CLINICAL ARTICLE

Rate and Risk Factors of Superior Facet Joint Violation during Cortical Bone Trajectory Screw Placement: A Comparison of Robot-Assisted Approach with a Conventional Technique

Xiao-feng Le, MD†, Zhan Shi, MD†, Qi-long Wang, MD, Yun-feng Xu, MD, Jing-wei Zhao, MD, Wei Tian, MD, FRCSEd (Ortho)

Department of Spine Surgery, Beijing Jishuitan Hospital, Beijing, China

Objective: To compare the incidence and risk factors of superior facet joint violation (FJV) during cortical bone trajectory screw placement in robot-assisted approach versus conventional technique.

Methods: A retrospective study, including 69 patients having cortical bone trajectory (CBT) screw instrumentation for symptomatic degenerated diseases or trauma, was conducted between June 2015 to January 2019. All patients underwent CBT surgery performed by the same team of experienced surgeons. Patients were randomly divided into two groups: a conventional group (CG, 46 cases) and a robot group (RG, 23 cases). The surgical robotic system was used for screw instrumentation in the robot group and the traditional screw instrumentation with fluoroscopic guidance was used in the conventional group. Cortical screws followed a medio-to-lateral path in the transverse plane and a caudal-to-cephalad path in the sagittal plane. Preoperative and postoperative computed tomography (CT) scans were obtained to determine the degree and incidence of FJV. The violation status of facet joint was evaluated according to the modified classification: grade 0, no violation; grade 1, screw shaft, screw head or rod within 1 mm of or abutting the facet joint, but did not enter the articular facet joint; grade 2, screw shaft, screw head or rod clearly in the facet joint. The following factors that may contribute to the occurrence of FJV were analyzed: age, sex, body mass index (BMI), proximal fusion level, fusion length, the side of screw, preoperative vertebral slip, superior facet angle, and degenerative scoliosis. The chi-squared test and Student’s t-test were used for analysis of the variables for significance ($P < 0.05$).

Results: FJV occurred in 41.3% of patients in CG and 17.3% of patients in RG. A chi-squared analysis revealed a significantly lower rate of FJV for RG compared with CG ($P = 0.04$). In the CG, 17 of the 109 cephalad screws were grade 1 (15.6%), and five were grade 2 (4.6%). In the RG, three of the 46 cephalad screws were grade 1 (6.5%), and three were grade 2 (6.5%). There was a statistically significant difference in the incidence of FJV between the left and right screw with fluoroscopy-assisted CBT screw instrumentation ($P < 0.05$). A significant correlation between scoliosis with the FJV was found in CG ($P < 0.05$) and in RG ($P < 0.05$). With regard to superior facet angle, a measurement $≥45°$ was a significant risk factor of FJV in CG ($P < 0.05$) and in RG ($P < 0.05$).

Conclusions: A robot-assisted approach could reduce the incidence of FJV compared with the conventional approach in CBT technique.

Key words: Cortical bone trajectory; Facet joint violation; Risk factors; Fluoroscopy; Robot

Address for correspondence Wei Tian, MD, FRCSEd (Ortho), Department of Spine Surgery, Beijing Jishuitan Hospital, No. 31, Xinjiekou East St, Xicheng District, Beijing, China 100035 Tel: 0086-018910723876; Email: tianwei2019@yeah.net
†Xiao-feng Le and Zhan Shi contributed equally to this study.

Disclosure: There are no relevant financial activities outside the submitted work for this study. The manuscript submitted does not contain information about medical device(s)/drug(s). No relevant financial activities outside the submitted work.

Received 5 August 2019; accepted 19 November 2019

Orthopaedic Surgery 2020:12:133–140 · Doi: 10.1111/os.12598

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.
**Introduction**

Cortical bone trajectory (CBT) screw placement has emerged as a novel technique of instrumentation with superior mechanical properties. First reported by Santoni et al., CBT screw follows a medial-to-lateral path in the transverse plane and a caudal-to-cephalad path in the sagittal plane. This approach increases the screw purchase by maximizing thread contact with dense cortical bone. CBT technique is also considered to be more minimally invasive compared with traditional pedicle screw (PS) placement, as wide muscle dissections are avoided in the medial approach. Some cadaver studies have shown CBT screw fixation is superior to traditional pedicle screw fixation in posterior lumbar fusion surgery. Furthermore, some clinical studies investigated that CBT was superior to PS with a significantly lower postoperative Oswestry Disability Index (ODI) and higher Japan Orthopaedic Association (JOA) recovery rate. Therefore, CBT technique is expected to update traditional lumbar fixation strategies.

