

# Three-dimensional Fluoroscopy-based Navigation for the Pedicle Screw Placement in Patients with Primary Invasive Spinal Tumors

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## Abstract

**Background:** Although pedicle screw placement (PSP) is a well-established technique for spine surgery, the treatment of patients with primary invasive spinal tumor (PIST) has high surgical risks secondary to destroyed pedicles. Intraoperative three-dimensional fluoroscopy-based navigation (ITFN) system permits safe and accurate instrumentation of the spine with the advantage of obtaining intraoperative real-time three-dimensional images and automatic registration. The aim of this study is to evaluate the feasibility and accuracy of PSP using ITFN system for patients afflicted with PIST in the thoracic spine.

**Methods:** Fifty-one patients diagnosed with PISTs were retrospectively analyzed, and 157 pedicles screws were implanted in 23 patients using the free-hand technique (free-hand group) and 197 pedicle screws were implanted in 28 patients using the ITFN system (ITFN group). Modified classification of Gertzbein and Robbins was used to evaluate the accuracy of PSP, and McCormick classification was applied for assessment of neurological function. Demographic data and factors affecting accuracy of screw insertion were compared using independent *t*-test while comparison of accuracy of screw insertion between the two groups was analyzed with Chi-square test.

**Results:** Of 51 patients, 39 demonstrated improved neurological status and the other 12 patients reported that symptoms remained the same. In the free-hand group, 145 screws (92.4%) were Grade I, 9 screws (5.7%) were Grade II, and 3 screws (1.9%) were Grade III. In the ITFN group, 192 screws (97.4%) were Grade I, 5 screws (2.6%) were Grade II, and no Grade III screw was detected. Statistical analysis showed that the accuracies of pedicle screws in the two groups are significantly different ( $\chi^2 = 4.981$ ,  $P = 0.026$ ).

**Conclusions:** The treatments of PISTs include total tumor resection and reconstruction of spine stability. The ITFN system provides a high accuracy of pedicle screw placement.

**Key words:** Navigation; Pedicle Screw Placement; Spinal Cord Tumor; Three-dimensional Fluoroscopy

## INTRODUCTION

Primary neoplasms of the spinal cord develop in the spinal canal and can cause spinal cord compression.<sup>[1]</sup> The incidence of primary spinal tumors has been estimated at 2.5–8.5 per 100,000 people yearly.<sup>[2,30]</sup> Some primary spinal tumors may not only cause a compressive effect to the cord, but also can destroy the adjacent bony structures due to its invading nature.<sup>[11,12,16]</sup> The author named this category of tumors as primary invasive spinal tumors (PISTs).

Patients diagnosed with PISTs need to undergo tumor resection via laminectomy.<sup>[3,11,16]</sup> Both tumor invasion and surgical intervention may cause a disruption in the balance of the spine's three-column, predisposing it to

disequilibrium and instability.<sup>[4,11]</sup> Therefore, pedicle screw placement (PSP) is necessary for these patients to maintain spinal stability.<sup>[5,11]</sup> However, there are some difficulties in pedicle screw insertion. (1) PSP in thoracic spine is full of

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risks because of the smaller pedicle size and more complex three-dimensional (3D) anatomy.<sup>[7]</sup> According to previous literature, thoracic screws perforate the cortical margins of the pedicle at a rate ranging from 16% to 54%.<sup>[13,20]</sup> Incorrect placement may cause neurovascular injury.<sup>[7,13]</sup> (2) Tumor may invasively extend into the intervertebral foramen and destroy laminae and pedicles, which causes absence of normal anatomical landmarks for guiding surgeons to insert pedicle screws. (3) The spinal cord can be compressed to one side in spinal canal with tumor growth, which leads to the reduction of a safe zone between the cord and pedicles and increases the risks of neurovascular injury.

