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Original Article

A minimally invasive posterior lumbar interbody fusion using percutaneous long arm pedicle screw system for degenerative lumbar disease

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Abstract: The aim of this study is to evaluate the therapeutic efficacy of patients with lumbar degeneration and instability treated with percutaneous pedicle screw fixation and minimally invasive lumbar interbody fusion. Twenty-one patients were selected in our hospital from November, 2012 to March, 2013. The patients with an average age 55.62 years, including 8 vertebral spondylolisthesis, 4 lumbar intervertebral disc herniation, and 9 lumbar spinal canal stenosis cases. All the patients were managed to take the lumbar MRI and radiographs. The comparison of preoperative and postoperative (3 days, 2 weeks, 3 months) VAS and ODI score were analyzed. The results indicated that VAS scores were 7.14 ± 0.79 before operation, and 5.19 ± 0.81 in 3 days after operation, 4 ± 0.84 after 2 weeks, and 2.67 ± 0.66 after 3 months. The pain was relieved, and the postoperative VAS score was lower than that before treatment ($P < 0.05$). ODI score was 55.8 ± 11.4 before operation, 47.38 ± 9.38 after 3 days, 41.38 ± 8.09 after 2 weeks, 35.76 ± 4.50 after 3 months. ODI score was obviously decreased ($P < 0.05$). In conclusion, percutaneous pedicle screw fixation combined with minimally invasive interbody fusion is a safe, effective, feasible minimally invasive spine operation, with worthy for spreading.

Keywords: Percutaneous pedicle screw fixation, minimally invasive, lumbar degeneration

Introduction

For the treatment of a lumbar degenerative disease or lumbar instability, a posterior pedicle screw fixation and an interbody fusion, with the use of cages, are the gold standard that have been recognized by most spine surgeons [1, 2]. However, this surgery has some deficits including intense trauma, severe bleeding, long-term hospitalization, postoperative lumbar pain [3, 4]. However, a recently developed percutaneous pedicle screw fixation technique makes up for these shortcomings, and its efficacy exceeded that of a conventional open surgery [5-7].

The percutaneous pedicle screw fixation technique comprises three stages including external fixation, subcutaneous internal fixation, and deep muscle layer internal fixation. An early-stage external fixation is performed by placing a connecting device on the outside of the skin [8], and later, a subcutaneous internal fixation is performed by placing a connecting device within the subcutaneous tissue [9]; this procedure has been abandoned nowadays as it does not meet certain mechanical and biological requirements. At present, an internal fixation of the deep muscle layer, just as in an open surgery, is the most commonly conducted [10]. The fixation strength of the percutaneous fixation is similar to that of an open surgery, while the procedure involves significantly less surgical trauma. However, a percutaneous pedicle screw fixation technique requires specially designed screws and supporting tools, frequent intraoperative x-ray monitoring, and a long operative time, so surgeons should have sufficient experience and surgical skills. Therefore, these factors have become a bottleneck of this technique and limit its extensive application.

Many types of design patterns are currently utilized in the percutaneous pedicle screw system.