Superior facet joint violation (FJV) is a common complication during lumbar screw placement, which was defined as a screw within 1 mm of the facet joint. Facet joints are situated on the dorsolateral aspect of the spine between the adjacent vertebrae, playing a critical role in balancing the lumbar spine unit by sharing load in compression and extension, thereby protecting the disk from anterior shear forces and excessive rotational strain. Injury of facet joint is associated with the alternation in spine stability and load-bearing ability, ultimately leading to the adjacent segment disease. Levin et al. have demonstrated that FJV was independently associated with a higher reoperation rate and diminished improvement in quality of life. Another two studies showed that FJV resulted in higher back pain scores qualified via VAS and ODI. Therefore, a concern in these cases is the development of adjacent-segment FJV. Several studies have reported the incidence and risk factors of FJV during pedicle screw placement. In open surgery, the radiographic rate of FJV was reported to occur in 8.6% to 100% of patients and in 4.3% to 100% of screws. In minimally invasive surgery, the reported rates of FJV varied from 6.3% to 76% in patients and 2.8% to 62% in screws. The wide variation is explained by the variability in surgical techniques. Moreover, conditions such as patient characteristics (age, sex, Body Mass Index [BMI]), proximal fusion level, fusion length, the side of screw, vertebral slip, superior facet angle, and degenerative scoliosis) may also be risk factors.

With the development of minimally invasive approaches, minimally invasive surgery has been widely adopted due to its advantages in less intraoperative blood loss, fast recovery, and shorter hospitalization. However, with percutaneous techniques, anatomical landmarks are not directly visualized, several recent studies raised the concern that these techniques may have a higher incidence of violation of the superior cephalad unfused facet joint. Thus, a variety of robots have been introduced for use in spinal procedures, attracting more and more attention. However, there have been conflicting results regarding the safety and accuracy of robot-assisted fixation. The TiRobot orthopaedic robot (TINA Medical Technologies Co., Ltd., Fenton, Missouri, USA) provides a new technology for the precise screw placement in minimally invasive percutaneous surgery. Intraoperative 3D imaging may allow improved accuracy in cortical screw placement. The emergence of this technology may simplify the surgeon’s selection of the screw entry point and trajectory, and thus open the route to image-guided minimally invasive therapy with decreased rates of the violation of the superior cephalad unfused facet joint. Theoretically, the rate of FJV could be reduced with robot-assisted approach when the entry point is selected farther away from the facet joint.

A thorough review of the literature revealed only one study that investigated the incidence of risk factors of FJV secondary to CBT screw instrumentation. Due to the CBT entry point being near the pars articularis, which is far from the superior facet joint, Matsukawa et al. showed that lumbar pedicle screw placement via CBT would reduce damage to the adjacent cranial facet joint, and special care should be taken in patients aged >70 years, with vertebral slip >10%, and facet degeneration. However, they only investigated patients with fluoroscopy-assisted instrumentation in open surgery. Furthermore, no previous study has defined strict grade criteria of FJV with CBT technique. Therefore, we know little about the incidence of facet violation with robot-assisted CBT screw instrumentation.

In this study, we focused on three major points: (i) comparison of the rates of FJV during CBT screw placement with robot-assisted approach versus conventional technique; (ii) risk factors including the patient characteristics and anatomical factors of superior FJV with robot-assisted approach and conventional technique; and (iii) comparison of the performance between robot-assisted approach and conventional technique.

**Patients and Methods**

**Participant Demographics**

All participants provided their informed consent for this study. The study was conducted in Beijing Jishuitan Hospital and was approved by the Ethics Committee of Beijing Jishuitan Hospital.

