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Radiographic Evaluation of Minimally Invasive Instrumentation and Fusion for Treating Unstable Spinal Column Injuries

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Abstract

Study Design: Retrospective cohort.

Objective: Facet fusion in minimally invasive spine surgery (MISS) may reduce morbidity and promote long-term construct stability. The study compares the maintenance of correction of thoracolumbar (TL) trauma patients who underwent MISS with facet fusion (FF) and without facet fusion (WOFF) and evaluates instrumentation loosening and failure.

Methods: TL trauma patients who underwent MISS between 2006 and 2013 were identified and stratified into FF and WOFF groups. To evaluate progressive kyphosis and loss of correction, Cobb angles were measured at immediate postoperative, short-term, and long-term follow-up. Evidence of >2 mm of radiolucency on radiographs indicated screw loosening. If instrumentation was removed, postremoval kyphosis angle was obtained.

Results: Of the 80 patients, 24 were in FF and 56 were in WOFF group. Between immediate postoperative and short-term follow-up, kyphosis angle changed by 4.0° (standard error [SE] 1.3°) in the FF and by 3.0° (SE 0.4°) in the WOFF group. The change between immediate postoperative and long-term follow-up kyphosis angles was 3.4° (S.E 1.1°) and 5.2° (S.E 1.6°) degrees in the FF and WOFF groups, respectively. Facet fusion had no impact on the change in kyphosis at short term ($P = .49$) or long term ($P = .39$). The screw loosening rate was 20.5% for the 80 patients with short-term follow-up and 68.8% for the 16 patients with long-term follow-up. There was no difference in screw loosening rate. Fifteen patients underwent instrumentation removal—all from the FF group.

Conclusion: FF in MISS does not impact the correction achieved and maintenance of correction in patients with traumatic spine injuries.

Keywords

thoracolumbar fracture, unstable spinal injury, radiographic evaluation, percutaneous pedicle screws, minimally invasive facet fusions, kyphosis, instrumentation failure

Introduction

Thoracolumbar (TL) injuries are common, occur due to blunt trauma,[1] and may require surgical management for decompression, kyphosis correction, stabilization, maintenance of spinal alignment, and restoration of vertebral height.[2] Compared with traditional open approach, recent reports have demonstrated lower blood loss, shorter operative times, reduced infection rates, and less postoperative pain with minimally invasive spine surgery (MISS), especially in patients suffering from

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polytrauma.[3] In light of these findings, MISS is increasingly being used in trauma.[4-6]

Despite growing evidence regarding MISS for unstable injuries, long-term results of MISS for these injuries are lacking. In addition, recent studies have brought into question the need for arthrodesis in addition to instrumentation. Open arthrodesis did not show a significant difference in radiological and clinical outcomes in TL trauma.[7,8] Despite this evidence, there continues to be a concern that fixation of TL fractures without fusion can lead to loss of correction due to construct instability and instrumentation failure or loosening.[9] Facet fusion has been shown to be effective in management of degenerative spondylolisthesis but the role of facet fusion in MISS for TL trauma has not been evaluated.[10] This study evaluates unstable spine fractures that underwent fixation and stabilization with MISS with or without facet fusion with the aim to compare correction of kyphosis angles, maintenance of correction, screw loosening, and implant removal.

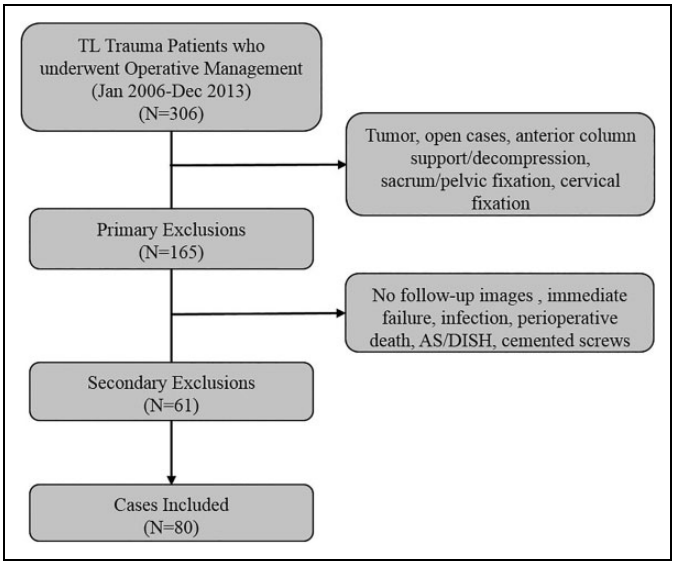

Figure 1. Flowchart for study selection. A total of 306 consecutive patients underwent surgery for thoracolumbar trauma patients between Jan 2006 and December 2013. Out of these, 80 patients were included in the study.