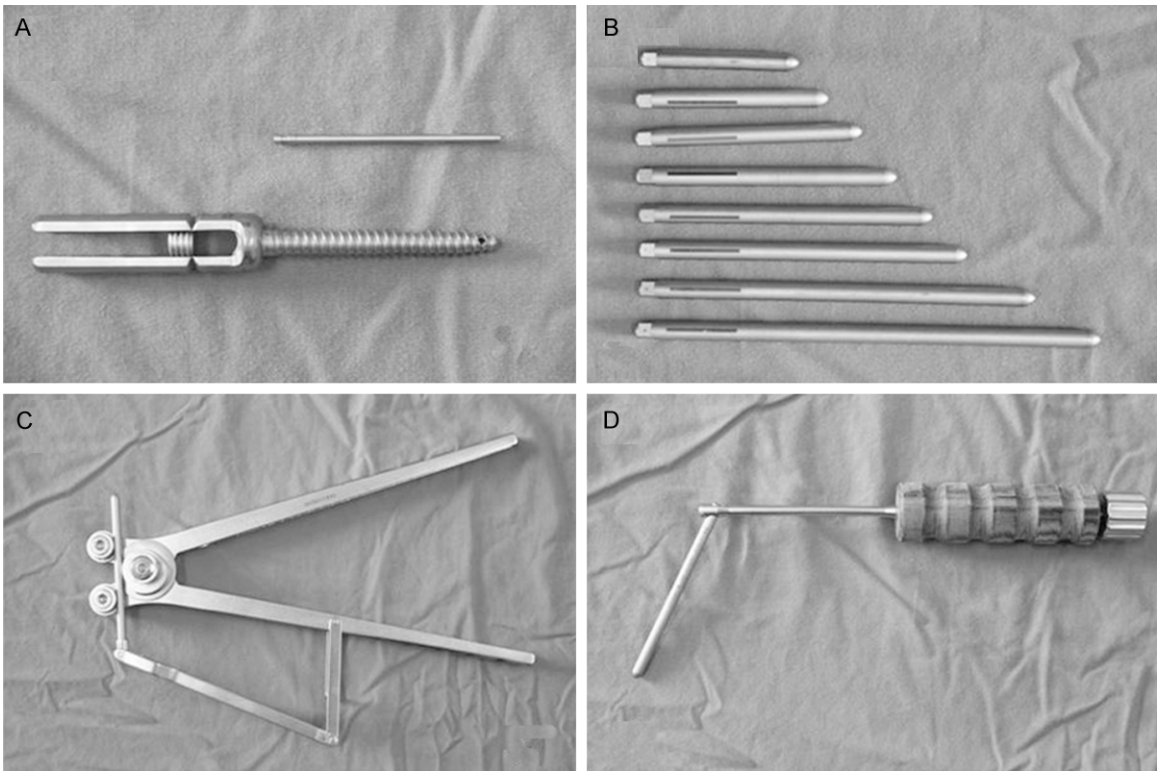

Figure 1. The tools of long-arm percutaneous pedicle screw. A: A long-arm percutaneous pedicle screw with a hollow core and a core pin enhancing the screw strength. B: Straight rods without bending in different sizes: one end is cone-shaped and the other end has three planes matching the rod holder, which contains scales for identifying the direction during rod bending. C: Compared with a common rod bender, ours has an additional direction control device, which can control the bending direction via the three-plane structure. D: The connection portion of the rod holder and the rod is in an annular shape. The rod rotation can be controlled by utilizing the three planes of the rod. After being tightened, there is an angle of 120 degrees between the rod holder and the rod.

However, the extender that was designed to match a U-shaped screw head in the Sextant system is commonly used as a guiding device [10-13]. Therefore, those designs have a common shortcoming, namely, the extenders may cross one another if the angle between the two adjacent pedicles was relatively large and if it restricts manipulation. This situation is usually seen during a lower lumbar fixation. To compensate for this shortcoming, some scholars have tried to connect a double-flap soft retractor to a screw head. The difference between its design and that of the Sextant system is that the extension part is completely open, which enables easy manipulation [14].

The particular screw that is used for a percutaneous pedicle screw fixation is different from that used in an open surgery. The screw head was specially designed, so it could be connected to an extender for a subsequent rod installation, a set-screw placement, compression, distraction, etc. The whole procedure is complicated. The long-arm pedicle screw that was used in the current study has been utilized in a spinal reduction and correction. After inserting the screw into the pedicle, the elongated U-shaped arm could be exposed outside of the body, which serves a guiding function such as an extender. However, no reports exist regarding whether this kind of screw could be used in a percutaneous screw fixation or minimally invasive posterior lumbar fixation and fusion.

Materials and methods

General data

Twenty-one patients (10 males and 11 females) who were admitted to the Department of Spine Surgery in our hospital between November 2012 and March 2013 were included in the current study. Their ages ranged from 22 to 79 years, with a mean age of 55.62 years. All

