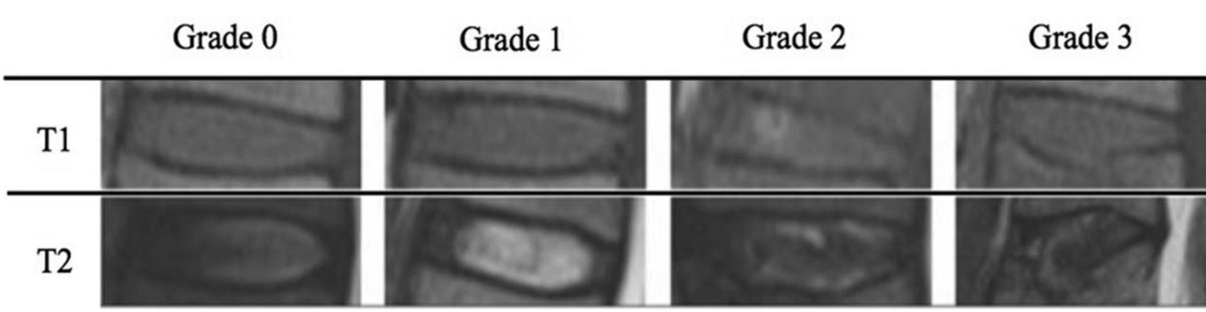

Figure 2. Sander's classification of traumatic intervertebral disc lesions. Intervertebral disc injuries are classified as grade 0 to 3 as follows: grade 0, uninjured discs in their normal condition; grade 1, hyperintense appearance on T2-weighted magnetic resonance imaging; grade 2, decreased signal intensity with perifocal hyperintense appearance on T2-weighted images and isointense to isointense appearance on T1-weighted images; and grade 3, an infraction of the disc into the vertebral body, annular tears, or herniation into the endplate.

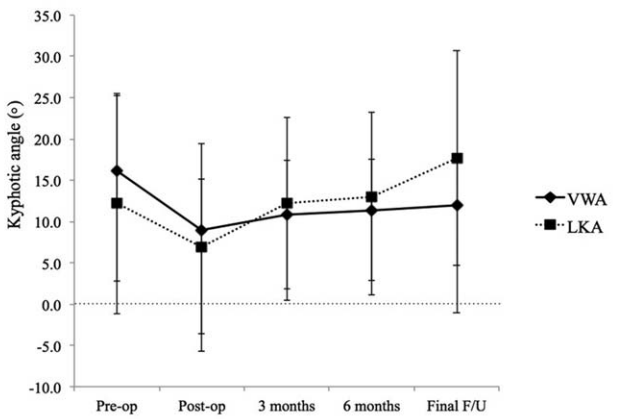

Figure 3. Results for plain radiograph measurements of vertebral wedge angle (VWA) and local kyphosis angle (LKA). Mean VWA was 16.1° (standard deviation [SD], 9.1°) preoperation. It improved to 9.0° (SD, 6.1°) postoperation and was 11.9° (SD, 6.1°) at final follow-up. Correction loss at the site of the vertebral body was 3.0° (SD, 3.3°). Mean LKA was 12.2° (SD, 13.4°) preoperation. It improved to 6.9° (SD, 12.6°) postoperation and was 17.7° (SD, 13.0°) at final follow-up. The LKA correction loss was 10.8° (SD, 9.1°).

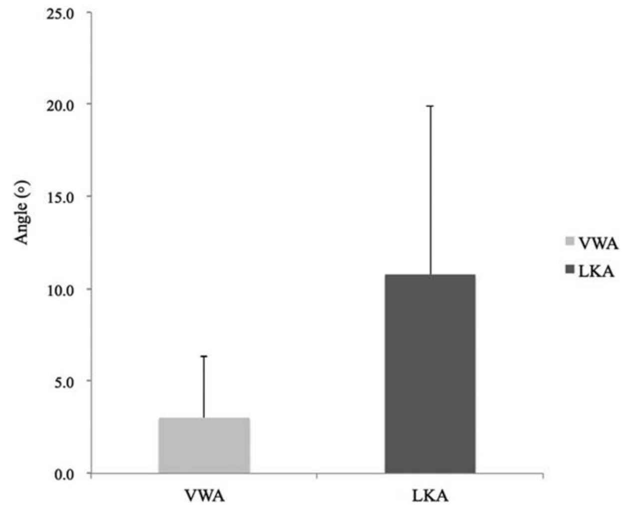

Figure 4. Comparison of local kyphosis angle (LKA) and vertebral wedge angle (VWA) correction losses. Correction losses were greater in terms of LKA than VWA.