Materials and Methods

Study Design

This a retrospective cohort study. After obtaining institutional review board approval, our Trauma Center database was queried to determine a consecutive series of patients who underwent operative treatment of spine fractures between January 2006 and December 2013. Since no specific CPT (Current Procedural Terminology) code exists for MISS, the database was queried for all cases with the CPT codes of 22 325 and 22 327 (open treatment of lumbar and thoracic spine fractures) 22 840 and 22 842 (posterior instrumentation), and 22 889 (unlisted spine procedure).

Patient Inclusion/Exclusion

We followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines to enhance the quality and minimize the bias of this observational study.[11] From review of operative reports, patients with percutaneous instrumentation were selected. A total of 306 cases of operative thoracic and lumbar fractures were identified. Exclusion criteria included the following: open cases, cases with anterior column support or laminectomy, pathologic fractures stemming from infection or tumor, cases where the instrumentation was extended to the sacrum or pelvis, cement augmentation, ankylosing spondylitis, diffuse idiopathic skeletal hyperostosis, and patients that lacked appropriate follow up imaging (Figure 1). A total of 80 cases were included and stratified into 2 groups: With facet fusion (FF) and without facet fusion (WOFF).

Patient Variables

Chart review was used to obtain patient characteristics, including age, gender, Glasgow Coma Scale (GCS), Injury Severity Score (ISS), mechanism of injury, and preoperative neurological status. The fracture levels were classified into T1-T9, T10-L2, or L3-L5 groups. Fracture morphology was classified according the AOSpine Thoracolumbar Spine Injury Classification System.[12]

Follow-up for Radiographic Outcomes

All 80 cases had initial upright x-rays within 1 week of surgery and available follow-up imaging. On preoperative and all postoperative radiographs, the local kyphosis angle was measured (one level above and below the injury level). The kyphosis angle was measured to evaluate for loss of correction (Figure 2). In addition, each radiograph was examined for instrumentation failure or loosening. Greater than 2 mm of radiolucency around any screw was used as an indication of screw loosening.[13-15] Unless clinically indicated, computed tomography scans were not obtained for patients at their follow up visits. Therefore, actual adequacy of facet fusion was not evaluated. We were simply interested to know whether the addition of an attempt at facet fusion improved stability and maintenance of alignment. In cases where instrumentation was removed, kyphosis angle was obtained from post-removal upright radiographs. Of the 80 patients included in the study, all patients had short-term follow-up (<1 year) radiographs. The patients were contacted and requested to return to clinic for follow-up radiographs if needed. Medical records were also reviewed for perioperative complications.

Operative Procedures

All procedures were performed by one of the four fellowship trained spine surgeons. Patients were placed prone on a Jackson table. Jamshidi needles were used to initially cannulate each