Surgical navigation system is a promising technique that addresses many of these concerns. The advent of the intraoperative 3D fluoroscopy-based navigation (ITFN) system permits safe and accurate instrumentation of the spine with the advantage of obtaining intraoperative real-time 3D images and automatic registration. The aim of this study was to evaluate the feasibility and accuracy of PSP using ITFN system for the patients of PIST.

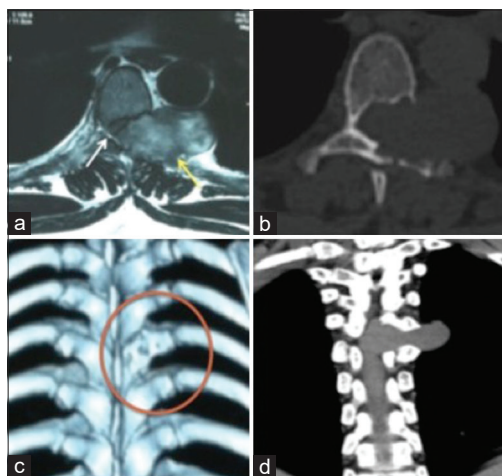
## METHODS

From January 2002 to June 2016, 78 consecutive patients diagnosed with PIST underwent surgery in our center, 51 of these patients were retrospectively analyzed. A number of 157 pedicle screws were implanted in 23 patients (8 females and 15 males) using the free-hand technique (free-hand group) and 197 pedicle screws were implanted in 28 patients (11 females and 17 males) using the ITFN system (ITFN group). Pre- and post-operative magnetic resonance imaging (MRI), computed tomography (CT) scan, and X-rays were performed in all cases. Representative preoperative MRI and CT images are shown in Figure 1. Written informed

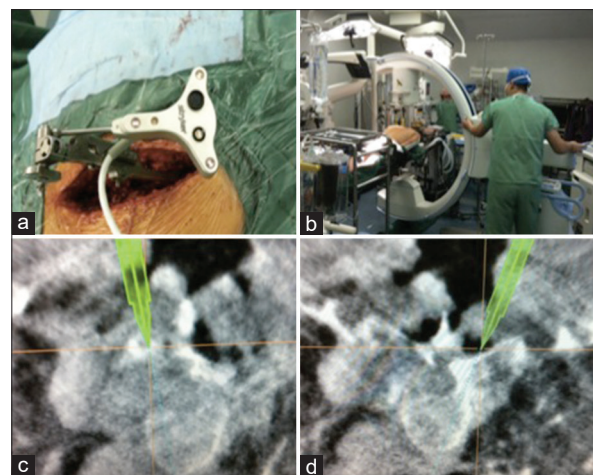
consents following doctor-patient discussion were obtained from all participants, and all procedures were approved by the Medical Ethics Committee of Beijing Tiantan Hospital. The inclusion criteria for the study were cases of primary spinal tumors located in the thoracic segments. The bony structures on the side of the tumor were completely or partially destroyed due to the tumor invasion. Patients with spinal traumatic history and/or spinal surgical history were excluded from this study.

In the free-hand group, the patient was positioned prone on a Jackson table under general anesthesia. The screws were implanted according to the technique of Roy-Camille.<sup>[31]</sup> After identifying the entry points on bony surface, a drill canal was opened on each pedicle by the awl. After tapping and screw application, the position of screws was assessed by C-arm. When the position of one or more of the screws was not optimal, the screw will be revised and the new position will be checked again by the C-arm. All the patients were subjected to postoperative CT scan to evaluate the position of the screws.

In the ITFN group, after the patient had been positioned and anesthetized, a tracker was attached to the appropriate lamina. The motorized C-arm (Arcadis Orbic 3D; Siemens, Medical Solutions, Erlangen, Germany) moved continuously around 190° to acquire the 3D images and transferred them to the navigation workstation where automatic registration was achieved [Figure 2]. The image data were transferred to the image-processing software on the computer to reconstruct a 3D bone structure model of the involved spinal segments. Furthermore, the procedure of selecting reference points on the dorsal bony surface at the posterior element was repeated for every motion segment. Finally, the motorized C-arm moved around again to acquire the 3D images of the operating field to verify the accuracy of screw placement [Figure 3]. Tumor resection was performed after the PSP was accomplished.