3. Results

3.1. Patient clinical features and surgical outcomes

Among the 48 patients with thoracolumbar injuries that were treated with posterior fixation, there were 13 cases of AO type-A3 fracture, 6 cases of type-A4 fracture, 2 cases of type-B1 fracture, 18 cases of type-B2 fracture, 5 cases of type-B3 fracture, and 4 cases of type-C fracture. The mean TLICS score was 5.1 (2.0) (range, 2–9). Thirty-two patients out of the 48 had posterior bone grafting (i.e., fusion) and posterior instrumentation had been removed (i.e., implant removal) in 29. Mean ASIA Impairment Scale scores were 4.0 (1.3) preoperation and 4.4 (1.2) at final follow-up. The mean Denis pain scale score at final follow-up was 2.4 (1.1) (Table 1).

3.2. Radiographic measurements

Results from plain radiograph measurements of VWA and LKA are shown in Fig. 3. Overall, mean VWA was 16.1° (9.1°: SD) preoperation. It improved to 9.0° (6.1°) postoperation and was 11.9° (6.1°) at final follow-up. Correction loss at the site of the vertebral body was 3.0° (3.3°). Mean LKA was 12.2° (13.4°) preoperation. It improved to 6.9° (12.6°) postoperation and was 17.7° (13.0°) at final follow-up. LKA correction loss in terms of LKA was 10.8° (9.1°). Our comparison between VWA and LKA correction losses is shown in Fig. 4, with correction losses being greater in terms of the latter. Results for measurements of AVH, MVH, PVH, and A/P ratio are shown in Table 2 and Fig. 5. Finally, MRI evaluation of IDIs upon admission revealed 4 grade 0 cases, 7 grade 1 cases, 9 grade 2 cases, and 28 grade 3 cases according to Sander's classification.

3.3. Comparisons between patients with and without kyphosis

For these analyses, patients were allocated into either the "kyphosis group" or the "control group" based on LKA angle. Specifically, those whose LKA deteriorated by ≥10° between postoperation and final follow-up were allocated to the kyphosis group, while those whose LKA deteriorated by <10° were allocated to the control group. Between-group comparisons of the clinical features and radiographic measurements above were then carried out to identify factors associated with kyphotic deformity.

Twenty-three patients were allocated to the kyphosis group and 25 were allocated to the control group. The results of our between-group univariate analysis are shown in Table 3. Sex, AOSTLC, TLICS, preoperative VWA, and correction angle (i.e., the difference between pre- and postoperative VWA/LKA) were not significantly different between groups. On the other hand, mean age was significantly lower in the kyphosis group (37.6 [16.9] years) than in the control group (51.7 [19.7] years) (P=.016). The level at which injury occurred also significantly differed between the 2 groups (P=.014). Furthermore, more patients in the kyphosis group underwent fusion (kyphosis, 19 vs control, 13; P=.034) and implant removals (kyphosis, 19 vs

Table 2

AVH, MVH, PVH, and A/P ratio.

	Preop	Postop	3 mo	6 mo	Final F/U
AVH	19.9 (4.3)	22.4 (4.4)	20.2 (3.9)	20.2 (3.9)	19.8 (3.9)
MVH	18.3 (4.3)	19.1 (3.8)	18.4 (4.1)	18.1 (4.1)	17.8 (4.2)
PVH	26.3 (3.5)	27.0 (3.5)	26.2 (3.5)	26.4 (3.4)	26.1 (3.6)
A/P ratio	0.76 (0.16)	0.83 (0.16)	0.77 (0.13)	0.77 (0.13)	0.76 (0.14)

A/P = anteroposterior, AVH = anterior vertebral body height, MVH = middle vertebral body height, PVH = posterior vertebral body height.