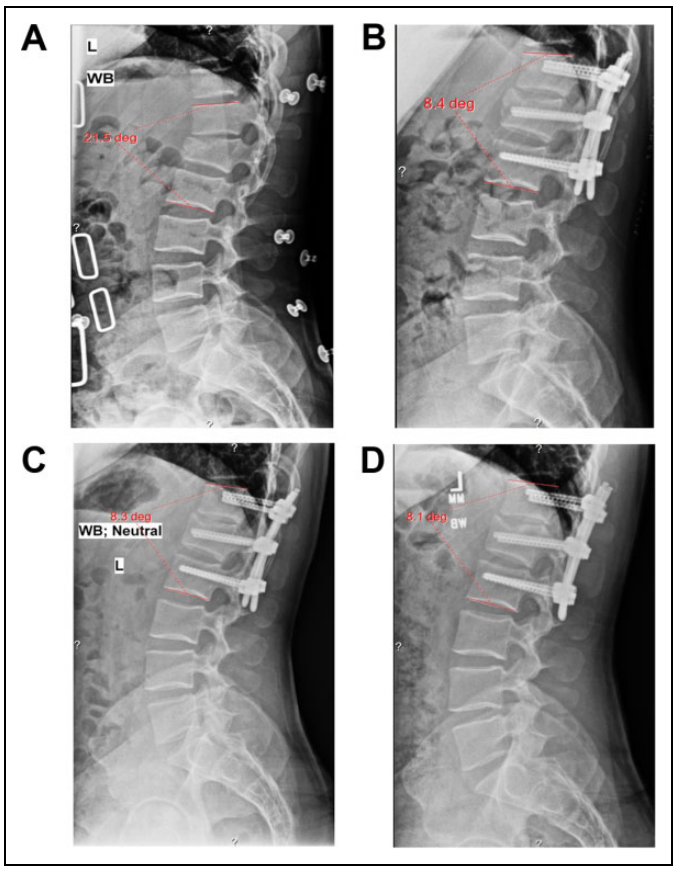

Figure 2. Measurement of kyphosis angle in a patient with L1 burst fracture. Kyphosis angles were measured one level above and below the injury level. (A) Injury radiograph with L1 burst fracture. Kyphosis angle was measured on immediate postoperative radiographs (B). Short-term follow-up radiographs (38 weeks) (C) and long-term follow-up radiographs (82 weeks) (D).

pedicle under fluoroscopic guidance through a para-median approach utilizing the lateral to medial trajectory technique. Cannulated pedicle screws were placed at each level. Construct length was determined by the surgeon through consideration of bone quality and injury severity. Screws were inserted at the level of injury if the pedicle integrity was intact and there was no significant vertebral body comminution. Subfascial rod placement was performed. Rods were contoured to approximate anatomic contour at the level being instrumented. The primary method of reduction was by positioning on the operating table followed by cantilever reduction of the screws to the anatomically contoured rod.

In cases where facet fusion was performed, a tubular retractor was inserted through the incision and localized over the facet. The facet capsule was first removed with electrocautery followed by a Leksell rongeur and burr to decorticate each facet joint bilaterally throughout the fusion construct. In cases where bone morphogenetic protein (BMP) was employed, the collagen sponge was cut and a portion of it placed into the decorticated facet joint. If no BMP was used, cadaveric crushed allograft was packed into the decorticated facet joint with a tamp and mallet. For patients who underwent facet fusion, fusion was performed at all instrumented levels.

Postoperatively, patients were transferred to the floor and managed with multimodal pain therapy. No bracing was performed postoperatively and the patients had no postoperative weightbearing restrictions. Depending on their comorbidities, patients started ambulating with assistance from physical therapy 1 to 2 days after surgery.

Statistical Analysis

Data was entered into Microsoft Excel for data cleaning and management (Microsoft Office Professional Plus 2016, Microsoft, Redmond, WA, USA). JMP Pro (Version 13.0.0, SAS Institute Inc, Cary, NC, 1987-2007) was used for all statistical analysis. Continuous variables were tested for normality with the Shapiro-Wilk test ($P > .05$). Unpaired T test was used for continuous variables that were normally distributed (long-term follow-up), and Mann-Whitney U test was used for those that were not normally distributed (age, short-term follow-up, kyphosis angles). Because of the small sample size, Fisher's exact test was used for all nominal variables. Post hoc analysis by multiple 2×2 Fisher's exact tests were performed for variables with >2 categories that had a statistically significant P value. To decrease the risk of type 1 error, the Bonferroni correction was used to adjust P values for significance in post hoc analysis. A modified chi-square, Cochran Armitage trend test, was used to assess ordinal data (GCS, ISS, levels instrumented). For maintenance of correction at short term, a paired T-test was used to compare immediate postoperative and short-term follow-up kyphosis angles. For comparison of long-term kyphosis angles, repeated-measures analysis of variance was used. All tests were 2-tailed, and the significance level was .05.

Results

A total of 80 cases were included in the study with a total of 89 fractures; some patients had fracture at more than 1 level. The average age of patients was 39.6 $\pm$ 18.3 years and 36.3% of the patients were female. GCS and ISS were 14.2 $\pm$ 1.9 and 22.3 $\pm$ 12.7, respectively (Table 1). The most common mechanisms of injury included fall (26.3%), motor cycle crashes (25.0%), and pedestrian struck (22.5%). The majority of the patients (58.8%) were neurologically intact. Only 6 (7.5%) of patients suffered from more than 1 spinal fracture. The mean short- and long-term follow-up rates were 29.6 (range 1.6-66) and 123.32 (range 3-66) weeks, respectively.