**Figure 1:** Preoperative MRI and CT images of a patient who diagnosed with giant invasive spinal schwannoma on T4–T5. (a) Axial thoracic T1-weighted image showing a giant invasive spinal schwannoma with spinal cord compression extended to the left extraforaminal region. White arrow indicates the spinal cord, yellow arrow indicates the tumor mass. (b) The axial thoracic CT showing a destroyed pedicle and bony structures due to tumor erosion. (c) 3D thoracic CT image showing destroyed lamina at T4 level. (d) Coronal thoracic CT image. MRI: Magnetic resonance imaging; CT: Computed tomography; 3D: Three-dimensional.



**Figure 2:** Intraoperative images of a patient who diagnosed with giant invasive spinal schwannoma on T4–T5. (a) A tracker was located on lamina. (b) The motorized C-arm moved around to acquire the 3D images from the operating field. (c and d) The trajectories for pedicle screw insertion into T4 vertebrae determined by intraoperative 3D fluoroscopy-based navigation. 3D: Three-dimensional.

Postoperative CT scan was performed in all patients to evaluate the position and accuracy of screws according to the modified classification of Gertzbein and Robbins, which was examined independently by a surgeon and radiologist.<sup>[6,8,9]</sup> In this classification, there are three main categories for screw misplacement: Grade I (completely within the pedicles); Grade II (<2 mm of the pedicle perforation); and Grade III (>2 mm of the pedicle perforation) [Figure 4]. It is worthy to mention that the ideal position of the screw is achieved when the screw lies in the middle of the pedicle in both axial and sagittal reconstruction on CT scans.

All patients were followed up for at least 3 months with assessment of symptoms, spine stability, and tumor recurrence. We applied a McCormick classification for the assessment of neurological function in our patients.<sup>[10]</sup> This assessment was performed before surgery, 3 months after surgery, and annually thereafter.

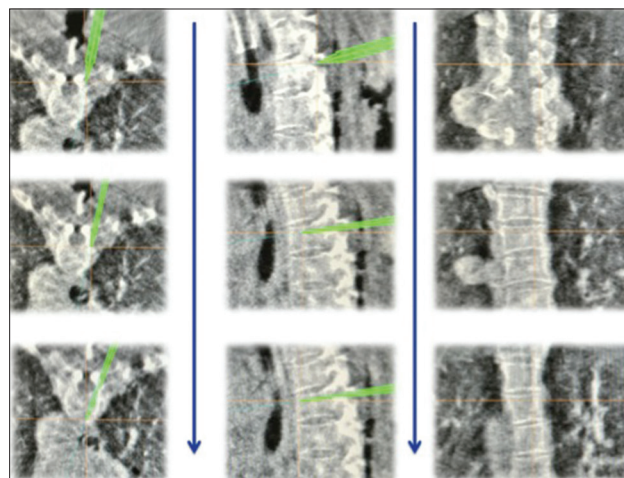
SPSS 20.0 software (IBM, Armonk, NY, USA) was used in statistical analysis. Demographic data and factors affecting accuracy of screw insertion were compared using independent *t*-test while comparison of accuracy of screw insertion between free-hand group and 3D navigation group was analyzed with Chi-square test. *P* < 0.05 was considered statistically significant.

## RESULTS

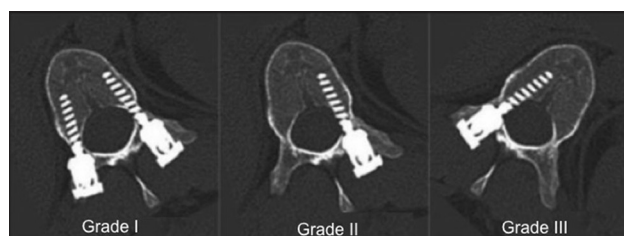
Demographic data of patients in free-hand group and ITFN group are shown in Table 1. The mean follow-up period is  $9.6 \pm 4.9$  months (range, 3–16 months). There were no complications observed throughout the most recent follow-up. Pathological types of tumors included schwannoma (31 cases) [Figure 5], epidermoid cyst (12 cases), neurofibroma (5 cases), hemangioma (2 cases), and melanotic schwannoma (1 case). There were no statistical differences between the two groups in demographic data of patients.