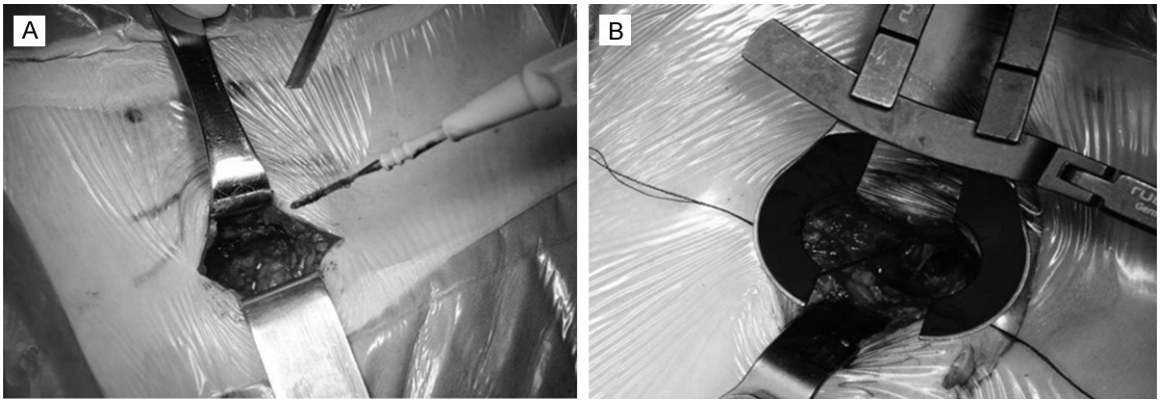

Figure 2. Surgery processes. A: A 3-4 cm paramedian longitudinal skin incision was made, which was located approximately 3cm lateral to the posterior midline. B: The paraspinal muscles were dissected along the spinous process to the articular process and a Caspar retractor was used for soft tissue retraction to expose the interlaminar space. Through an interlaminar approach, the intraspinal lesion, the disc tissue disc tissue and endplate cartilage were removed.

patients had varying degrees of lower back pain, as well as unilateral/bilateral numbness, lower extremity radiating pain, intermittent claudication, or any combination of these. Their disease duration ranged from 2 to 204 months. All patients had received at least 6 weeks of conservative treatment without any significant symptom improvement. Before surgery, anteroposterior (AP), lateral, and dynamic flexion-extension spinal x-rays were obtained, and a lumbar spine MRI was performed in order to identify the location and extent of disc herniation, as well as the state of spinal stenosis. Eight cases had lumbar spondylolisthesis; 4 cases had a lumbar disc herniation; and 9 cases had spinal stenosis. Their pathology was located at L3-4 (1 case); L4-5 (10 cases); L5-S1 (5 cases); L3-4 and L4-5 (3 cases); L4-5 and L5-S1 (1 case); and L3-4, L4-5, and L5-S1 (1 case). The follow-up duration ranged from 3.3 to 8.2 months, with a mean duration of 5.8 months.

Long-arm percutaneous pedicle screw

Screw: The pedicle screw that was used in the current study was a cannulated screw (Dabo, Xiamen, China), which could also be used as a guiding tube for a bone cement injection. It was a multi-axial screw with a long U-shaped screw head (5 cm). The core pin of the screw could be inserted into the hollow portion after placing the screw into the pedicle in order to enhance the strength of the screw (**Figure 1A**). Rod: There were straight rods of different lengths. One end of the rod was cone shaped, and the other end had three planes that matched the rod holder. There were scales that helped to identify directionality while bending the rod (**Figure 1B**). Rod-bending device: A portion of the rod was bent with a common rod-bending device. However, a direction-control device was on one side, which could control the direction of bending by using the three-plane structure of the rod (**Figure 1C**). The connection portion of the rod holder, as well as the rod, was an annular shape. Rod rotation could be controlled by utilizing the three planes of the rod. After tightening, an angle of 120 degrees existed between the rod holder and the rod (**Figure 1D**).

Surgical procedure

A unilateral spinal canal decompression and cage placement were carried out by a minimally invasive incision: A 3-4 cm paramedian longitudinal skin incision was made that was located approximately 3 cm lateral to the posterior midline (**Figure 2A**). The paraspinal muscles were dissected along the spinous process to the articular process, and a Caspar retractor was used for soft tissue retraction in order to expose the interlaminar space. Through an interlaminar approach, an intraspinal lesion, the disc tissue, and the endplate cartilage were removed (**Figure 2B**). A cage (Kanghui, Suzhou, China) was inserted after intervertebral bone grafting.

Percutaneous pedicle screw fixation: A skin incision was retracted laterally in order to be used for decompression and to expose a proper site for screw insertion. A spinal needle was