From June 2015 to January 2019, the inclusion criteria for open surgery with CBT screw instrumentation were the following: (i) patients presented with recurrent low back pain or lower limb symptoms due to symptomatic degenerated disks, spinal stenosis, spondylolisthesis (grade I/II) or trauma; (ii) patients previously underwent posterior lumbar interbody fusion (PLIF) or transformaminal lumbar interbody fusion (TLIF) using CBT technique; (iii) placement using fluoroscopy-assisted technique or robot-assisted technique; (iv) conservative treatment failed to relieve the recurrent pain; and (v) received open surgery. Exclusion criteria were
as following: (i) spinal infections or tumors; (ii) requiring revision procedures; (iii) age < 18 years; and (iv) congenitally small pedicles or congenital pars defects. All patients underwent surgery performed by the same team of experienced surgeons.

Patients were randomly divided into two groups: a conventional group (CG, 46 cases) and robot group (RG, 23 cases). Forty six patients underwent CBT screw instrumentation using fluoroscopic guidance and 23 patients underwent CBT screw instrumentation using robotic guidance. The decision to operate using robotic assistance or conventional technique was based on the surgeon’s discretion and logical reasons. The demographic and clinical data for both groups included age, sex, BMI, spine surgery level, and diagnosis.

Surgical Procedures
After the induction of general anesthesia, patients were placed in the prone position. An incision was made through a posterior median approach and the soft tissue were dissected until the cortical screw entry points were exposed. Cortical screws (CD Horizon Solera Spinal System 4.75, Medtronic, Memphis TN, USA) were inserted according to the original method1. In the conventional group (CG), by identification of anatomical landmarks with fluoroscopy guidance, the cortical screw entry point was supposed to be the junction located at the center of the superior articular process and 1 mm inferior to the inferior border of the transverse process16. The cortical trajectory was confirmed by a ball-tip pedicle probe and then the appropriately chosen screws were inserted and secured with rods.

In the robot group (RG), the robot workstation was connected to the data line of the C-arm scanner (Siemens Medical Solutions, Erlangen, Germany). The cortical screw trajectories and screw length and diameter were adjusted appropriately on the robot computer. K wires were inserted using the robotic system and the surgeon determined whether the position of the wires should be adjusted or not according to experience after the AP and lateral images from the C-arm were performed17. The cortical screws were placed after the safety of the trajectory was confirmed.

Fluoroscopy was used to confirm the position of the K-wire and/or screws. In both groups, subsequent decompression or arthrodesis were performed where necessary.

Clinical Assessment
Each participant was asked to complete preoperative and postoperative computed tomography (CT) scans with a 1-mm thickness slice, including coronal and sagittal reconstructions.

Screw Violation Grade
The screw violation grade of the FJV at the proximal adjacent segment was evaluated according to the modified classification described by Yson et al.18 and Moshirfar et al.19: grade 0, no violation (Fig. 1); grade 1, screw shaft, screw head or rod within 1 mm of or abutting the facet joint, but did not enter the articular facet joint (Fig. 2); and grade 2, screw shaft, screw head or rod clearly in the facet joint (Fig. 3). The slice with the largest violation was chosen for grading. The assessment of FJV included the adjacent cranial segments of patients with degenerative disease and all fixation segments of patients who had experienced trauma. Because decompression in patients with degenerative disease destroys the facet joints, fracture patients did not require decompression. The violation status of facet joint was determined by three independent spine surgeons, who were blinded to surgical approaches. When two or more observers agreed on the violation status, it was considered the consensus grade.

Vertebral Slip
The vertebral slip grade represents the displacement of one vertebral body over the inferior one on plain lateral lumbar radiograph, which was classified in five subtypes by Meyerding20: grade I, less than 25% of displacement; grade II, between 25% and 50%; grade III, between 50% and 75%; grade IV, between 75% and 100%; and grade V, representing more than a 100% slip or spondyloptosis.

