Observational Study

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Three-dimensional navigation (O-arm) versus fluoroscopy in the treatment of thoracic spinal stenosis with ultrasonic bone curette

A retrospective comparative study

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Abstract

Three-dimensional intraoperative navigation (O-arm) has been used for many years in spinal surgeries and has significantly improved its precision and safety. This retrospective study compared the efficacy and safety of spinal cord decompression surgeries performed with O-arm navigation and fluoroscopy. The clinical data of 56 patients with thoracic spinal stenosis treated from March 2015 to April 2017 were retrospectively analyzed. Spinal decompression was performed with O-arm navigation and ultrasonic bone curette in 29 patients, and with ultrasonic bone curette and fluoroscopy in 27 patients. Patients were followed-up at postoperative 1 month, 3 months, and the last clinic visit. The neurologic functions were assessed using the Japanese Orthopaedic Association (JOA) Back Pain Evaluation Questionnaire. The accuracy of screw placement was examined using three-dimensional computed tomography (CT) on postoperative day 5. There was no significant difference in the incidences of intraoperative dural tear, nerve root injury, and spinal cord injury between the two groups. The two groups showed no significant difference in postoperative JOA scores ($P > .05$). The O-arm navigation group had significantly higher screw placement accuracy than the fluoroscopy group ($P < .05$). O-arm navigation is superior to fluoroscopy in the treatment of thoracic spinal stenosis with ultrasonic bone curette in terms of screw placement accuracy. However, the two surgical modes have similar rates of intraoperative complications and postoperative neurologic functions.

Abbreviations: CT = computed tomography, JOA = Japanese Orthopaedic Association, O-arm = three-dimensional intraoperative navigation.

Keywords: O-arm navigation, thoracic spinal stenosis, ultrasonic bone curette

1. Introduction

Posterior resection of the spinal canal and circumferential decompression are effective treatments for thoracic spinal stenosis. However, these procedures are associated with unintended durotomy.[1–3] Precise decompression and cautious operation are critical to avoid intraoperative injuries to the spinal cord, nerve roots, and dura. Three-dimensional intraoperative navigation (O-arm) has been used for many years in spinal surgeries and has significantly improved its precision and safety.[4–6] Ultrasonic bone curette is a recently developed surgical device with many desirable features such as precise cutting, low heating, and minimum scrolling,[7–11] and is getting increasingly popular in spinal surgeries. Combination of the two techniques may provide better efficacy and less complications for the treatment of spinal diseases.

Our study aimed to compare the efficacy and safety of the combination of O-arm navigation and ultrasonic bone curette versus fluoroscopy and ultrasonic bone curette in spinal cord decompression surgeries.

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2. Materials and methods

2.1. Patients

The clinical data of 56 patients with thoracic spinal stenosis treated with thoracic spinal posterior operations at our hospital from March 2015 to April 2017 were retrospectively analyzed. Thoracic spinal stenosis was diagnosed based on symptoms, signs, magnetic resonance imaging, and computed tomography (CT). The symptoms and signs of thoracic spinal stenosis include lower limb weakness, numbness, hypertonus, patellar hyper-reflexia, and Achilleal hyperreflexia. Clinical imaging may find ossification of the ligamentum flava and the posterior longitudinal ligament, thoracic disc herniation, and spinal cord compression. Patients with thoracic vertebral fractures, tuberculosis, or tumors were excluded from the analysis.

All methods were performed in accordance with the relevant guidelines and regulations. Informed written consent was obtained from all participants before the enrollment in the study. Approval for the study was obtained from the Research Ethics Committee of Peking University International Hospital.

2.2. Surgical procedure

Patients with ossification of the ligamentum flavum, or ossification of the ligamentum and the posterior longitudinal ligament, were treated with resection of the posterior wall of the spinal canal. Spinal infusion was additionally performed if the thoracic lumbar spine was decompressed. Patients with ossification of the posterior longitudinal ligament, or ossification of the posterior longitudinal ligament and the ligamentum flavum, were treated with resection of the posterior wall of the spinal canal and optional circumferential decompression. Patients with thoracic disc herniation, or thoracic disc herniation and ossification of the ligamentum flavum, were treated with circumferential decompression through the posterior approach.