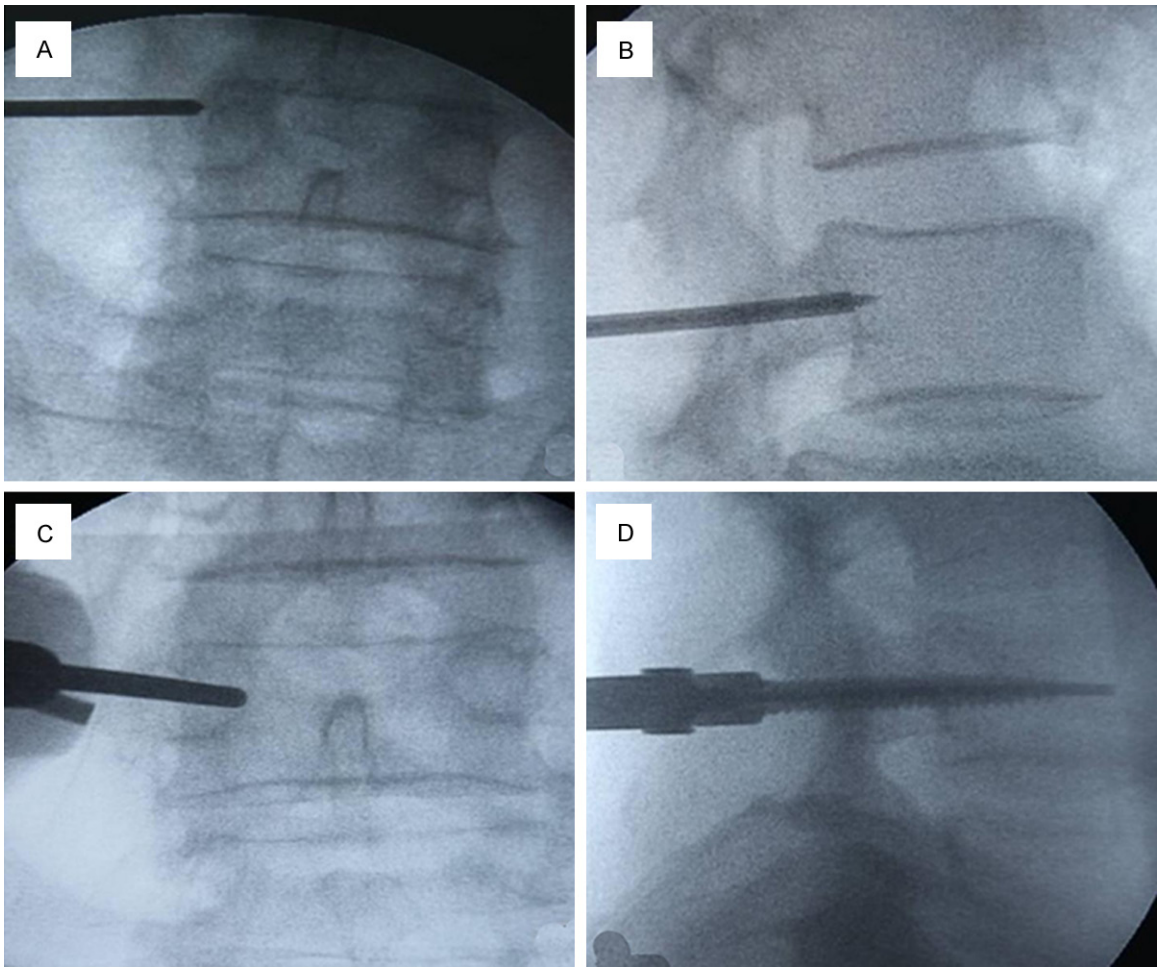

Figure 3. The localization of the needles. A: Criteria for identifying the correct localization: The needle insertion point should be located in the lateral margin of the projection of pedicle axis or the second virtual image center directly lateral to it. B: On the lateral image, the needle should be advanced parallel to the pedicle axis and its extension line should cross the pedicle center to reach the posterior margin of the vertebra. C: The need tip is located just in the medical margin of the pedicle on the AP image. D: A right size screw is inserted along the guide wire.

inserted through the deep fascia and advanced by using the Wiltse intermuscular approach. An entry point on the pedicle was confirmed and anchored. On the contralateral side, a needle was inserted by using the Wiltse approach and anchored by using the above-mentioned percutaneous method. AP and lateral X-ray films were obtained in order to guide a needle inside the entire length of the pedicle. With the same method, two spinal needles were inserted into the pedicles on an adjacent lower level. Criteria for identifying the correct localization: A needle insertion point should be located in the lateral margin of the pedicle axis projection or the center of an imaginary second projection that would be directly lateral to it (**Figure 3A**); this entry point was consistent with that of Weinstein's pedicle fixation approach. On a lateral image, the needle should be advanced parallel to the pedicle axis, and its extension line should cross the pedicle center. After the needle was inserted along the whole length of the pedicle, namely, the end of the needle had been passed through the pedicle center and had reached the posterior margin of the vertebral body in a lateral image (**Figure 3B**); it should be located just in the medical margin of the pedicle in an AP image (**Figure 3C**). The core of the spinal needle was removed, and a guide wire was inserted. The end of the guide wire should be 0.5 cm longer than that of the spinal needle. The needle was then removed; a cannulated tapper was used in order to prepare the route for screw insertion; and a screw of a correct