Superior Facet Angle
Superior facet angle was used to calculate the facet joint orientation using the method described by Noren et al.21 The first line was drawn passing through the center of the disk and the center of spinous process, and the second line was

Fig. 1 Grade 0 violation: no facet joint violation is evident in the axial, sagittal, or coronal computed tomography scans.
formed by connecting the two end points of each facet. The facet joint angle is defined as the angle between the two lines (Fig. 4). In addition, proximal fusion level, fusion length, degenerative scoliosis, and the side of screw were documented.

**Statistical Analysis**

Statistical analyses were performed with SPSS, version 20.0 software (IBM Corp., Armonk, New York, USA). All variables were described by their absolute (no.) and relative (%) frequencies and continuous variables as the mean and standard deviation. The chi-squared test was used for analysis of within-group variables and the Student's *t*-test for independent samples was carried out to compare the two sets of data when a Gaussian distribution was expected. The Wilcoxon test was used for samples that were not normally distributed. Statistical significance was set at *P* < 0.05.

**Results**

**Demographic Data**

In total, 69 patients were studied, 46 in the CG and 23 in the RG. The mean BMI was significantly higher in RG than CG (28.5 ± 3.6 vs. 25.3 ± 3.4, *P* < 0.01). In terms of the other parameters, including age, sex, or preoperative diagnosis, no significant difference between the two groups was found (Table 1).

**Clinical Outcomes**

There was a statistically significant difference in the incidence of FJV between the left and right screw with fluoroscopy-assisted CBT screw instrumentation (*P* < 0.05). Moreover, a significant correlation between scoliosis with the FJV was found in CG (*P* < 0.05) (Table 2). Similarly, a significant correlation between scoliosis with the FJV was found in RG (*P* < 0.05) (Table 3). However, no significant differences in the incidence of FJV were found in the two groups in terms of proximal fusion level and fusion length.

**Screw Violation Grade**

FJV occurred in 41.3% of patients (19 of 46) for CG and 17.3% of patients (four of 23) for RG. A chi-squared analysis revealed a significantly lower rate of FJV for RG compared with CG (*P* = 0.04) (Table 4). CBT screw violation grades were detailed in Table 5. In the CG, 17 of the 109 cephalad screws were grade 1 (15.6%), and five were grade 2 (4.6%).
In the RG, three of the 46 cephalad screws were grade 1 (6.5%), and three were grade 2 (6.5%). Although the FJV rate of screw in RG tended to decrease compared with CG, there was no statistical difference. However, when we only compared the FJV rate of screw shaft between the two groups, the rate in RG was significantly lower than that in CG ($P = 0.021$).

| TABLE 1 Baseline characteristics |
|----------------------------------|
| Variables                        | CG (109 screws) | RG (46 screws) | $P$ value |
| Patients (cases)                 | 46              | 23             | -         |
| Age (years, mean±SD)             | 58.9±13.0       | 65.1±8.0       | 0.052     |
| Sex (female/male)                | 31/15           | 17/6           | 0.587     |
| BMI (kg/m², mean±SD)             | 25.3±3.4        | 28.5±3.6       | 0.001     |
| Pathologic entity (cases)        |                 |                |           |
| Degeneration                     | 42              | 23             | 0.29      |
| Trauma                           | 4               | 0              |           |

BMI, Body Mass Index; CG, conventional group; RG, robot group.
Vertebral Slip
There was no significant correlation between vertebral slip and FJV in CG (P = 0.147). Vertebral slip is not a significant risk factor of FJV with CBT technique in RG (P = 0.658).

Superior Facet Angle
With regard to superior facet angle, a measurement ≥45° was a significant risk factor of FJV in CG (P < 0.05). Similarly, superior facet angle ≥45° was a risk factor of FJV in RG (P < 0.05).

Discussion
CBT is a novel technique for lumbar fusion, and FJV is one of the most common complications, which have attracted more and more attention in recent years. Although several studies have reported the incidence and risk factors of FJV for PS, only one study of FJV for CBT screw with fluoroscopic assistance in open surgery has been reported so far. Recently, a variety of robots have been introduced for use in spinal procedures. However, there have been conflicting results regarding the safety and accuracy of robot-assisted instrumentation. Therefore, in this study, we compared the incidence and risk factors of superior FJV with robot-assisted insertions versus fluoroscopy-assisted insertions in open surgery for CBT technique.