Tumors were totally removed in all patients via microsurgery. In assessment of neurological functions based on McCormick classification, 39 of the 51 patients demonstrated improved neurological status at the latest

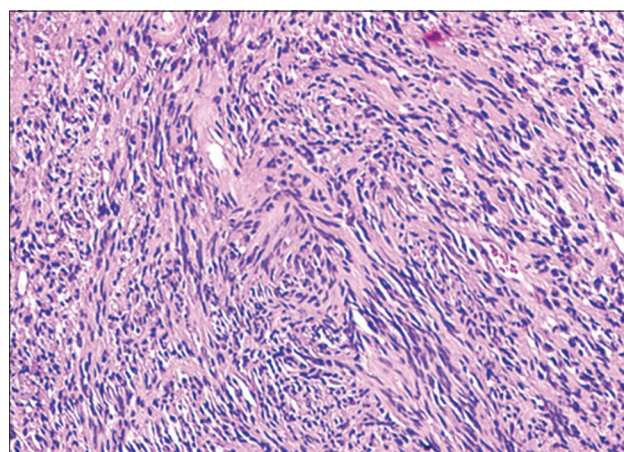
follow-up (16 in free-hand group, 23 in ITFN group; between 3 months and 16 months postoperatively). The other 12 patients (7 in free-hand group and 5 in ITFN group) reported that symptoms remained the same. In these 12 patients, statistical analysis demonstrated that the duration of preoperative symptoms might be the potential factor that affects the surgical outcome ( $t = 4.639$ ,  $P < 0.005$ ) [Figure 6]. No tumor recurrences were found during follow-up.



**Figure 3:** The real-time trajectories for pedicle screw insertion into T4 vertebrae determined by intraoperative 3D fluoroscopy-based navigation. 3D: Three dimensional.



**Figure 4:** Grading used for pedicle breaches on postoperative CT scan images. CT: Computed tomography.



**Figure 5:** Pathological photograph of a patient who diagnosed with giant invasive spinal schwannoma on T4–T5. Microphotograph showing densely packed spindle cells, intermingled with loosely textured tissue with extracellular clear spaces (H and E,  $\times 200$ ).

**Table 1: Demographic data of patients diagnosed with primary invasive spinal tumor**

Characteristics	Free-hand group	ITFN group	<i>P</i>
Female:male, <i>n</i>	8:15	11:17	0.175
Age (years)	$39.8 \pm 10.8$	$39.5 \pm 9.6$	0.925
Duration of symptoms (months)	$11.3 \pm 9.6$	$13.2 \pm 9.7$	0.776
Operating time (h)	$3.9 \pm 0.7$	$4.4 \pm 0.7$	0.975
Blood loss (ml)	$308.7 \pm 101.9$	$344.6 \pm 105.7$	0.224

Data are presented as mean  $\pm$  standard deviation unless otherwise indicated. ITFN: Intraoperative three-dimensional fluoroscopy-based navigation.

Postoperative CT scan demonstrated satisfactory results in all cases. Based on the intraoperative CT, 25 pedicles were completely or partially destroyed in free-hand group and 29 pedicles were destroyed in ITFN group due to the tumoral invasion. Eight pedicles in ITFN group were thought to be impassable because of altered pedicle anatomy and size. In the free-hand group, 145 screws (92.4%) were Grade I, 9 screws (5.7%) were Grade II, and 3 screws (1.9%) in Grade III. In the ITFN group, 192 screws (97.4%) were Grade I, 5 screws (2.6%) were Grade II, and no Grade III screw was detected in this study. Statistical analysis showed that the accuracies of pedicle screws in two groups were significantly different ( $\chi^2 = 4.981, P = 0.026$ ) [Figure 7].