size was inserted along the guide wire (**Figure 3D**). If a slight deviation existed in the direction of the spinal needle, despite a correctly located pedicle entry point, it was adjusted by using the method that is discussed below. After removing the needle, a tapper was inserted along the guide wire and twisted forward about 1 cm, and then, the guide wire was removed. The direction of the tapper could be adjusted for a moment. The tapper was advanced along the correct direction through the whole length of the pedicle or deep into the vertebral body. The guide wire was inserted into the tapper again, and its end was 0.5 cm longer than that of the end of the tapper. If the pedicle entry point was not correct or if there was a serious directional deviation, the needle was removed, and the entire procedure was re-performed. After inserting the pedicle screws, appropriately sized rods were selected and bent according to the physiological curvature of the lumbar spine. The long arms of the screws were broken off after the rods were inserted and fixed. A drainage tube was placed in the decompression window, and wound closure was performed after sufficient irrigation.

Postoperative treatment

Anti-infective agents, dehydration measures, pain control, and other symptomatic treatments were carried out after surgery. AP and lateral x-ray films were obtained. After 2-3 days of bed rest, patients began ambulation after wearing a brace.

Observation indicators

The operative time, frequency, amount of radiation exposure, intraoperative and postoperative blood loss, preoperative and postoperative VAS and ODI scores, length of stay, screw location, complication occurrence, etc., were observed. Criteria for determining screw position: (1) Good location: In an AP X-ray image, screw inclination was appropriate, and the screw tip did not exceed that of the bisector on the right or left half of the vertebral body. In a lateral X-ray image, the screw head was tightly against the facet joint, while the axis of the screw was located in the pedicle axis and reached the front one-third of the vertebral body. (2) Fair location: In an AP X-ray image, screw inclination could be observed, and the screw tip did not exceed the bisector on the right or left half of the vertebral body. In a lateral X-ray image, the screw head was tightly against the facet joint, and the axis of the screw was parallel to the pedicle axis or formed a slight angle with the pedicle axis. However, the screw was still located between the upper and lower margins of the pedicle and reached the front one-third of the vertebral body. (3) Poor location: Indicators could not meet the above-mentioned standards.

Statistical analysis

The obtained data were expressed as mean ± standard deviation. SPSS 13.0 was used to perform a data analysis. The paired *t* test was conducted, and a significance level of 0.01 was adopted.

Results

Ninety-six long-arm screws were implanted in this study. The total operative time ranged from 105 to 317 minutes, with a mean of 197.0 ± 55.02 minutes. The time for pedicle screw insertion ranged from 15 to 44.5 minutes, with a mean of 21.92 ± 7.52 minutes. The time for single-level decompression and fusion ranged from 26.67 to 90 minutes, with a mean of 46.48 ± 18.61 minutes. The operating time required the placement of negative pressure drainage tubes and the closure of the surgical incision, and it ranged from 15 to 35 minutes, with a mean of 21.81 ± 5.3 minutes. The frequency of intraoperative X-ray imaging for inserting one pedicle screw ranged from 5.25 to 14 minutes, with a mean of 7.99 ± 2.45 minutes. The intraoperative blood loss for single-level decompression ranged from 50 to 120 mL, with a mean of 81.98 ± 21.76 mL. The amount of postoperative drainage ranged from 15 to 100 mL, with a mean of 58.62 ± 23.79 mL. The preoperative VAS scores ranged from 6 to 9 points, with a mean of 7.14 ± 0.79 points, the VAS scores on the 3rd postoperative day ranged from 4 to 7 points, with a mean of 5.19 ± 0.81 points, the VAS scores obtained 2 weeks after surgery ranged from 3 to 5 points, with a mean of 4.0 ± 0.84 points, and the VAS scores obtained 3 months after surgery ranged from 2 to 4 points, with a mean of 2.67 ± 0.66 points (**Figure 4A**). The mean preoperative ODI scores were 55.88 ± 11.4 points, ranging from 32 to 73 points, the mean ODI scores on the 3rd postoperative day were 47.38 ± 9.38 points, rang-

