Observational Study

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Evaluation of lumbar fusion using the anterior to psoas approach for the treatment of L5/S1 spondylolisthesis

Wei He, MD, Da He, MD, Wei Tian, PhD*

Abstract

To date, no studies have evaluated the outcomes of lumbar interbody fusion using the anterior to psoas (ATP) approach in patients with spondylolisthesis at L5/S1. We; therefore, aimed to evaluate short-term surgical outcomes of interbody fusion using the ATP approach combined with posterior fixation in these patients.

We performed a retrospective analysis of 9 patients with grade I spondylolisthesis at L5/S1 who were treated with fusion and posterior fixation using the ATP approach at our hospital from April to July 2018. The recorded parameters included operation time, intraoperative blood loss, complications, intervertebral fusion rate, radiological intervertebral height, intervertebral foramen height, intervertebral foramen width, pain, visual analog scale, and Oswestry disability index.

Four men and 5 women at an average age of 57.8 years (range: 46–71 years) were enrolled in the study. The average operation time was 152.8 ± 22.9 minutes, and the average blood loss during surgery was 165 ± 27.5 mL. All patients confirmed the relief of their low back pain, and there were no serious complications. The follow-up time was more than 6 months. The visual analog scale and Oswestry disability index scores 3 days postoperatively and at the last follow-up were significantly lower than those before surgery ($P < .05$). At the last follow-up, the intervertebral space of the surgical segment showed bony fusion in all patients, and the intervertebral height and intervertebral foramen height and width were significantly increased compared with those before surgery ($P < .05$).

The ATP approach was safe and effective for the treatment of spondylolisthesis at L5/S1. It showed low vascular injury and cage shift rates and was technically easy to perform. We recommended that surgeons identify the vessels in the surgical field preoperatively so that they can be secured or safely ligated during surgery.

Abbreviations: ATP = anterior to psoas, MI-TLIF = minimally invasive transforaminal lumbar interbody fusion, ODI = Oswestry disability index, OLIF = oblique lumbar interbody fusion, VAS = visual analog scale.

Keywords: anterior to psoas, iliac vein, lumbar vein, spondylolisthesis, vein injury

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request. All data generated or analyzed during this study are included in this published article [and its supplementary information files].

Department of Spinal Surgery, Beijing Jishuitan Hospital, 4th Medical College of Peking University, Xicheng District, Beijing, PR China.

** Correspondence: Wei Tian, Department of Spinal Surgery, Beijing Jishuitan Hospital, Xicheng District, Xinjiekou No. 31 East Street, Beijing 100035, PR China (e-mail: tianwei_victor@163.com).*

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1. Introduction

Lumbar interbody fusion is a classic surgical procedure in the treatment of lumbar degenerative disease. Recently, numerous minimally invasive interbody fusion procedures have emerged, including minimally invasive transforaminal lumbar interbody fusion (MI-TLIF), introduced by Foley et al[1] in 2003, and oblique lumbar interbody fusion (OLIF), described by Silvestre et al[2] in 2012. MI-TLIF directly decompresses the compressed nerve tissue through a tubular retractor and achieves clinical outcomes comparable to those after traditional open TLIF.[3] However, the correction of lordosis and coronal imbalance is difficult with TLIF.[4,5] The main goal of OLIF is to implant a significantly larger intervertebral cage than the TLIF cage to restore intervertebral height and segment lordosis using a lateral approach through the natural passway (through a corridor between the peritoneum and psoas muscle). It corrects any sagittal imbalance to promote fusion but retains the posterior column structure of the vertebral body and limits paravertebral muscle damage.[6]

However, in some patients, the anatomical location of the blood vessels in the area may obstruct access. Therefore, OLIF can only be used for the L2–L5 segments and not for the L5/S1 segment. The anterior to psoas (ATP) approach employs a dedicated surgical retractor and improved operating technique not only for the L2–L5 segments but also for the L5/S1 segment.

Table 1

Basic patient information.

	Sex	Age, yr	Top of iliac wing above the L4/L5 disc level	Level	Follow-up time, mo
1	Woman	46	Yes	L5/S1	10
2	Man	55	Yes	L5/S1	8
3	Woman	52	Yes	L5/S1	6
4	Man	48	Yes	L5/S1	6
5	Man	65	Yes	L5/S1	7
6	Woman	71	Yes	L5/S1	9
7	Woman	63	Yes	L5/S1	10
8	Woman	59	Yes	L5/S1	11
9	Man	61	Yes	L5/S1	8

No studies have evaluated the ATP approach for patients with spondylolisthesis of L5/S1 so far. Therefore, we decided to retrospectively analyze data from patients who were operated using the ATP approach, compare the pre- and postoperative imaging findings, and evaluate clinical efficacy, with the aim of providing new insights to the treatment of spondylolisthesis at L5/S1.