Furthermore, among the screw pedicles of Grade II in ITFN group, we analyzed the factors that affect the accuracy of PSP, and the result demonstrated that the number of vertebral bodies between the screws and the tracker were statistically different in ITFN group (Grade I vs. Grade II:  $2.93 \pm 0.93$  vs.  $4.29 \pm 0.48, t = 6.279, P < 0.001$ ). No medial cortical penetration or anterior vertebral cortical penetration was observed. No cases of iatrogenic neurological injury were found [Figure 8].

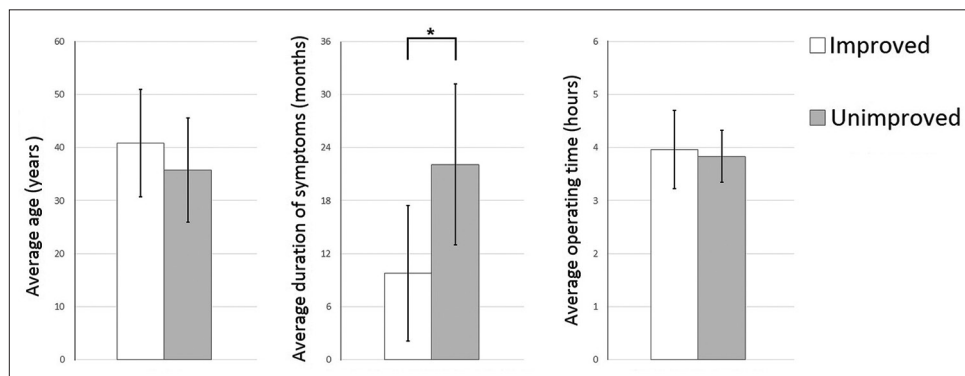
## DISCUSSION

The term of PIST has not been proposed in prior literature; however, earlier articles reported some specific spinal tumors with this invasive nature. Sridhar *et al.*<sup>[11]</sup> defined giant invasive spinal schwannoma as a tumor that extends more than two vertebral levels with extraspinal extension of  $>2.5$  cm and those with vertebral body erosion and posterolateral extension into myofascial planes. Tureyen *et al.*<sup>[12]</sup> described a series of idiopathic spinal epidural arachnoid cysts with obvious vertebral erosion because of long-term compression. Varying lesions with an invasive nature in spinal canal have been described in sporadic case reports as well, pathological types most commonly include epidermoid cysts, neurofibroma, spinal giant-cell tumor, and hemangioblastoma.<sup>[11,12,14-16]</sup> Surgery plays an important role in the treatment of PISTs.<sup>[11]</sup> The treatment goals include the restoration and preservation of neurological function, pain relief, and local lesion control.<sup>[16,17]</sup> Total resection is

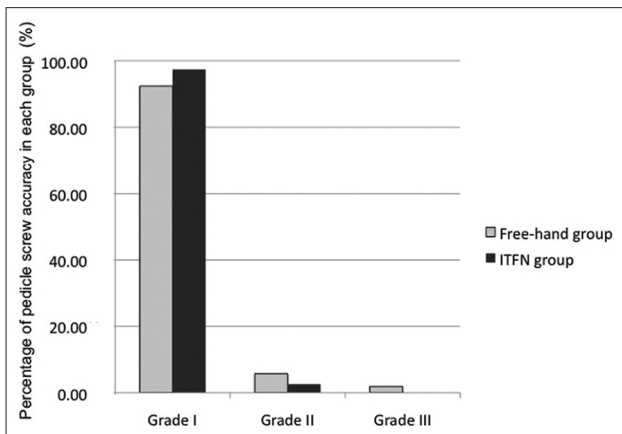
recommended because inadequate removal may be followed by recurrence.<sup>[11,16,17]</sup> In our study, 39 of 51 patients showed significant symptoms' improvement postoperatively based on McCormick classification, and 12 patients' symptoms remained the same. We further analyzed some factors that affect the surgical outcome, such as patients' age and the duration of preoperative symptoms. The statistical result demonstrated that the duration of preoperative symptoms has positive correlation to the surgical outcome. We considered that the neurological deficits were caused by direct tumor compression of the cord, and preoperative duration of compression may affect the surgical outcome. Thus, early surgical treatment allows rapid neurological function recovery. The accuracy of pedicle screw was not considered to be associated with the neurological status.