Twenty-nine patients were treated with spinal decompression using O-arm navigation (O-Arm 1000, Medtronic, USA) and ultrasonic bone curette (SMTP Technology, Jiangsu, China). General anesthesia was induced and the patient was put into the prone position. The diseased segments of the spine were confirmed using the O-arm fluorescence. A reference frame was fixed onto the spine and the 3D images of the diseased segments were obtained using the O-arm scanning. The entry points and trajectories of the pedicle screws were determined using the O-arm navigation system (Fig. 1). Screws were selected and placed in accordance with the pedicle diameter and length. The scope of the ossified ligamentum flava was detected using a probe and marked on the vertebral laminae. The posterior wall of the spinal canal and the ossified ligamentum flava were resected using an ultrasonic bone curette (Fig. 2).

Another 27 patients were treated with spinal decompression using ultrasonic bone curette and fluoroscopy. General anesthesia was induced and the patient was put into the prone position. The diseased segments of the spine were confirmed using fluoroscopy. The posterior wall of the spinal canal was longitudinally cut through using an ultrasonic bone curette, and then transversely cut through to decompress the caudal and cranial laminae. Then the posterior wall was lifted to decompress the posterior spinal cord. The pedicle screws were placed with fluoroscopy guidance.

2.3. Clinical evaluation

Patients were followed-up at postoperative 1 month, 3 months, and the last clinic visit. The neurologic functions were assessed using the Japanese Orthopaedic Association (JOA) Back Pain Evaluation Questionnaire (11 points).[12] The intraoperative durotomy, cerebrospinal fluid leak, and spinal/nerve root injury were recorded. The accuracy of screw placement was examined using three-dimensional CT on postoperative day 5 and graded as:

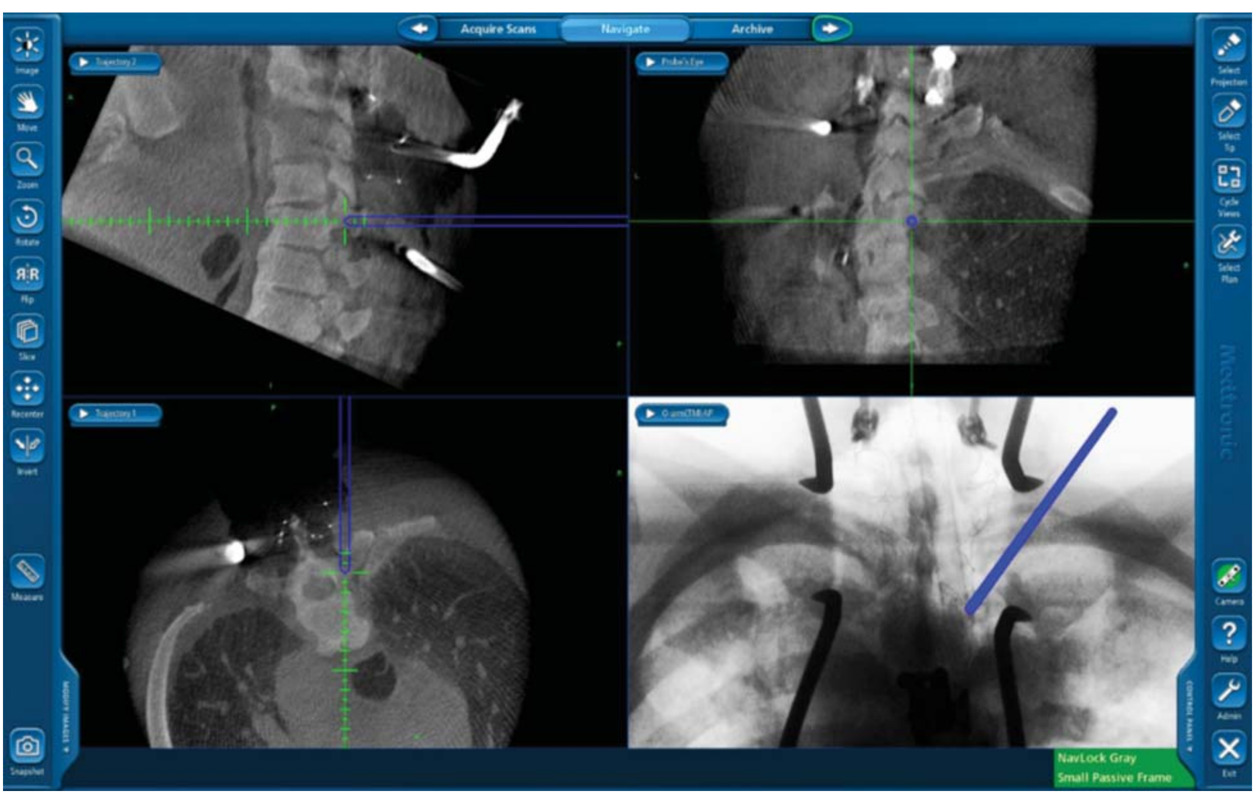

Figure 1. A intraoperative screenshot of the O-arm navigation system showing the placement of screws.

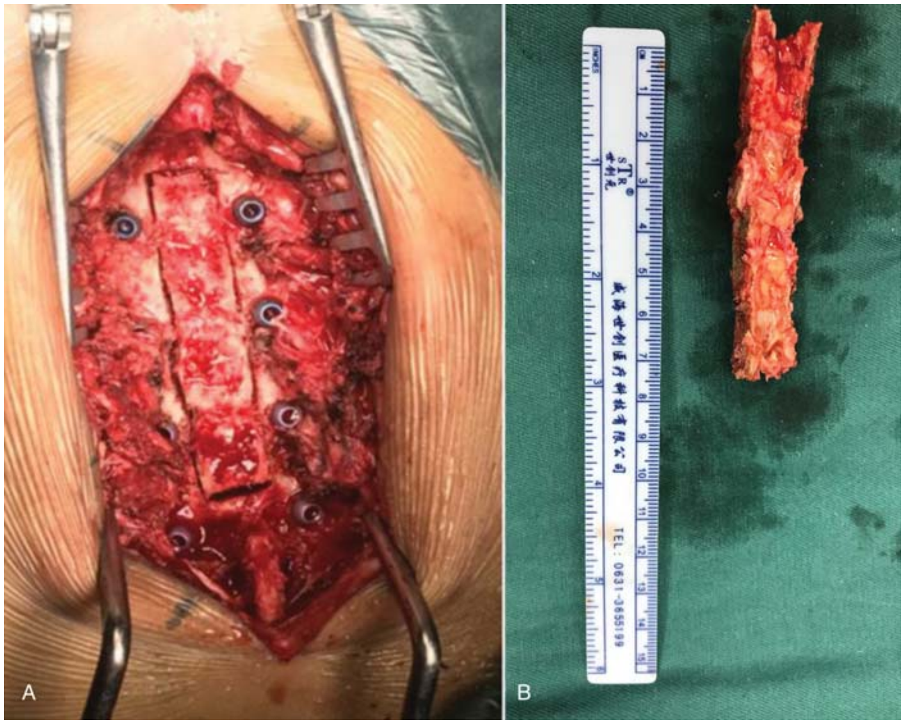

Figure 2. The posterior wall of the spinal canal and the ossified ligamentum flava were resected using an ultrasonic bone curette. A: Intraoperative view of the dissection. B: The ossified ligamentum flava.