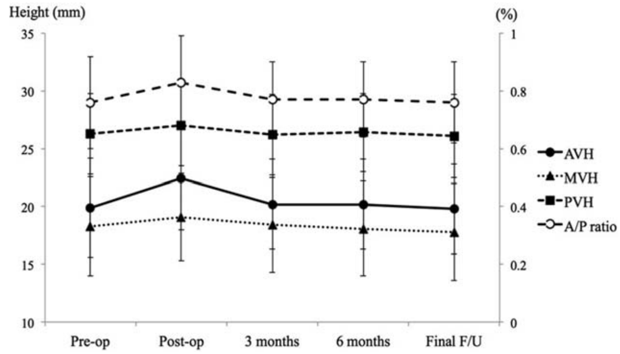

Figure 5. Results for the measurement of anterior vertebral body height, middle vertebral body height, posterior vertebral body height, and anteroposterior ratio.

control, 10; $P=.03$) than in the control group. Finally, IDI severity in terms of Sander's classification also significantly differed between the 2 groups. Specifically, the control group contained 4 group 0 cases, 7 group 1 cases, 5 group 2 cases, and 9 group 3 cases. On the other hand, there were no group 0 or group 1 cases in the kyphosis group, and 19 out of the 23 kyphosis group cases were classified into group 3. Other radiographic assessment results are shown in Table 4.

Table 3

Comparison between control and kyphosis group.

	Control group	Kyphosis group	*P*
Patients (n)	25	23	
Year	51.7 (19.7)	37.6 (16.9)	.016
Sex (male/female): (n)	17/8	18/5	.523
Follow-up period: (mo)	28.5 (21.9)	37.3 (26.1)	.147
AOTLC (n)			.935
Type A	10	5	
Type B	13	4	
Type C	2	2	
TLICS	4.8 (2.1)	5.4 (1.9)	.481
Level of injury (n)			.014
T3–T10	6	0	
T11–L2	18	18	
L3–5	1	5	
Fusion (n)	13	19	.034
Implant removal: (n)	10	19	.003
ASIA impairment scale			
Preoperative	3.8 (1.5)	4.1 (1.1)	.770
Final follow-up	4.2 (1.5)	4.7 (0.7)	.376
Denis pain score	2.3 (1.1)	2.4 (1.2)	.763
Sander's classification (n)			.000
Grade 0	4	0	
Grade 1	7	0	
Grade 2	5	4	
Grade 3	9	19	
VWA (°)			
Preoperation	14.5 (9.4)]	17.9 (8.8)	.080
correction angle	5.5 (7.9)	8.7 (8.3)	.166
LKA (°)			
Preoperation	13.6 (10.0)	10.6 (16.4)	.680
correction angle	3.1 (9.4)	7.7 (11.3)	.105

AOSTLC = AO spine thoracolumbar spine classification, ASIA = American Spinal Injury Association, LKA = local kyphosis angle, TLICS = thoracolumbar injury and classification score, VWA = vertebral wedge angle.

Table 4

Comparison of radiographic measures between control and kyphosis group.

	Control group	Kyphosis group	*P*
Patients (n)	25	23	
VMA			
Preoperative	14.5 (9.4)	17.9 (8.8)	.080
Postoperative	8.9 (6.9)	9.0 (5.4)	.940
Postoperative 3 mo	9.5 (7.3)	12.6 (5.0)	.111
Postoperative 6 mo	9.8 (6.9)	12.9 (5.0)	.048
Final follow-up	10.4 (6.6)	13.6 (5.2)	.040
LKA			
Preoperative	13.6 (10.0)	10.6 (16.4)	.680
Postoperative	10.5 (9.8)	2.9 (14.2)	.025
Postoperative 3 mo	12.8 (9.7)	11.4 (11.5)	.453
Postoperative 6 mo	13.2 (9.3)	12.9 (11.3)	.790
Final follow-up	14.4 (9.2)	21.2 (15.6)	.0.22
AVH			
Preoperative	20.6 (4.3)	19.1 (4.6)	.312
Postoperative	22.0 (5.2)	22.8 (3.3)	.353
Postoperative 3 mo	20.2 (4.4)	20.1 (3.4)	.861
Postoperative 6 mo	20.5 (4.5)	19.8 (3.2)	.665
Final follow-up	20.2 (4.2)	19.3 (3.5)	.570
MVH			
Preoperative	19.2 (4.0)	17.4 (4.6)	.112
Postoperative	19.1 (4.1)	19.2 (3.6)	.893
Postoperative 3 mo	18.1 (4.3)	18.8 (4.1)	.882
Postoperative 6 mo	18.1 (4.3)	18.0 (4.1)	.757
Final follow-up	17.9 (4.4)	17.7 (4.0)	.749
PVH			
Preoperative	25.7 (3.9)	26.9 (3.0)	.380
Postoperative	26.1 (4.0)	28.0 (2.6)	.107
Postoperative 3 mo	25.4 (3.9)	27.2 (2.7)	.140
Postoperative 6 mo	25.6 (3.9)	27.2 (2.6)	.197
Final follow-up	25.2 (4.0)	27.2 (2.8)	.076
A/P ratio			
Preoperative	0.81 (0.16)	0.71 (0.15)	.027
Postoperative	0.84 (0.14)	0.81 (0.10	.476
Postoperative 3 mo	0.80 (0.14)	0.74 (0.11)	.163
Postoperative 6 mo	0.80 (0.14)	0.73 (0.11)	.042
Final follow-up	0.81 (0.13)	0.72 (0.13)	.020