In achieving total tumor resection, multilevel laminectomy with facet removal has to be done.<sup>[11,13-16]</sup> Meanwhile, operators should further consider the influence to spinal stability. Tumor erosion plus surgical destruction may worsen the spinal deformity or instability. This situation following procedure has raised concerns by more and more surgeons.<sup>[18,19]</sup> Contemporary pedicle-based spinal instrumentation is thought to be the most effective method with the aim of reconstructing spine stability until now.<sup>[7]</sup> Although this technique has been widely used among different medical centers in the world, PSP in the thoracic spine is still full of risks because of the smaller pedicle size and more complex 3D anatomy.<sup>[20]</sup> In practice, screw malposition may lead to highly severe vascular and neurological complications, especially when the patient's anatomy is changed or destroyed by some certain reasons, such as scoliosis, idiopathic deformities, or tumor erosion.<sup>[21,22]</sup> In our study, 29 pedicles were totally destroyed and 8 pedicles became extremely slim in furthermore, the spinal cord was compressed to the one side in spinal canal, which leads to a safe zone reduction between the cord and pedicles. The odds of neurological structure injury significantly increased because of the above reasons while inserting pedicle screws.

Given these potential risks, multiple studies of varying pedicle screw installation have been developed to evaluate



**Figure 6:** The potential factors that affect the surgical outcome of neurological function were analyzed. Data are shown as mean  $\pm$  standard deviation. \* $t = 4.639, P < 0.05$ . Improved group ( $n = 39$ , including 16 in free-hand group and 23 in ITFN group); Unimproved group ( $n = 12$ , including 7 in free-hand group and 5 in ITFN group).

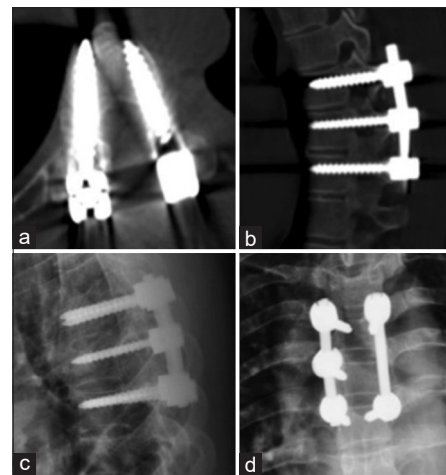


**Figure 7:** The accuracy of pedicle screws in each group. The accuracy demonstrated by modified classification of Gertzbein and Robbins (I–III). There was a significant difference for the percentages of Grade I and non-Grade I (Grade II or Grade III) between free-hand group and ITFN group ( $\chi^2 = 4.981, P = 0.026$ ). ITFN: Intraoperative three-dimensional fluoroscopy-based navigation.

the accuracy of its usage. Puvanesarajah *et al.*<sup>[23]</sup> reviewed a series of reported studies and concluded the accuracy rate in the thoracic spine by free-hand ranging from 71.9% to 98.3%. Of note, the lowest accuracies were associated with the mid-thoracic spine. Parker *et al.*<sup>[24]</sup> found that screws inserted into T4 and T6 were most likely to breach while Modi *et al.*<sup>[25]</sup> found that screws inserted into the pedicles of T5–T8 had a greater incidence of breaches. Furthermore, as expected, free-hand techniques have been noted to have a significant learning curve.<sup>[21,23]</sup> In this study, our rate in the free-hand technique was 92.4%. Although three screws showed penetration 2–4 mm on CT images, none of the misplaced screws resulted in neurological deficits.