1. excellent, the screw was entirely within the pedicle;
2. good, the pedicle breached the isthmus cortex with <1/4 of the screw diameter;
3. poor, the pedicle breached the isthmus with over 1/4 of the screw diameter.[13]

2.4. Statistical analysis

Continuous data with a normal distribution were presented as means ± standard deviations and compared using the Student's *t*-test. Continuous data with a non-normal distribution were presented as medians and interquartile ranges and compared using the Mann–Whitney *U* test. Categorical data were presented as frequencies or percentages and compared using the chi-square test. All statistical analyses were performed using the SPSS 18.0 software (SPSS Inc., Chicago, IL, USA). $P < .005$ was considered statistically significant.

3. Results

3.1. General information

The mean age of our patients was 53.2 ± 6.1 years (range, 35–77 years). The preoperative symptoms included lower limb numbness and weakness in 24 patients, chest or abdominal zonesthesia in 21 patients, chest or back pain in 19 patients, and lower limb pain in 19 patients. The pathology included ossification of the ligamentum flavum, ossification of the posterior longitudinal ligament, and thoracic disc herniation. The two groups of patients did not differ significantly in the baseline data (all $P > .05$, Table 1).

3.2. Postoperative outcomes

All patients were followed up for a mean of 14 months (range, 3–25 months). There was no significant difference in the incidences of intraoperative complications between the two groups (all $P > .05$, Table 2). At the last follow-up, no patients showed signs of screw loosening, fracture, or deviation. The two groups showed no significant difference in the JOA scores postoperatively (all $P > .05$, Table 3). The screws placed using the O-arm navigation had significantly higher rates of excellent/good accuracy than those placed not using the O-arm navigation at T1–T4 ($P = .038$) and T5–T8 ($P = .041$) (Table 4).

4. Discussion

O-arm navigation in combination ultrasonic bone curette was effectively used to treat 29 patients with thoracic spinal stenosis. Another 27 patients were treated with ultrasonic bone curette

Table 1

Baseline characteristics of the patients.

	Group O-arm (n = 29)	Group fluoroscopy (n = 27)	*P*
Male	31.0% (9/29)	33.3% (9/27)	.567
Age (year)	53.2 ± 6.2	52.8 ± 6.5	.564
Disease course (month)	46.2 ± 30.2	49.1 ± 29.8	.709
Intraspinal hyperintensity	8/29	7/27	.531
Number of decompression segments	2.63 ± 1.18	2.59 ± 1.02	.803
JOA score	4.7 ± 1.2	4.9 ± 1.1	.682

JOA = Japanese Orthopaedic Association.

Table 2

Comparison of intraoperative complications.

	Group O-arm (n=29)	Group fluoroscopy (n=27)	P
Cerebrospinal fluid leak	20.7% (6/29)	22.2% (6/27)	.573
Nerve root injury	6.9% (2/29)	7.4% (2/27)	.667
Spinal cord injury	0	11.1% (3/27)	.106

Table 3

Comparison of postoperative JOA scores.

	Group O-arm (n=29)	Group fluoroscopy (n=27)	P
Postoperative 1 month	7.6 ± 1.1	7.4 ± 1.3	.612
Postoperative 3 months	8.2 ± 1.4	8.1 ± 1.3	.496
Last follow-up	8.9 ± 1.0	8.6 ± 1.4	.586

Table 4

Screws placed with excellent or good accuracy.

	Group O-arm (n=29)	Group fluoroscopy (n=27)	P
T1–T4	94.5% (52/55)	82.7% (43/52)	.038
T5–T8	96.6% (86/89)	84.5% (71/84)	.041
T9–T12	96.6% (85/88)	83.8% (67/80)	.091

and fluoroscopy. We found no significant difference in the postoperative JOA scores between the two groups. However, O-arm navigation was associated with significantly higher screw placement accuracy than fluoroscopy.