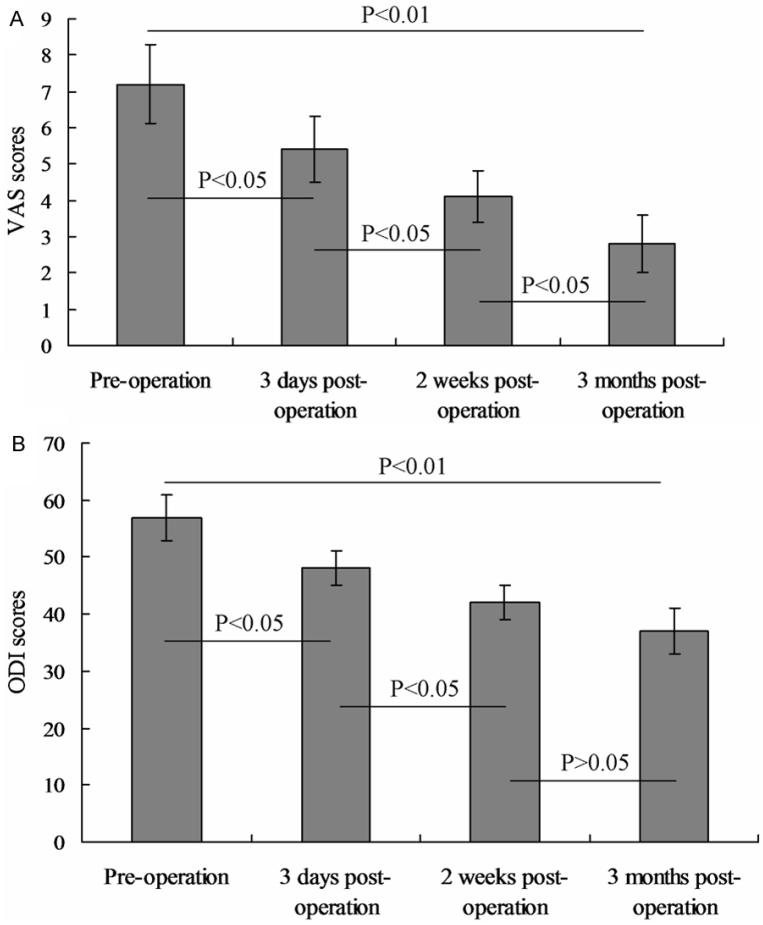

Figure 4. VAS and ODI score. A: VAS score. The pain was relieved obviously on the 3rd postoperative day and VAS scores decreased gradually after surgery ($P < 0.05$). B: ODI score. The patient began ambulation on the 3rd postoperative day and the quality of life improved gradually ($P < 0.05$).

There were no significant differences between this technique and open surgery, with respect to the operative time. However, our procedure had less intraoperative blood loss, shorter length of stay, and faster postoperative functional recovery. Its short-term outcome was significantly better than that of the traditional open surgery.

Percutaneous pedicle screw insertion techniques are classified into two major types depending on the rod insertion instruments. The first type is the geometrical coordinating device. It has an extender at the screw head and the rod should be inserted via another incision to connect the screws. The other device is the open screw head type used for direct insertion of the rod. However, these two kinds of devices have a common shortcomings. Moreover, as in China all products should be imported, this is less likely to become a routine procedure due to its high cost.

ing from 28 to 62 points, the mean ODI scores obtained 2 weeks after surgery were 41.38 ± 8.09 points, ranging from 25 to 53 points, and the mean ODI scores obtained 3 months after surgery were 35.76 ± 4.50 points, ranging from 21 to 45 points (**Figure 4B**). The mean length of stay was 9.05 ± 2.6 days, ranging from 6 to 14 days. 71 screws were graded as excellent (**Figure 5**), 22 as fair, and 3 as poor (excessive medial inclination of the pedicle screw due to the more lateral entry point for pedicle screw placement) (**Table 1**). There were no complications including neural injury, cerebrospinal fluid leak, hematoma, and wound infection.

Discussion

In the current study, we used percutaneous long-arm pedicle screws posterior to the lumbar spine to further make the posterior intervertebral fusion surgery minimally invasive. In the current study, we applied screws with a 5 cm long arm that were produced by a domestic manufacturer. This length can ensure that the end of the screw head is located within the subcutaneous tissue or exposed about 1 cm above the skin surface. Because the length of the long arm is less than half of the extender, it can effectively avoid colliding with each other outside the body. In the current study, the long arms did not affect our manipulation. Because the extended part of the long arm is open, the process of placing the rod into the U-shaped groove of the screw head can be observed clearly under a common surgical lighting system, which makes the rod insertion relatively easy. The thread in the long arm makes the reduction of spondylolisthesis possible. In the current study, reduction of spondylolisthesis was carried out easily in two patients and the outcomes were satisfactory. In addition, the