Rate of Facet Joint Violation
The current study demonstrated that the FJV rate of patients was lower for the robot-assisted approach (17.3%) than the conventional approach (41.3%). Although there was no difference in the total incidence of FJV for the screw between the two groups, the FJV rate of screw shaft in the RG (0%) was significantly lower than that in the CG (11.0%). This difference can be explained by the mechanism of guidance. In the CG, relying on the two-dimensional intra-operative radiographic images, it was difficult to choose the perfect trajectory. However, in the RG, by selecting the ideal screw trajectory in three planes on the blueprint preoperatively, it was significantly easier to avoid the facet joints.

| Variable                      | Cephalad facet joint | Cephalad facet joint | n  | χ²  | P value |
|-------------------------------|----------------------|----------------------|----|-----|---------|
| Age (years)                   |                      |                      |    |     |         |
| <70                           | 21                   | 14                   | 46 | 0.102 | 0.508   |
| ≥70                           | 6                    | 5                    |    |      |         |
| Sex                           |                      |                      |    |     |         |
| Female                        | 16                   | 15                   | 46 | 1.967 | 0.139   |
| Male                          | 11                   | 4                    |    |      |         |
| BMI (kg/m²)                   |                      |                      |    |     |         |
| <30                           | 24                   | 17                   | 46 | <0.001 | 0.667   |
| ≥30                           | 3                    | 2                    |    |      |         |
| Proximal fusion level         |                      |                      |    |     |         |
| Upper lumber (L₂-L₃)          | 5                    | 2                    | 46 | 0.106 | 0.38    |
| Lower lumber (L₄-L₅)          | 22                   | 17                   |    |      |         |
| Fusion length                 |                      |                      |    |     |         |
| 1 or 2 segments               | 13                   | 11                   | 46 | 0.124 | 0.363   |
| 3 segments or more            | 14                   | 8                    |    |      |         |
| The side of screw             |                      |                      |    |     |         |
| Right                         | 49                   | 5                    | 109| 7.928 | 0.004   |
| Left                          | 38                   | 17                   |    |      |         |
| Vertebral slip grade          |                      |                      |    |     |         |
| 0                             | 22                   | 13                   | 46 | 3.584 | 0.147   |
| I                             | 4                    | 6                    |    |      |         |
| II                            | 1                    | 0                    |    |      |         |
| III                           | 0                    | 0                    |    |      |         |
| IV                            | 0                    | 0                    |    |      |         |
| Facet angle                   |                      |                      |    |     |         |
| <45°                          | 71                   | 10                   | 109| 12.024| 0.001   |
| ≥45°                          | 16                   | 12                   |    |      |         |
| Scoliosis                     |                      |                      |    |     |         |
| Yes                           | 2                    | 6                    | 46 | 3.009 | 0.042   |
| No                            | 25                   | 13                   |    |      |         |

| Variable                      | Cephalad facet joint | Cephalad facet joint | n  | χ²  | P value |
|-------------------------------|----------------------|----------------------|----|-----|---------|
| Age (years)                   |                      |                      |    |     |         |
| <70                           | 16                   | 2                    | 23 | 0.707 | 0.194   |
| ≥70                           | 3                    | 2                    |    |      |         |
| Sex                           |                      |                      |    |     |         |
| Female                        | 15                   | 2                    | 23 | 0.327 | 0.27    |
| Male                          | 4                    | 2                    |    |      |         |
| BMI (kg/m²)                   |                      |                      |    |     |         |
| <30                           | 13                   | 2                    | 23 | 0.016 | 0.435   |
| ≥30                           | 6                    | 2                    |    |      |         |
| Proximal fusion level         |                      |                      |    |     |         |
| Upper lumber (L₂-L₃)          | 4                    | 0                    | 23 | 0.06  | 0.456   |
| Lower lumber (L₄-L₅)          | 16                   | 4                    |    |      |         |
| Fusion length                 |                      |                      |    |     |         |
| 1 or 2 segments               | 17                   | 3                    | 23 | <0.001 | 0.453   |
| 3 segments or more            | 2                    | 1                    |    |      |         |
| The side of screw             |                      |                      |    |     |         |
| Right                         | 20                   | 3                    | 46 | <0.001 | 0.667   |
| Left                          | 20                   | 3                    |    |      |         |
| Vertebral slip grade          |                      |                      |    |     |         |
| 0                             | 8                    | 3                    | 23 | 1.714 | 0.658   |
| I                             | 10                   | 1                    |    |      |         |
| II                            | 1                    | 0                    |    |      |         |
| III                           | 0                    | 0                    |    |      |         |
| IV                            | 0                    | 0                    |    |      |         |
| Facet angle                   |                      |                      |    |     |         |
| <45°                          | 37                   | 2                    | 46 | 8.311 | 0.005   |
| ≥45°                          | 4                    | 4                    |    |      |         |
| Scoliosis                     |                      |                      |    |     |         |
| Yes                           | 1                    | 3                    | 23 | 6.858 | 0.009   |
| No                            | 18                   | 1                    |    |      |         |