A/P = anteroposterior, AVH = anterior vertebral body height, LKA = local kyphosis angle, MVH = middle vertebral body height, PVH = posterior vertebral body height, VWA = vertebral wedge angle.

3.4. Multiple logistic regression analysis to identify clinical and radiographic factors associated with kyphotic change

Based on our univariate analysis, the 5 factors that significantly differed between the kyphosis and control groups—age, level of injury, occurrence of fusion surgery, occurrence of implant removal, and IDI severity—were chosen for multiple logistic regression analysis to reveal the factors related associated with kyphotic change. No variables were found to have a marked linear relationship, which was confirmed by scatter diagrams. Results from our multiple regression analysis using the forward selection method (likelihood ratio) are shown in Table 5. Grading of IDIs according to Sander's classification ($P=.005$; odds ratio, 5.263; 95% CI, 1.637–16.927) and implant removal ($P=.011$; odds ratio, 7.980; 95% CI, 1.603–39.728) were statistically significant among the independent variables tested. Figure 6 showed a representative case. A chi-squared test of our model yielded a significant result ($P<.01$). A Hosmer and Lemeshow test also yielded a favorable result ($P=.356$), and the correct classification rate was 78.3%. There were no outliers exceeding ±3SD.

Table 5

Multiple logistic regression analysis.

	Partial regression coefficient	Significant probability	Odds ratio	95% confidence interval
Sander's classification	1.661	0.005	5.263	(1.637–16.927)
Implant removal	2.077	0.011	7.98	(1.603–39.728)
Constant	−5.411	0.002	0.004	

Model chi-squared test: $P<.01$. Percentage of correct classification: 78.3%.

4. Discussion

In the present study, the median VWA correction loss was 2°, while the median LKA correction loss was 9°. These results imply that the kyphotic changes we observed occurred mainly at the intervertebral disc level rather than at the site of the vertebral body. In terms of treatment to minimize these changes, McCormack et al[5]'s load-shearing classification recommends that severe comminution of the vertebral body should not be treated only with posterior fixation. This was supported by Toyone et al,[20] who reported that the median vertebral body kyphosis angle was −1° postoperation and 1° at final follow-up in their study of thoracolumbar burst fractures treated with both short-segment pedicle screw fixation and transpedicular hydroxyapatite augmentation. However, due to recent advancements in spinal instrumentation and surgical procedures, vertebral body angle correction by posterior fixation can be maintained long enough to achieve bone union. Indeed, VWA correction loss in our study was comparable to that in Toyone et al's, even without anterior augmentation.

However, while the vertebral body kyphosis angle does not change after bone union, injured intervertebral discs can still undergo degeneration. This can in turn cause disc space narrowing and/or kyphotic deformity, with previous studies having identified an association between IDI and kyphotic deformity.[8,14,16] In particular, Wang et al[16] found that in their patients, injured discs adjunct to fractured cranial endplates degenerated gradually over a mean follow-up period of 23.5 months. In accordance with these results, we found that kyphotic deformity occurred mainly at the intervertebral disc level, which is also consistent with results reported by Aono et al.[11]

Although post-traumatic disc degeneration has been associated with recurrent kyphosis; however, it cannot be used to predict this in the initial phase of injury assessment. Our study is