For overcoming the disadvantages of free-hand techniques, some surgeons identify anatomical landmarks via K-wires placement based on fluoroscopy guidance into the pedicles, and the incidence of pedicle screw misplacement ranges from 1.5% to 25% using the K-wire-guided methods.<sup>[26,32]</sup> Although previous researches showed only 1.5% misplacement, they admitted that the actual rate would be higher on those patients who have severe spine deformity or destroyed pedicles. Meanwhile, the conventional K-wire-guided technique could not allow direct visualization of the starting point on the intraoperative fluoroscopy and/or radiography.<sup>[26,27]</sup> The accuracy of PSP depends largely on the patient's anatomic landmarks and the surgeon's experience.<sup>[28,29]</sup> Furthermore, radiation exposure of surgeon and operating room personnel has raised concerns as well.<sup>[30]</sup>

The advent of the intraoperative 3D fluoroscopy-based navigation system helps us address many of these concerns. The ITFN system permits a safe and accurate instrumentation of the spine with the advantage of obtaining intraoperative real-time 3D images and automatic registration. In this report, we used the ITFN system to guide



**Figure 8:** Postoperative CT images of a patient who diagnosed with giant invasive spinal schwannoma on T4–T5. (a and b) Postoperative CT images showing accurate placement of pedicle screws without penetration. (c and d) Postoperative X-ray images performed 3 months after surgery showing ideal positions of pedicle screws. CT: Computed tomography.

the surgeon in the placement of pedicle screws according to an intraoperative planned trajectory. In this study, the accuracy rate is 92.4% in free-hand group and 97.4% in ITFN group. This system perfectly showed an enhanced image quality. It facilitates surgical workflow and reduces the rate of technical problems compromising the utility of image guidance in routine use. Although there were five screws of Grade II in ITFN group, none of these screws threatened major prevertebral vessels or viscera. During follow-up, there were no tumor recurrences and any sign of spine instability observed as well.

Despite the advantages of using ITFN system, we cannot ignore the fact that there are still 2.6% screws breaching the cortex, although they are all silent clinically. Imaging shifting is thought to be a major reason for this error. Patient's position can be shifted while the screws are placed. Thus, we suggest the operator should manipulate gently in pedicle screw insertion to avoid touching the patient. Meanwhile, in analyzing the position of every single screw, we discovered a gradual rise in screw misplacement rate was demonstrated with increasing distance between instrumented segment and the tracker by Spearman rank correlation analysis. The screws closing to the tracker (within two segments) have significantly higher accuracy compared to the ones that extend the range of two vertebrae. As a result, we considered that the increasing distance to tracker is an important factor of impacting the accuracy of screw placement. Last but not least, Scheufler *et al.*<sup>[26]</sup> reported that ventilatory arrest during scan acquisition and registration of the lower thoracic does not appear to be warranted. The impact of ventilation on chest cage and spinal motion depends on several factors, such as tidal volume, chest cage volume, configuration, and rigidity, as well as positioning of the patient. Therefore, we suggest that the surgeon should

verify the accuracy of the navigation system during the operation if there is any doubt.

There may be some bias in our study. First, the quantity of samples in each group is less. Second, there could be a learning curve that may have influenced our results. Before this study, we sufficiently performed thoracic tumor resection without ITFN system. Thus, we believe that the effect of a learning curve in using 3D ITFN may be minor.

Conclusively, the treatments of PISTs include total tumor resection and reconstruction of spine stability. The ITFN system could provide high accuracy of PSP, especially for incomplete pedicles in thoracic spine. The promising result suggests that this technique is feasible and safe. However, considering the accuracy rate, further studies will be required in the future.

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### Conflicts of interest

There are no conflicts of interest.

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