Table 1. Basic information, operative time, blood loss, frequency of intraoperative X-ray

Cases	Sex	Age	Diagnosis	Levels	Operative time (min)		Blood loss (ml)			
					Decompression and fusion for each level (min/level)	Wound closure	Time for screw insertion (min/screw)	Intraoperative blood loss of each level (ml/level)	Amount of postoperative drainage (ml)	
1	F	44	Lumbar spine stenosis	L4/5	55	30	37.5	120	50	56 (14)
2	M	22	Lumbar disc herniation (L3/4, central, extrusion)	L3/4	60	20	44.5	100	40	52 (13)
3	M	23	Lumbar disc herniation (L5/S1, central to left, extrusion)	L5/S1	50	20	31.25	100	50	42 (10.5)
4	M	70	Lumbar spinal stenosis	L4/5	76	35	32.75	75	55	40 (10)
5	M	74	L4 spondylolisthesis	L4/5, L5/S1	27	18	28.83	100	100	65 (10.8)
6	F	53	Lumbar spinal stenosis	L4/5	30	15	30	100	70	40 (10)
7	F	44	Lumbar disc herniation (L4/5, central to right, extrusion)	L4/5	51	30	28.5	100	70	28 (7)
8	F	63	Lumbar spinal stenosis	L5/S1	33	20	30.5	100	80	26 (6.5)
9	M	71	Lumbar spinal stenosis	L4/5	30	20	32.5	100	16	26 (6.5)
10	F	54	Lumbar spinal stenosis	L4/5	27	22	17.25	50	15	23 (5.75)
11	F	47	Lumbar spinal stenosis	L4/5	30	20	27.5	50	55	24 (6)
12	M	70	L4 spondylolisthesis I°	L4/5	50	20	22.5	100	60	30 (7.5)
13	F	65	Spondylolisthesis (L4 II°, L3 I°)	L3/4, L4/5	58	20	20	100	90	44 (7.3)
14	F	71	L4 spondylolisthesis	L4/5	30	15	15	50	40	21 (5.3)
15	M	79	L4 spondylolisthesis	L2/3, L3/4, L4/5	26.7	30	19.75	66.7	100	60 (7.5)
16	F	43	Lumbar spinal stenosis	L4/5	35	20	19.75	50	40	23 (5.8)
17	M	37	Lumbar disc herniation (L5/S1) with instability	L5/S1	50	18	27.25	70	50	25 (6.3)
18	M	72	L3 spondylolisthesis	L3/4, L4/5	90	23	19	75	90	42 (7)
19	F	41	L5 spondylolisthesis	L5/S1	80	17	21.75	60	45	27 (6.8)
20	M	53	Lumbar spinal stenosis	L5/S1	40	20	20	75	55	25 (6.3)
21	F	72	1. L5 spondylolisthesis (II°) 2. L4 vertebral instability	L3/4, L4/5	47.5	25	18.33	80	60	49 (8.2)

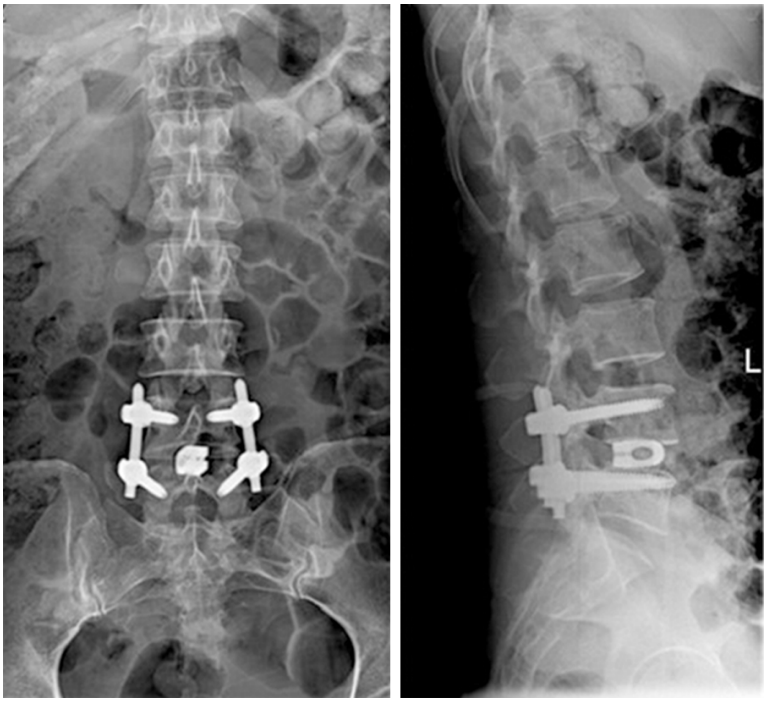

Figure 5. Position of pedicle screw. A: Antero-Posterior view. B: Lateral view.