Comparison of Patients With and Without Facet Fusion

There were 24 and 56 patients in the FF and WOFF groups. Of the 56 patients WOFF, only 6 had more than 1 fracture. The 2 patient groups were comparable with regard to gender ($P = .8$), age ($P = .48$), GCS ($P = .28$), and ISS ($P = .1$) (Table 1). The mechanism of injury ($P = .48$) and neurological status

Table 1. Characteristics for Patients Included in the Study Who Underwent Minimally Invasive Spine Surgery With and Without Facet Fusion.

	All Patients	FF	WOFF	*P*
Total patients, n	80	24	56	
Total fractures, n	89	24	64	
Patients with >1 fracture	6		6	
Female sex, n (%)	29 (36.3)	8 (33.3)	21 (37.5)	.8
Age, years, mean ± SD	39.6 ± 18.3	41.6 ± 18.8	38.7 ± 18.2	.48
GCS, mean ± SD	14.2 ± 1.9	14.5 ± 1.3	14.0 ± 2.1	.28
ISS, mean ± SD	22.3 ± 12.7	18.8 ± 11.5	23.8 ± 12.9	.1
Mechanism of injury, n (%)				.48
Fall	21 (26.3)	8 (33.3)	13 (23.2)	
MCC	20 (25.0)	8 (33.3)	12 (21.4)	
Pedestrian struck	18 (22.5)	3 (12.5)	15 (26.8)	
MVC	17 (21.3)	4 (16.7)	13 (23.2)	
GSW	4 (5.0)	1 (4.2)	3 (5.4)	
Neurological status, n (%)				.47
Complete loss	18 (22.5)	6 (25.0)	12 (21.4)	
Incomplete loss	15 (18.8)	6 (25.0)	9 (16.1)	
Intact	47 (58.8)	12 (50.0)	35 (62.5)	
Short-term follow-up, weeks, mean (range)	29.6 (1.6-66)	33.4 (3-66)	26.5 (1.6-55.1)	.15
Availability of long-term data, n (%)	16 (20.0)	9 (37.5)	7 (12.5)	
Length of follow-up, weeks, mean (range)	123.3 (75.3-255.1)	127.2 (75.3-255.1)	118.4 (89.9-144.6)	.34

Abbreviations: FF, facet fusion; WOFF, without facet fusion; SD, standard deviation; GCS, Glasgow Coma Score; ISS, Injury Severity Score; MVC, motor vehicle crash; MCC, motorcycle crash; GSW, gun shot wound.

($P = .53$) were also similar between the 2 groups. Long-term data (>1 year) was available for a total of 16 patients (9 in the FF and 7 in the WOFF group).

The details of injuries and operation are summarized in Table 2. The WOFF group had significantly more patients with a T1-T9 injury (32.8%) compared with the FF group (0) ($P = .00054$). Compared with 53.1% of fractures in the nonfusion group, 91.7% of fractures in the fusion group were dislocations ($P = .00092$). Burst fractures were the second most common fracture type in the WOFF groups (29.7%). Short segment fixation was performed in 79.2% and 48.2% of FF and WOFF groups, respectively ($P = .01$). BMP was used in less than half (45.8%) of the FF group.

Table 2. Details of Injuries and Operative Parameters for Patients Who Underwent Minimally Invasive Spine Surgery with and Without Facet Fusion.

	FF	WOFF	*P*
Fracture level,[a,b] n (%)	n = 24	n = 64	.0013*
T1-T9	0	21 (32.8)	.00054**
T10-L2	20 (83.3)	37 (57.8)	.043
L3-L5	4 (16.7)	6 (9.4)	.45
Fracture morphology,[a,b] n (%)	n = 24	N = 64	.0059*
Burst/compression (AO A1-A4)	1 (4.2)	19 (29.7)	.010***
Flexion distraction (AO B1-B2)	1 (4.2)	9 (14.1)	.27
Extension distraction (AO B3)	0	2 (3.1)	1.00
Fracture dislocation (AO C)	22 (91.7)	34 (53.1)	.00092***
Levels instrumented[b,c], n(%)	n = 24	n = 56	.012*
2	1 (4.2)	2 (3.6)	1.00
3	19 (79.2)	27 (48.2)	.01****
4	1 (4.2)	7 (12.5)	.42
5	3 (12.5)	15 (26.8)	.24
6	0	5 (8.9)	.32
BMP used, n (%)	11 (45.8)	0	—