BMI, body mass index; FJV, facet joint violation.
possible to avoid the facets without compromising on screw purchase within the pedicle. Nevertheless, there is a problem that has rarely been noticed before. The robotic guidance only can help us to choose the perfect trajectory of screw shaft on the workstation, but this often leads the surgeon to ignore the FJV of the screw head and the rod. The latter usually depends on the screw type and the operation of the surgeon, which can’t be solved by the robot. Therefore, our results showed that although the robot reduced the rate of FJV by the screw shaft, the FJV by the screw head and the rod did not change significantly. This factor should be taken into account in future robot improvements or operations of surgeons.

A report from Matsukawa et al.\textsuperscript{15} showed that the FJV rate by CBT screws with the conventional approach was 11.8\%, which was lower than our results of the CG. The difference may result from the evaluation methods. In most studies\textsuperscript{19,22–24}, FJV was defined as a screw within 1 mm of the facet joint. However, in their study, FJV occurred when the screw was in contact with the facet joint, which was more rigorous than ours. Overall, our study proved the advantages of robot-assisted placement over traditional placement in CBT technique for FJV.

Table 4 Comparison of two groups regarding different FJV grades of patients (cases [%])

| FJV       | CG (46 cases) | RG (23 cases) | P value |
|-----------|---------------|---------------|---------|
| Intact    | 27 (58.7)     | 19 (82.6)     | 0.04    |
| Violated  | 19 (41.3)     | 4 (17.3)      |         |

CG, conventional group; FJV, facet joint violation; RG, robot group.

Risk Factors of FJV

We also explored different factors that may contribute to FJV in CBT technique. Our results demonstrated that left-side CBT screw, facet angle $\geq 45^\circ$, and scoliosis were risk factors for FJV of CBT with fluoroscopy-assisted instrumentation. Meanwhile, the risk factors affecting FJV for robot-assisted instrumentation included: facet angle $\geq 45^\circ$ and scoliosis. Our study indicated that age, sex, BMI, proximal fusion level, fusion length, and slippage grade had no correlation with the incidence of FJV.

Table 5 Comparison of two groups regarding different FJV grades of screws (cases [%])

| FJV       | CG (109 cases) | RG (46 cases) | P value |
|-----------|---------------|---------------|---------|
| Grade 0   | 87 (79.8)     | 40 (87.0)     |         |
| Grade 1   | 17 (15.6)     | 3 (6.5)       |         |
| Screw shaft| 9            | 0             |         |
| Screw head| 5            | 1             |         |
| Rod       | 3            | 2             |         |
| Grade 2   | 5 (4.6)       | 3 (6.5)       |         |
| Screw shaft| 3            | 0             |         |
| Screw head| 1            | 2             |         |
| Rod       | 1            | 1             | $P = 0.206$|

CG, conventional group; FJV, facet joint violation; RG, robot group.

The Side of Screw

One possible explanation for the lower FJV rate of right-side CBT screw in the CG is the difference between right-hand and left-hand. It may be because the insertion of CBT screws, particularly at L and S (due to their caudal and medial trajectory), are easier for a right-handed surgeon from the patient’s right side rather than the left. Moreover, all the surgeons are right-handed in our department. Therefore, this study showed that the right screw had a lower rate of FJV. Interestingly, the application of the robot seems to weaken the effect of the side. Nevertheless, it is not a formal study, because we have no routine record on the position of the attending surgeon and assisting surgeon (i.e., right or left side of the patient). In future studies, assessing this variable to see if there is a statistically significant learning curve would be interesting.