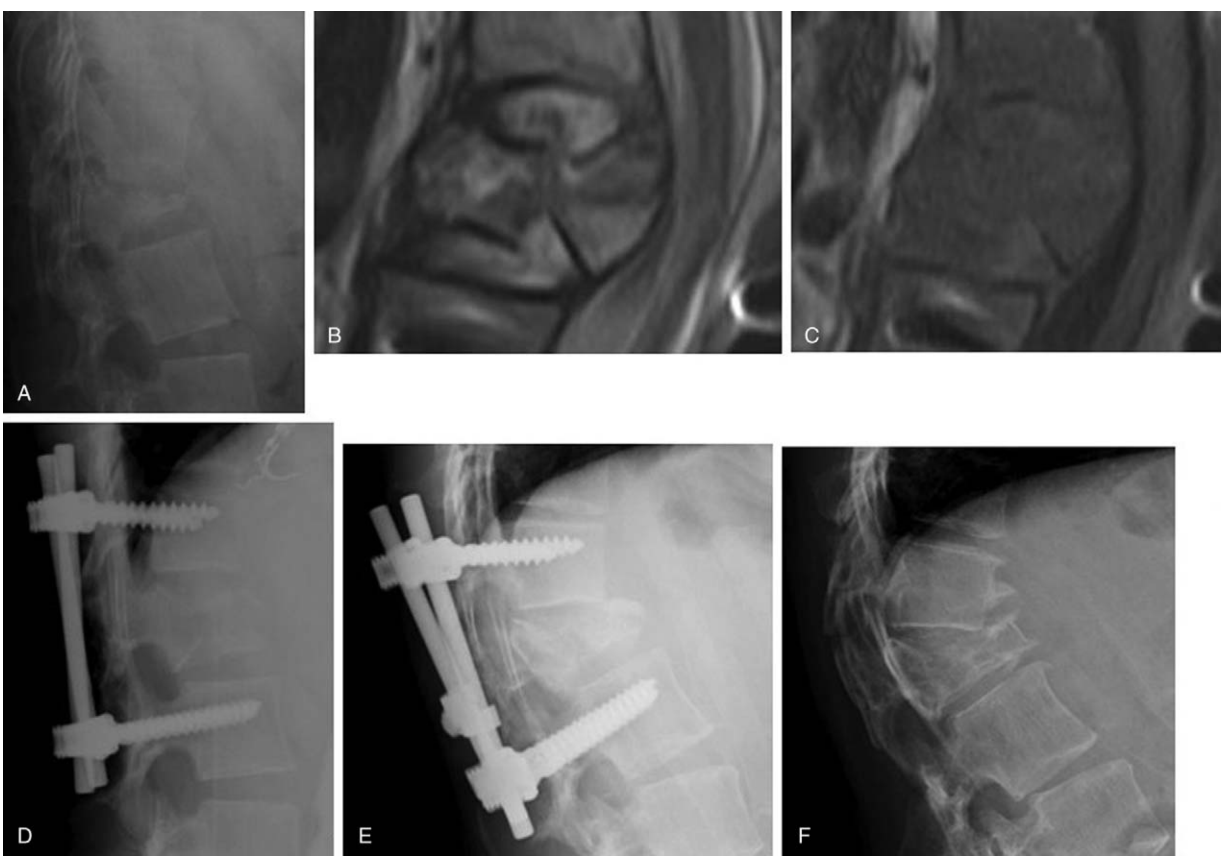

Figure 6. Female, 32 years old. L1 burst fracture, AO spine thoracolumbar spine classification (AOSTLC) A4 (A). Sander's classification: grade 3 (B and C). Although vertebral wedge angle (VWA) and local kyphosis angle (LKA) were successfully corrected at postoperative X-ray (D). Correction loss had occurred at 13 months after surgery (E). LKA loss was aggravated at the injured intervertebral disc following implant removal, while VWA was maintained at 8 years after injury. AO = Arbeitsgemeinschaft für Osteosynthesefragen.

advantageous because it investigated the association between kyphotic deformity and factors that can be evaluated on initial MRI scans, which are routinely performed in the assessment of spinal injuries.[21,22] Specifically, we used MRI scans to grade IDIs according to Sander's classification to investigate the correlation between IDI severity and fracture type. However, we could not find any correlation between kyphosis and these 2 factors. Further studies would reveal the relationship between IDI severity and fracture classifications (e.g., TLICS, AOSTLC, etc.) later.