structural characteristics of the polyaxial screw allow 360° movement of the long-arm, which allows placing two screws via a small incision. Similar to other percutaneous pedicle screws, the long-arm screws are hollow. We designed the long-arm screw according to the percutaneous spinal needle used to inject bone cement into the diseased vertebra. After being tightly locked, there is a 120° angle between the rod holder and the rod, which makes the control of rod direction simple. Placing the rod into the completely open U-shaped groove of the screw is relatively easy.

The X-ray projection technique used by Magerl [15] is complicated, as it requires the projection direction to be consistent with the longitudinal axis of the pedicle. Several adjustment times are needed during the operation. Wiesner [16] proved that an accurate pedicle screw placement can be achieved under the guidance of the routine anteroposterior projection technique. There are no differences between two methods with respect to the accuracy. However, the anteroposterior images are more familiar to the orthopedic surgeons. Therefore, we used the routine anteroposterior projection technique in the current study and no complications, including neural injury, occurred. Pedicle screws are commonly instrumented with the appropriate entry site as described by Weinstein [17] and Roy-Camille [18]. The entry point described by Weinstein is located in the root of the transverse process, laterally to the facet joint. On the anteroposterior X-ray image, it is located in the lateral margin of the pedicle or the lateral part of the pedicle (the second virtual image center). During the actual manipulation, the surgeon can locate the transverse process using the needle tip and place the needle medially to reach the entry point. The bone in this entry point is rarely too hard to result in medial sliding of the needle during its insertion, and the screw head is less likely to affect the facet joint movement after screw placement. Compared with the entry site described by Roy-Camille, this site has obvious advantages, particularly when the entry point described by Roy-Camille cannot be accessed in young patients and in patients with hard bone.

In the beginning stage of our study, the mean operative time of four cases was more than 4 hours due to our lack of experience. During the operation, we did not effectively utilize the external anatomical landmarks and the measurement results of X-ray images. As a result, the time for finding the entry point on the pedicle was long and the frequency of intraoperative X-ray imaging was high. Later, the mean operative time became about 2 hours and the mean frequency of intraoperative X-ray imaging was about 20 times, values that are similar to those during open surgery. The mean intraoperative blood loss was about 106 mL, which was significantly less than that during open surgery. It was reported that the incidence of nerve injury during percutaneous pedicle screw placement is only 0.5% [19]. In the current study, no nerve injury was observed. Despite of our small sample size, it can be concluded that the percutaneous pedicle screw fixation may be safer than during open surgery.

We performed unilateral laminectomy via a small incision and implanted only one cage to further reduce the blood loss due to decompression and fusion, to decrease the operative time significantly and reduce medical costs. Because we did not carry out extensive dissection of the sacrospinalis, the patient-controlled analgesia was not needed after surgery. The postoperative pain was mild and oral administration of pain killers was sufficient to relieve it. The VAS scores and ODI scores significantly decreased two weeks after surgery. Our study and other reports [20-22] have proved that the unilateral decompression and one-cage implantation can achieve satisfactory outcomes just like total laminectomy and two-cage implantation. Therefore, minimally invasive posterior lumbar fusion can be achieved by using percutaneous pedicle screw fixation.

The long-arm screws used in the current study were the same size, and the length of the arm was 5 cm. This length was not suitable for every patient. In three cases, the length of the screw arm was not sufficient and the end of the long-arm screw was located 2 to 3 cm below the skin. In other cases, the screw end could be exposed outside the skin or located just beneath the skin, and the manipulation was not disturbed. In addition, of the handle of the spinal needle was relatively thick and it affected the simultaneous insertion of four adjacent pedicles. Repeated distraction and compression are also shortcomings of our system.

In conclusion, the percutaneous long-arm pedicle screw fixation system is a safe and feasible technique during lumbar spine surgery. This approach is superior to open surgery with regard to the aspect of the treatment outcome and postoperative rehabilitation. Compared to the percutaneous pedicle screw system using the extender, it can be used more easily and reduce the financial burden to patients. Therefore, this kind of technique can be widely applied in China.

Disclosure of conflict of interest

None.

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