Superior Facet Angle

Our study showed that the facet angle was a risk factor for FJV in CBT technique, both in the CG and in the RG. When the facet angle is greater than 45\$, the risk of FJV increases. One possible explanation for this is the trajectory of CBT screw. The orientation of the facet joint gradually changes to the coronal direction when the facet angle increases, which blocks the pathway of the CBT screw. This is determined by the screw trajectory, regardless of the type of screw placement assisted by the technique. Thus, the screw is more likely to violate the facet joints, leading to a higher FJV. Another possible explanation for this might be the projection of facet joint. In the intraoperative C-arm fluoroscopy, there is overlap between the oval-shaped pedicle ring and projection of the facet joint. Moreover, the overlap is more significant when the facet angle is larger. When the facet joint projection covers most of the oval-shaped pedicle ring, even covering the lateral edges of the pedicle rings, the incidence of FJV is bound to increase\textsuperscript{25}.

Degenerative Scoliosis

Scoliosis is another risk factor for FJV. There are two possible explanations. First, the instrumentation of most scoliosis patients involves L\textsubscript{1} to L\textsubscript{2} levels, where the pedicles are smaller and the facet-screw distance is shorter than other levels\textsuperscript{15,26}. This will increase the difficulty of choosing the perfect trajectory. Second, osteoporosis often occurs in patients with spinal deformities, which increases the difficulty of identifying bone markers for
surgeons. This may lead to an increase in the difficulty of operation.

Limitations

There were limitations in this study. First, considering the small sample size, additional studies involving more participants are needed. Second, we did not investigate the relationship between different grade FJV and clinical outcomes, which may be an interesting topic for future research.