Preoperative VWA and changes between pre- and postoperative VWA were also not found to be associated with kyphotic deformity. This contrasts with some other studies, which have reported a relationship between preoperative vertebral collapse and the recurrence of kyphosis.[12,13] Generally, however, severe comminution of the vertebral body does not frequently accompany IDIs. It must be noted that recurrent kyphosis secondary to vertebral comminution may partially reflect disc space narrowing or wedging. Our multiple regression analysis showed no relationship between fusion and kyphotic deformity. This result is consistent with previous studies,[18,19,25] which found no difference in postoperative kyphotic changes between patients who underwent fusion and those who did not.

In contrast, implant removal was identified by multiple regression analysis as one of the factors associated with kyphotic deformity, defined as a correction loss $\geq 10°$. This result is especially relevant because kyphosis after implant removal and whether implants should be removed have recently been topics of discussion in the literature.[11,12,23,24] For example, Jeon et al[23] reported improvement in functional outcomes after implant removal in patients who underwent long-segment fixation using the fusion technique. In contrast, Chou et al[24] found no changes in radiological and functional outcomes after implant removal in patients treated with short-segment fixation. From our results, we cannot definitively conclude whether implants should be removed. However, we do recommend that patients be informed that there is a risk of kyphotic change after implant removal, especially if they have severe IDIs.

IDI severity according to Sander's classification was also identified as a factor associated with kyphotic deformity. It is worthy of special mention that there were no kyphotic deformity cases with Sander's grades of 0 and 1. Given that over 1/3 of patients in the control group had grade 3 IDIs, it can be concluded that severe IDIs do not necessarily result in kyphotic deformity. Rather, it should be stated that intervertebral discs with no or slight injuries are less likely to undergo kyphotic changes. Indeed, endplate comminution and vertebral body involvement as evaluated by MRI have been reported to be predictive of kyphotic deformity after thoracolumbar spine fractures.[9] This is compatible with our results because a grade 3 IDI is defined by Sander's classification as "an infraction of the disc into the vertebral body, annular tears, or herniation into the endplate." Our results are particularly strong because we were able to accurately determine IDI severity using MRI, the only method of precisely identifying differences between grade 0, 1, and 2 IDIs.

Despite the insights provided by this study, there are some limitations to consider. These include its retrospective nature and small sample size, with a larger number of patients being more ideal for increased statistical power. Nonetheless, this study was conducted as an exploratory analysis and still has value in this capacity. Another limitation was the heterogeneity among patients with thoracolumbar spine injuries. This contrasts with most previous studies, which chose to focus on thoracolumbar burst fractures. Lumping patients with thoracic and lumbar spine injuries together could be a potential risk for bias because they may represent different forces due to unsupported nature of the lumbar vertebral bodies. Regardless of these limitations, however, we believe that the present study provides some novel perspectives on clinical practice, suggesting that thoracolumbar spine injuries should not only be assessed initially as bony and ligamentous injuries, but also as disc injuries.

5. Conclusion

Kyphotic deformity occurs mainly at the level of the intervertebral discs rather than the vertebral body. Our multiple regression analysis revealed that IDI severity as evaluated by initial MRI scans and implant removal are associated with kyphotic deformity after posterior fixation of thoracolumbar spine injuries. Findings from initial MRI scans of intervertebral discs could therefore be a useful predictor of recurrent kyphosis.