2. Methods

2.1. Study design

This observational study was a retrospective file review. The study protocol was approved by our hospital ethics committee (reference number: 201811-03). Inclusion criteria were lumbar spondylolisthesis (degree I) confirmed by imaging, with varying degrees of low back or lower extremity pain, with neurological dysfunction such as weakness in 1 or both the lower extremities, or hypothyroidism.

Exclusion criteria were lumbar spondylolisthesis (degree II and above), history of anterior or posterior lumbar surgery, lumbar trauma, infection, tumor, simple lumbar disc herniation, simple lumbar spinal stenosis, severe osteoporosis and lumbar deformity, and history of abdominal surgery within the previous year.

2.2. Study participants

We reviewed the files of patients with spondylolisthesis at L5/S1 treated at our institution between April and July 2018 (Table 1). All patients underwent surgery using the ATP approach and posterior percutaneous pedicle screw fixation (4 men, 5 women;

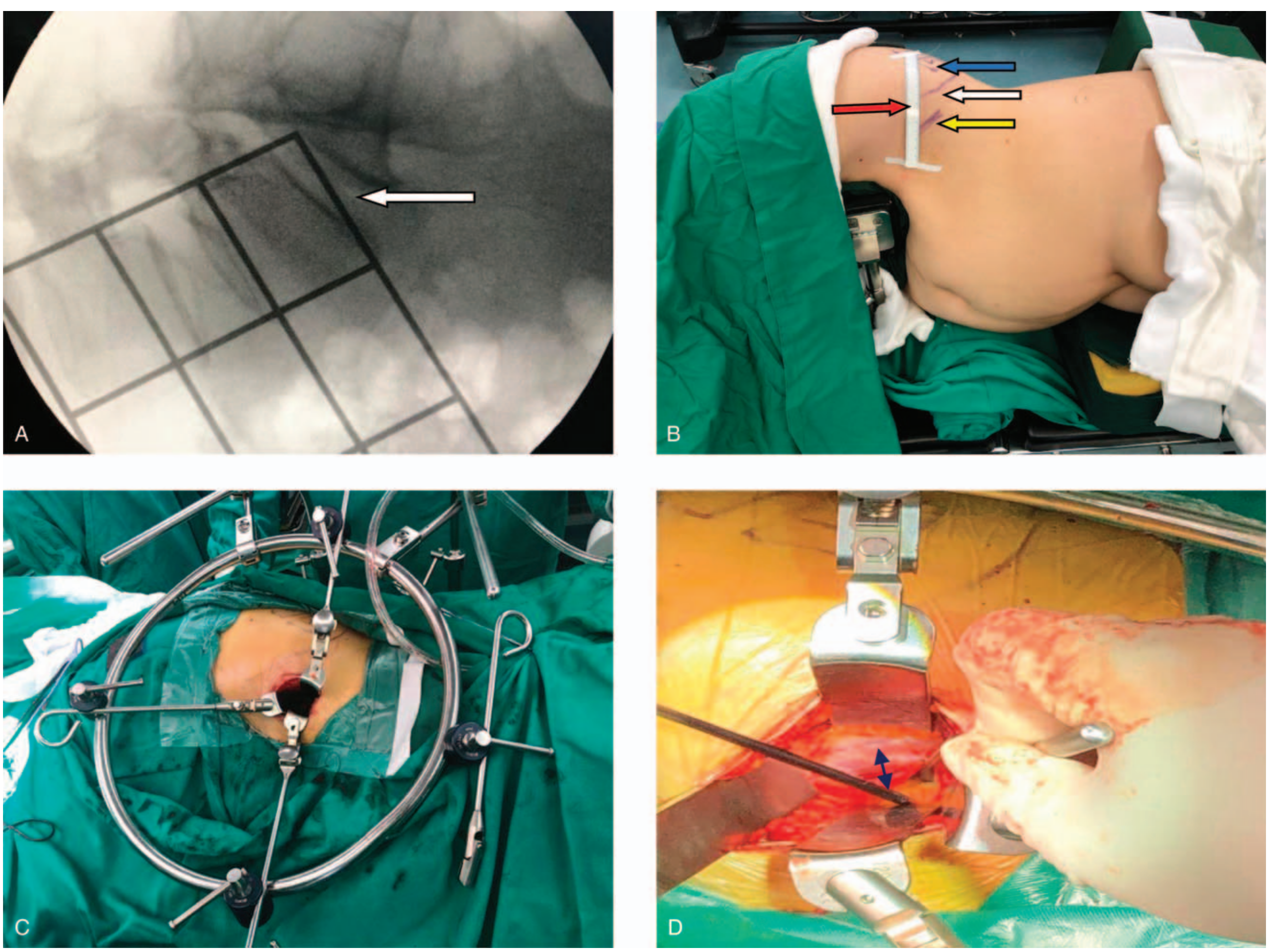