References

1. Santoni BG, Hynes RA, McGilveray KC, et al. Cortical bone trajectory for lumbar pedicle screws. Spine J, 2009, 9: 366–373.
2. Delgado-Fernandez J, Garcia-Paliero MA, Blasco G, Pulido-Rivas P, Sola RG. Review of cortical bone trajectory: evidence of a new technique. Asian Spine J, 2017, 11: 817–831.
3. Baluch DA, Patel AA, Lullo B, et al. Effect of physiological loads on cortical and traditional pedicle screw fixation. Spine (Phila Pa 1976), 2014, 39: E1297–E1302.
4. Sansur CA, Carfes NM, Ibrahim DM, et al. Biomechanical fixation properties of cortical versus transpedicular screws in the osteoporotic lumbar spine: an in vitro human cadaveric model. J Neurosurg Spine, 2016, 25: 467–476.
5. Perez-Ontbo L, Kaba S, Reyes PM, Chang SW, Crawford NR. Biomechanics of lumbar cortical screwrod fixation versus pedicle screw-rod fixation with and without interbody support. Spine (Phila Pa 1976), 2013, 38: 635–641.
6. Matsukawa K, Yato Y, Kato T, Imabayashi H, Asazuma T, Nemoto K. In vivo analysis of insertional torque during pedicle screwing using cortical bone trajectory technique. Spine (Phila Pa 1976), 2014, 39: E240–E245.
7. Levin JM, Alentado VJ, Healy AT, Steinmetz MP, Benzel EC, Morz TE. Superior segment facet joint violation during instrumented lumbar fusion is associated with higher reoperation rates and diminished improvement in quality of life. Clin Spine Surg, 2018, 31: E36–E41.
8. Jia L, Yu Y, Khan K, et al. Superior facet joint violations during single level minimally invasive transforminal lumbar interbody fusion: a preliminary retrospective clinical study. Biomed Res Int, 2018, 2018: 6152769.
9. Wang H, Ma L, Yang D, et al. Incidence and risk factors of adjacent segment disease following posterior decompression and instrumented fusion for degenerative lumbar disorders, Medicine, 2017, 96: e6032.
10. Wang L, Wang Y, Yu B, Li Z, Li Y. Comparison of cranial facet joint violation rate between percutaneous and open pedicle screw placement: a systematic review and meta-analysis. Medicine, 2015, 94: e504.
11. Teles AR, Paci M, Gutman G, et al. Anatomical and technical factors associated with superior facet joint violation in lumbar fusion. J Neurosurg Spine, 2018, 28: 173–180.
12. Archavis E, Amr N, Kantelhardt SR, Giese A. Rates of upper facet joint violation in minimally invasive percutaneous and open instrumentation: a comparative study of different insertion techniques. J Neurol Surg A Cent Eur Neurosurg, 2018, 79: 1–6.
13. Ringel F, Stuer C, Reinke A, et al. Accuracy of robot-assisted placement of lumbar and sacral pedicle screws: a prospective comparison to conventional freehand screw implantation. Spine (Phila Pa 1976), 2012, 37: E496–E501.
14. Kim HJ, Jung WJ, Chang BS, Lee OK, Kang KT, Yeon JS. A prospective, randomized, controlled trial of robot-assisted vs freehand pedicle screw fixation in spine surgery. Int J Med Robot, 2017, 13: e1779.
15. Matsukawa K, Kato T, Yato Y, et al. Incidence and risk factors of adjacent cranial facet joint violation following pedicle screw insertion using cortical bone trajectory technique. Spine (Phila Pa 1976), 2016, 41: E851–E856.
16. Matsukawa K, Yato Y, Nemoto O, Imabayashi H, Asazuma T, Nemoto K. Morphometric measurement of cortical bone trajectory for lumbar pedicle screw insertion using computed tomography. J Spinal Disord Tech, 2013, 26: E248–E253.
17. Le X, Tian W, Shi Z, et al. Robot-assisted versus fluoroscopy-assisted cortical bone trajectory screw instrumentation in lumbar spinal surgery: a matched-cohort comparison. World Neurosurg, 2018, 120: e745–e751.
18. Yson SC, Sembriano JN, Sanders PC, Santos ER, Ledenio CG, Polly DW Jr. Comparison of cranial facet joint violation rates between open and percutaneous pedicle screw placement using intraoperative 3-D CT (O-arm) computer navigation. Spine (Phila Pa 1976), 2013, 38: E251–E258.
19. Mohshifar A, Jenis LG, Spector LR, et al. Computed tomography evaluation of superior-segment facet joint violation after pedicle instrumentation of the lumbar spine with a midline surgical approach. Spine (Phila Pa 1976), 2006, 31: 2624–2629.
20. Meyerding HW. Spondylothesis. Surg Gynecol Obstet, 1932, 54: 39–48.
21. Noren R, Trafimow J, Andersson GBJ, Huckman MS. The Role of Facet Joint Tropism and Facet Angle in Disc Degeneration. Spine (Phila Pa 1976), 1991, 16: 530–532.
22. Park Y, Ha JW, Lee YT, Sung NY. Cranial facet joint violations by percutaneously placed pedicle screws adjacent to a minimally invasive lumbar spinal fusion. Spine J, 2011, 11: 295–302.
23. Tian W, Xu Y, Liu B, et al. Lumbar spine superior-level facet joint violations: percutaneous versus open pedicle screw insertion using intraoperative 3-dimensional computer-assisted navigation. Chin Med J (Engl), 2014, 127: 3852–3856.
24. Shah RR, Mohammed S, Safuddin A, Taylor BA. Radiologic evaluation of adjacent superior segment facet joint violation following transpedicular instrumentation of the lumbar spine. Spine (Phila Pa 1976), 2003, 28: 272–275.
25. Xu Z, Tao Y, Li H, Chen G, Li F, Chen Q. Facet angle and its importance on joint violation in percutaneous pedicle screw fixation in lumbar vertebrae: a retrospective study. Medicine, 2018, 97: e10943.
26. Ahmad FU, Wang MY. Use of anteroposterior view fluoroscopy for targeting percutaneous pedicle screws in cases of spinal deformity with axial rotation. J Neurosurg Spine, 2014, 21: 826–832.