Author contributions

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References

[1] Gnanenthiran SR, Adie S, Harris IA. Nonoperative versus operative treatment for thoracolumbar burst fractures without neurologic deficit: a meta-analysis. Clin Orthop Relat Res 2012;470:567–77.
[2] Cheng LM, Wang JJ, Zeng ZL, et al. Pedicle screw fixation for traumatic fractures of the thoracic and lumbar spine (review). Cochrane Database Syst Rev 2013;31:CD009073.
[3] Wood KB, Li W, Lebl DS, et al. Management of thoracolumbar spine fractures. Spine J 2014;14:145–64.
[4] Wang F, Zhu Y. Treatment of complete fracture-dislocation of thoracolumbar spine. J Spinal Disord Tech 2013;26:421–6.
[5] McCormack T, Karaikovic E, Gaines RW. The load sharing classification of spine fractures. Spine 1994;19:1741–4.
[6] Vaccaro AR, Oner C, Kepler CK, et al. AOSpine thoracolumbar spine injury classification system: fracture description, neurological status, and key modifiers. Spine 2013;38:2028–37.
[7] Vaccaro AR, Lehman RA, Hurlbert RJ, et al. A new classification of thoracolumbar injuries: the importance of injury morphology, the integrity of the posterior ligamentous complex, and neurologic status. Spine 2005;30:2325–33.
[8] Lindsey RW, Dick W. The Fixateur Interne in the reduction and stabilization of thoracolumbar spine fractures in patients with neurologic deficit. Spine 1991;16:S140–5.
[9] Oner FC, van Gils APG, Faber JAJ, et al. Some complications of common treatment schemes of thoracolumbar spine fractures can be predicted with magnetic resonance imaging. Spine 2002;27:629–36.
[10] Chou PH, Ma HL, Wang WT, et al. Fusion may not be a necessary procedure for surgically treated burst fractures of the thoracolumbar and lumbar spines. J Bone Joint Surg Am 2014;96:1724–31.
[11] Aono H, Tobimatsu H, Ariga K, et al. Surgical outcomes of temporary short-segment instrumentation without augmentation for thoracolumbar burst fractures. Injury 2016;47:1337–44.
[12] Chen JX, Xu DL, Sheng SR, et al. Risk factors of kyphosis recurrence after implant removal in thoracolumbar burst fractures following posterior short-segment fixation. Int Orthop 2016;40:1253–60.
[13] Wang XY, Dai LY, Xu HZ, et al. Kyphosis recurrence after posterior short-segment fixation in thoracolumbar burst fractures. J Neurosurg Spine 2008;8:246–54.
[14] Oner FC, van der Rijt RR, Ramos LMP, et al. Changes in the disc space after fractures of the thoracolumbar spine. J Bone Joint Surg Br 1998;80-B:833–9.

[15] Verlaan JJ, Dhert WJA, Oner FC. Intervertebral disc viability after burst fractures of the thoracic and lumbar spine treated with pedicle screw fixation and direct end-plate restoration. Spine J 2013;13:217–21.
[16] Wang J, Zhou Y, Zhang ZF, et al. Radiological study on disc degeneration of thoracolumbar burst fractures treated by percutaneous pedicle screw fixation. Eur Spine J 2013;22:489–94.
[17] Sander AL, Laurer H, Lehnert T, et al. A clinically useful classification of traumatic intervertebral disk lesions. Am J Roentgenol 2013;200: 618–23.
[18] Denis F. Spinal stability as defined by three-column spine concept in acute spinal trauma. Clin Orthop 1984;189:65–76.
[19] Chou PH, Ma HL, Wang ST, et al. Fusion may not be a necessary procedure for surgically treated burst fractures of the thoracolumbar and lumbar spines: a follow-up of at least ten years. J Bone Joint Surg Am 2014;96:1724–31.
[20] Toyone T, Tanaka T, Kato D, et al. The treatment of acute thoracolumbar burst fractures with transpedicular intracorporeal hydroxyapatite grafting following indirect reduction and pedicle screw fixation: a prospective study. Spine 2006;31:E208–14.
[21] Pizones J, Izquierdo E, Alvarez P, et al. Impact of magnetic resonance imaging on decision making for thoracolumbar traumatic fracture diagnosis and treatment. Eur Spine J 2011;20(suppl 3):S390–6.
[22] Su Y, Ren D, Zou Y, et al. A retrospective study evaluating the correlation between the severity of intervertebral disc injury and the anteroposterior type of thoracolumbar vertebral fractures. Clinics 2016;71:297–301.
[23] Jeon CH, Lee HD, Lee YS, et al. Is it beneficial to remove the pedicle screw instrument after successful posterior fusion of thoracolumbar burst fractures? Spine 2015;40:E627–33.
[24] Chou PH, Ma HL, Liu CL, et al. Is removal of the implants needed after fixation of burst fractures of the thoracolumbar and lumbar spine without fusion? Bone Joint J 2016;98-B:109–16.
[25] Wang ST, Ma HL, Liu CL, et al. Is fusion necessary for surgically treated burst fractures of the thoracolumbar and lumbar spine? Spine 2006;31:2646–52.