Abbreviations: FF, facet fusion; WOFF, without facet fusion; BMP, bone morphogenetic protein.
[a]Calculated on a by fracture basis.
[b]Post hoc analysis done with multiple Fisher exact tests and statistical significance assessed after alpha corrected with Bonferroni correction: ($\alpha = 0.05$)/3 = 0.017; (α=0.05)/4 = 0.0125; ($\alpha = 0.05$)/5 = 0.01.
[c]Calculated on a by patient basis.
*Indicates statistically significant values with $P < .05$.
**Indicates statistically significant values with $P < .017$.
***Indicates statistically significant values with $P < .0125$.
****Indicates statistically significant values with $P < .01$.

Kyphosis Angle Outcomes

All patients had follow-up radiographs available for short-term follow-up (<2 years). The average length of short-term follow-up was 33.4 ± 24.3 and 26.5 ± 21.9 weeks for the FF and WOFF groups, respectively ($P = .15$). For maintenance of correction, kyphosis angles obtained immediately postoperatively were compared with those taken at short- and long-term follow-up. In the FF group, the postoperative kyphosis angles increased from 4.1° (standard error [SE] 2.5°) at immediate postoperative to 7.7° (SE 3.2°) at short-term follow-up ($P = .0082$) (Figure 3A). In the group without fusion, the kyphosis angles changed from 10.6° (SE 1.9°) at immediate postoperative to 13.4° (SE 2.0°) at short-term follow-up ($P < .0001$).

To assess long-term stability, loss of correction was assessed in patients with more than 2 years of follow up. Of the 80 patients included in this study, 15 had their instrumentation removed within a 2-year period. Of the remaining 65 patients, 49 patients were lost to follow-up despite multiple attempts at contacting them. Thus, only 16 patients (20%) had postoperative radiographs greater than 2 years that were available for

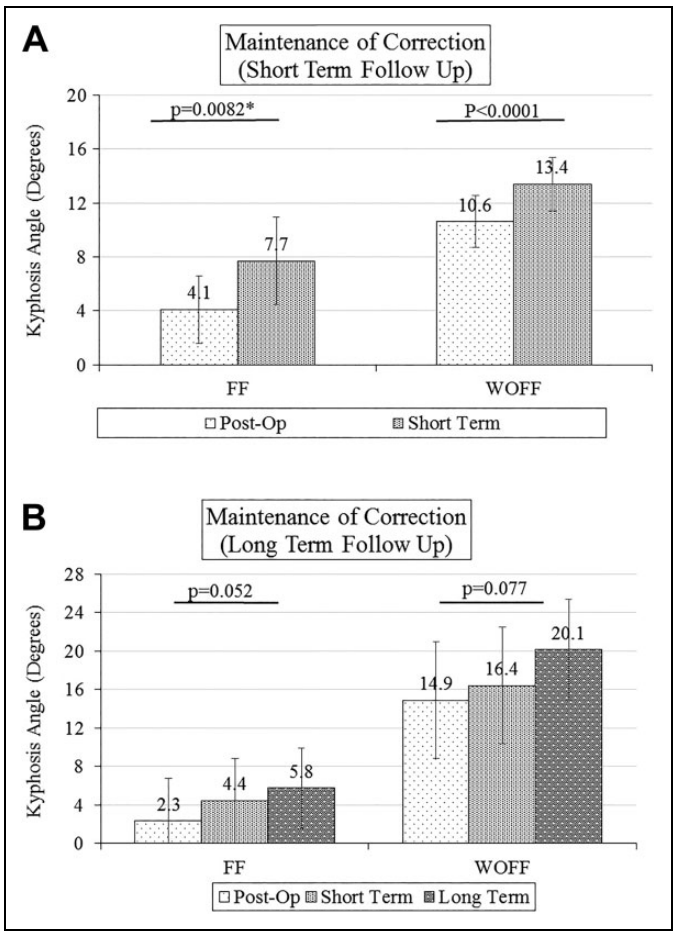

Figure 3. (A) Average and standard error (SE) for kyphosis angle measured at immediate postoperative and short-term follow-up (short term). (B) For the cohort of patients with long-term follow-up (n = 16), average and SE for kyphosis measured at immediate postoperative, short-term, and long-term follow-up. The differences are statistically significant for $P < .05$ values. FF, facet fusion; WOFF, without facet fusion.