The O-arm navigation system can provide three-dimensional information of the anatomy and the surgical instruments.[14] Real-time three-dimensional imaging has shown its great advantages in increasing the accuracy of pedicle screw placement.[15–17] A retrospective study comparing standard lateral fluoroscopy and three-dimensional navigation found that the latter can improve the accuracy and safety of thoracic and lumbar pedicle screw placement.[18] Three-dimensional navigation in thoracoscopic sublobar resection provided precise three-dimensional positional information and a potential viable alternative to conventional markers.[19] Aibinder et al used a navigated probe and burr in defining the most anterior, posterior, and medial extents of the coalition, which reduces the morbidity, with less bone removed and preservation of intact subtalar articulations and allows for an efficient, thorough, and controlled resection.[20] Chui et al reported that three-dimensional navigation-guided percutaneous screw fixation is a safe and accuracy surgical alternative in most pelvi-acetabular fractures.[21] Our study found that the screws placed using the O-arm navigation system had significantly higher accuracy than those placed using fluoroscopy. This may be associated with the real-time three-dimensional imaging of the O-arm navigation.

The O-arm navigation system also showed advantages in the decompression scope and accuracy. Spinal cord injury is the most severe complication of thoracic spinal stenosis surgeries. Tian et al indicated that intraoperative 3D navigation system with posterior decompression, reduction and monosegmental fusion required good efficacy for the facilitation of full nerve decompression, promotion of bony union, restoration of spinopelvic balance, and patient‘s ability to stand upright.[22] In our study, spinal cord injury occurred in 3 patients (5.4%), all in the fluoroscopy group. In many patients with thoracic stenosis, the ossified posterior longitudinal ligament and the ossified ligamentum flavum often merge by the side of the spinal canal. The traditional longitudinal cut along the bilateral zygapophyseal joint midline may also cut the anterior posterior longitudinal ligament. The dissected ossified posterior longitudinal ligament may be lifted together during the en-bloc removal of the posterior wall of the spinal canal. This may cause spinal cord injury or even paralysis. The O-arm navigation system can clearly show the lateral wall of the spinal canal as well as the connection part between the ossified posterior longitudinal ligament and the ossified ligamentum flavum. Thus, we can use the ultrasonic bone curette to precisely cut the ligamentum flavum at the lateral wall of the spinal canal rather than cutting the posterior longitudinal ligament. This technique ensures that the posterior longitudinal ligament is not lifted when preforming the en bloc resection of the posterior wall of the spinal canal, which avoids spinal cord injury.

Ultrasonic bone curette has been shown to reduce the incidence of cerebrospinal fluid leak in spinal surgeries. The reported incidence of dural tear or cerebrospinal fluid leak in spinal surgeries performed using ultrasonic bone curettes ranged from 1.6% to 9.8%.[23–26] In our study, cerebrospinal fluid leak occurred in 12 patients (21.4%). All the dural tears were caused by adhesion between the ligaments and the dura. None of the dural tears were caused by inappropriate use of the ultrasonic bone curette. Nerve root injury occurred in 4 patients (7.1%) due to the ultrasonic bone curette. In these 4 patients, the ossified part of the ligament was excessively large, and the spinal stenosis was quite severe. Thus, the nerve root was within a narrow space between the ossified part of the ligament and the posterior border of the vertebral body. Without a buffer space, once the ultrasonic bone curette cut through the ossified part of the ligament, it reached the posterior border of the vertebral body and caused nerve root injury. We suggest that caution should be used to control the cutting depth of the ultrasonic bone curette.

Our study has limitations. First, despite the relatively higher incidences of all postoperative complications in the fluoroscopy group than the O-arm group, these differences were not statistically significant. This may be associated with the relatively small sample size of our study. Second, the O-arm images have lower resolutions and more artifacts than CT images, which may decrease screw placement accuracy. Third, the sample size is small and may limit the generalizability of our findings. Our study used a retrospective design and provides level III evidence. The grade of recommendation of our study is group C.[27]

In conclusion, the O-arm navigation is superior to fluoroscopy in the treatment of thoracic spinal stenosis with ultrasonic bone curette in terms of screw placement accuracy. However, the O-arm navigation did not significantly improve the postoperative neurologic functions or reduce the incidence of intraoperative complications in comparison with treatment without navigation. Despite that the intraoperative complications were not significantly different between the navigated and the non-navigated patients, a misplaced screw has a higher chance of causing serious intraoperative complications.

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