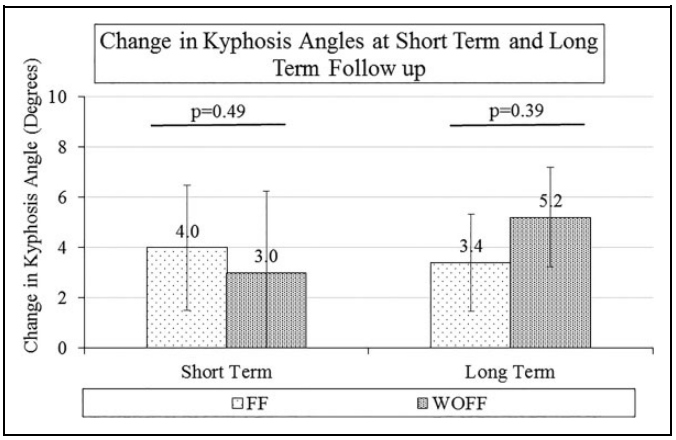

Figure 4. Mean and standard error (SE) for change in kyphosis angle between immediate postoperative radiographs and short-term or long-term follow-up radiographs. FF, facet fusion; WOFF, without facet fusion.

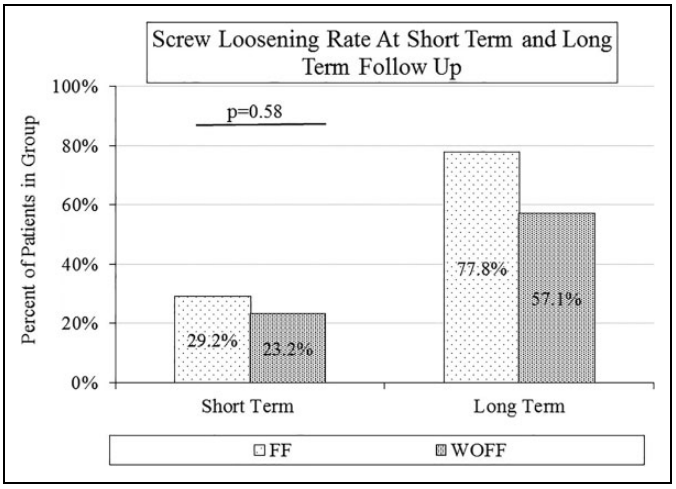

Figure 5. Percentage of patients with loose instrumentation. Of the patients with loose instrumentation at long term, 54.5% of cases did not have instrumentation loosening at short-term follow-up. Long-term subgroup was not statistically evaluated due to low power. FF, facet fusion; WOFF, without facet fusion.

review. The average length of follow-up was 127.2 ± 57.6 and 118.4 ± 22.9 weeks for in FF and WOFF groups, respectively ($P = .34$). There was a trend of increase in kyphosis angles from postoperative to short-term to long-term follow-up. The increase in kyphosis angle was not statistically significant in FF ($P = .052$) and WOFF group ($P = .077$) (Figure 3B). Note that kyphosis angles are higher in the WOFF group because it includes thoracic spine trauma patients.

There was no significant difference in the loss of correction seen when comparing the FF and the WOFF groups (short-term follow-up $P = .49$, long-term follow-up $P = .39$) (Figure 4).

Screw Loosening and Instrumentation Removal

A total of 20 patients (25%) at short-term follow-up and 11 patients (68.8%) at long-term follow-up had loose screws. At short-term follow-up, the rate of screw loosening was 29.2% and 23.2% in the FF and WOFF groups, respectively ($P = .58$) (Figure 5). In the long-term cohort, the rate of screw loosening was 77.8% and 57.1% in the FF and WOFF groups, respectively (Figure 5). The long-term subgroup was not statistically evaluated due to small numbers. Of the 11 patients with loose screws in the long-term cohort, 6 (54.5%) were newly diagnosed and not evident at short-term follow-up. Screws in the TL junction and lumbar spine were more likely to loosen than those in the thoracic spine (Table 3).

A total of 15 patients (18.8%) underwent instrumentation removal within 44 ± 36.5 weeks of the index surgery and all belonged to the WOFF group (Table 3). Of the 15 patients, 10 patients underwent elective removal because of concern for a hardware failure because spinal fusion was not performed. Only 5 of 15 patients had symptomatic hardware and required removal. In patients with implant removal, the kyphosis angles

Table 3. Screw Loosening and Implant Removal in the Study Patients.

	FF	WOFF	*P*
Patients with loose screws (short term)	7 (29.2)	13 (23.2)	.58
Total number of loose screws	9	16	
Screw loosening level (short term)[a]			
T5-T9		2	
T10-L2	7	7	
L3-L5	2	7	
Patients with loose screws (long term)	7 (77.8)	4 (5.7)	
Patients with implant removal	0	15 (26.8)	.0037*
Weeks to implant removal		44 ± 36.5	
Kyphosis angle (immediate postoperative)		9.5 ± 13.1	
Kyphosis angle (short term)		12.4 ± 14.2	
Kyphosis angle (postremoval)		4.2 ± 10.4	

Abbreviations: FF, facet fusion; WOFF, without facet fusion.
[a]All loose screws were counted for each patient.
*Indicates statistically significant values ($P \leq .05$).

were 9.5° ± 13.1° and 12.4° ± 14.2° at immediate postoperative and short-term follow-up, respectively. Postremoval kyphosis was 4.2° ± 10.4°. Postremoval, there was, on average, 5.3° of kyphosis decrease when compared with the postoperative kyphosis angle.

Discussion

Our study is the first of its kind to evaluate the short- and long-term rates of screw loosening and maintenance of kyphosis correction in TL trauma patients who underwent MISS with FF and WOFF. Facet fusion may be desirable because of limited dissection needs, ease of access, need for less bone graft, and proximity to adjacent segments.[10] The cross-sectional area of each facet joint is between 25% and 30% of the lumbar vertebral body.[10] Using ovine lumbar fusion models, Toth et al[16] showed that facet fusion had a slightly higher stiffness than posterolateral fusion. Despite the increasing use of facet fusion, its impact on pedicle screw fixation and the rate of instrumentation failure has not been evaluated. Furthermore, no studies have critically examined the outcome for percutaneous techniques at long-term (>2 years) follow-up.

In this retrospective cohort study, maintenance of kyphosis angle was evaluated in patients with and without facet fusion. Between immediate postoperative and short-term follow-up radiographs, the average kyphosis angles changed by 4.0° and 3.0° for the FF and WOFF groups, respectively. The small change of 3° to 4° is within the error rate of cobb angle measurements.[17] Similar to the short term cohort, the change of 3.4° and 5.2° in the FF and WOFF groups observed in the long-term cohort was not statistically significant and falls within the error range of kyphosis angle measurements.[17] Considering the average loss of correction at both short- and long-term follow-up, our data suggests that MISS is a viable option for maintaining alignment in unstable spinal columns injuries. Additionally, when attempting to maintain proper radiographic alignment in trauma setting, facet fusions may not be necessary.

The 2° to 5° kyphosis angle change observed in our study aligns with earlier studies evaluating maintenance of correction. Vanek et al[18] demonstrated that short-segment percutaneous pedicle screw instrumentation had similar radiographic results up to 2 years of follow-up compared with short-segment fixation performed through a standard midline incision. Despite the high rate of radiographic loosening in that study, the overall loss of correction was nominal, indicating that instrumentation was able to maintain successful vertebral alignment during the healing process. Unlike our study, the majority of fractures in that study were stable burst injuries. Similarly, Lyu et al[19] compared 2- and 3-level MISS in type A TL fractures and found a 2° to 3° loss of correction over a 1.5-year follow-up period. The loss of correction observed in our study, therefore, is minimal and comparable to the loss of correction reported in earlier studies on percutaneous fixation.

Our study is the first of its kind to evaluate screw loosening in addition to maintenance of correction. At short-term follow-up, the screw loosening rate was 29.2% and 23.2% in the FF and WOFF groups, respectively. Among the 16 patients with more than 2 years of follow-up, the overall screw loosening rate increased to 68.8% (fusion group n = 9, 77.8%; no fusion n = 7, 57.1%). With the majority of patients being lost to long-term follow-up, it is plausible that mostly symptomatic patients returned—a finding that could have potentially overstated the instrumentation loosening rate. Of note, studies on open fixation have reported implant failure rates whereas we evaluated screw loosening in our study. The 2 metrics are not directly comparable. The rate of implant failure reported in open procedures ranges from 2% to 8% with a slightly higher rate for those with spinal fusion compared to those without fusion.[9] Furthermore, we found that a greater rate of loosening occurred in the TL and lumbar regions of the spine. Given the greater degree of motion at these levels when compared with the thoracic spine, this finding makes sense biomechanically. To our knowledge, this finding has not been reported in the minimally invasive spine literature.

There is still controversy as to when posterior instrumentation without fusion should be removed. In our study, 18.8% of patients underwent implant removal within 44 ± 36.5 weeks of the surgery and all of them were without fusion. Postoperative radiographs taken after instrumentation removal demonstrated no clinically significant loss of correction. The average kyphosis angle decreased from 9.5° immediate postoperatively to 4.2° after instrument removal. This may represent measurement error or perhaps some change in disc height that occurs with instrumentation removal. Jeon et al[20] were able to demonstrate improved VAS scores and increased segmental motion after instrumentation removal for TL burst fractures. Early in our experience with percutaneous fixation, we routinely removed implants approximately 9 months after the index procedure. However, our clinical philosophy changed through the

study period such that only symptomatic patients underwent removal. To avoid a second surgery, we advocate for instrumentation removal only if it is symptomatic, regardless of its radiographic appearance.

Limitations

There are several limitations of our study and results should therefore be interpreted with caution. This was a retrospective chart review and therefore, relies on the clinical evaluations and accuracy of clinical notes. Findings that were not documented in the electronic medical record may introduce bias into the study analysis. The operating surgeon decided whether facet fusion was needed in the patient or not. As a result, there could have been selection bias at play in determining the patients who underwent facet fusion. This study is primarily a radiographic evaluation of screw loosening at 1 center with 4 spine surgeons. Large, multicenter clinical studies with more types of fractures and surgeons are required to assess the generalizability of our findings. Our study did not correlate screw loosening with clinical outcomes. Further research is needed to correlate screw loosening with clinical outcomes. Additionally, our long-term follow-up rate was poor as is often the case in trauma population. Since we are a tertiary care center, patients are frequently transported to our hospital for definitive care from various locations. With multiple surgeons, there is no standardized follow up protocol for postoperative management of patients. Thus, loss of follow-up is expected, as asymptomatic patients do not usually seek further care. Finally, postoperative flexion and extension views or computed tomography scans were not obtained to evaluate for the presence of solid fusion in the groups that underwent percutaneous facet fusion.

Conclusions

In summary, we present a retrospective radiographic review of unstable thoracic and TL fractures that were treated by minimally invasive techniques using percutaneous pedicle screw fixation with or without facet fusion. Loss of correction of kyphosis angle was observed for both the fusion and nonfusion group in short- and long-term follow-up but this loss of correction was not significant. We were also able to demonstrate that radiographic screw loosening is a common finding that seems to occur more frequently in regions of greater spinal mobility. However, this does not necessarily correlate with focal kyphosis or loss of correction. More patients were noted to have radiographic evidence of instrumentation loosening at long-term follow-up, but the clinical significance of this radiographic finding has yet to be determined.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Dr Gelb is a board member and fellowship committee chair for AOSpine NA. He receives payment for lectures and for development of educational presentations from AOSpine NA. He receives royalties from DePuy Synthes Spine and Globus Medical. He has stock in the American Society for Investigative Pathology. Dr Koh receives payment for consultancy from Biomet. His institution receives RO1 grant money from the National Institutes of Health. Dr Ludwig is a board member for Globus Medical, the American Board of Orthopaedic Surgery, the American Orthopaedic Association, the Cervical Spine Research Society, and the Society for Minimally Invasive Spine Surgery. He is a paid consultant for DePuy Synthes, K2M, and Globus Medical. He receives payment for lectures and travel accommodations from DePuy Synthes and K2M. He receives payment for patents and royalties from DePuy Synthes and Globus Medical. He has stock in Innovative Surgical Designs and the American Society for Investigative Pathology. He receives research support from AO Spine North America Spine Fellowship support, Pacira Pharmaceutical, and AOA Omega Grant. He is a board member of Maryland Development Corporation. He receives royalties from Thieme, Quality Medical Publishers. He is on the governing board of *Journal of Spinal Disorders and Techniques*, *The Spine Journal*, and *Contemporary Spine Surgery*. The authors have no further potential conflicts of interest to disclose.

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