Figure 1. Illustration of important steps in ATP surgery. (A) Intraoperative perspective positioning. The white arrows indicate the L5/S1 intervertebral disc. (B) Marking of the landmarks on the skin with the patient in a left lateral position. The white arrow indicates the iliac crest. The blue arrow indicates the tangent of the L5 vertebral body determined under fluoroscopy. The red arrow indicates the distance ruler. The yellow arrow indicates the planned surgical incision. (C) The surgical traction frame reveals the surgical field. (D) The iliac vein traffic tributaries. The black double-headed arrow indicates the width of the vein that straddles the L5/S1 intervertebral space and has been ligated. ATP = anterior to psoas.

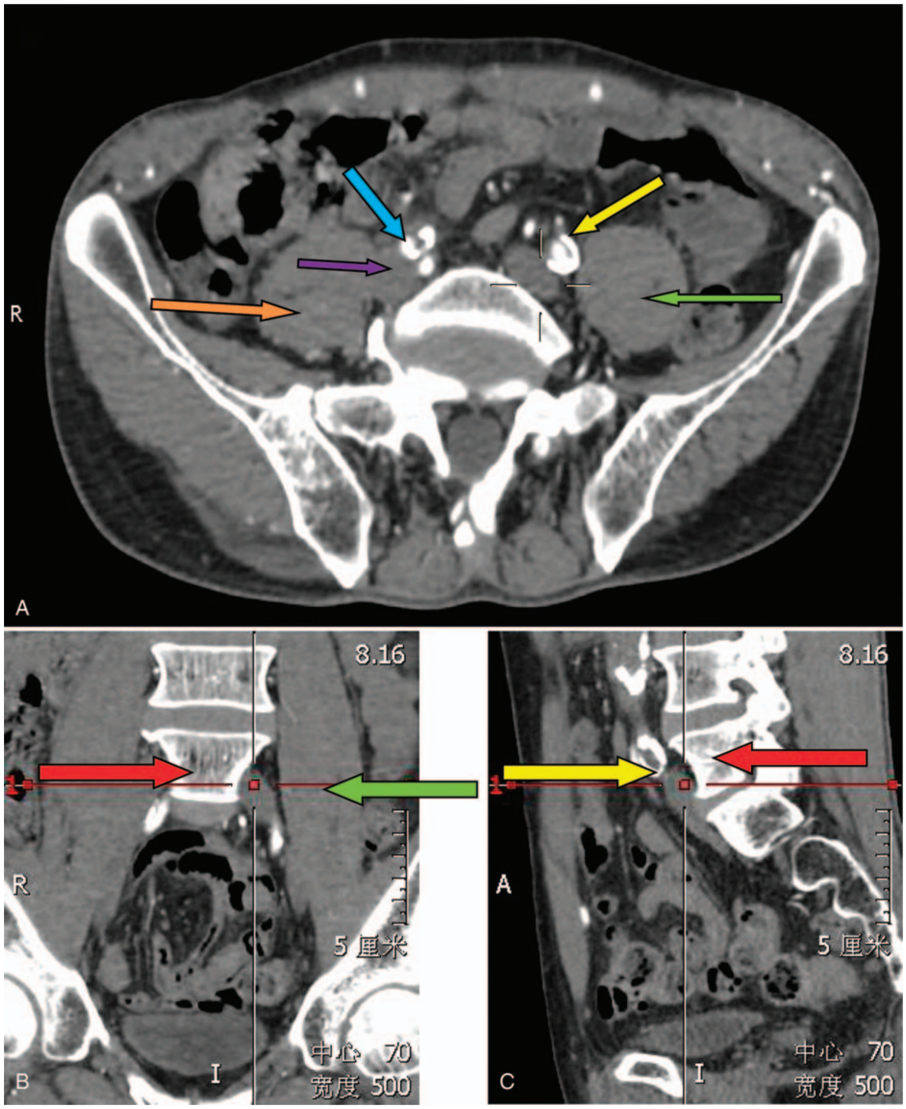

Figure 2. Three-dimensional CTA of the common iliac vein. (A) Lumbar CTA cross-section: The left L5 vertebral body is visible with the common iliac vein (cross), which is located in the middle and lateral third of the body. There is no fat tissue between the vein and vertebral body. The iliac vein, in this case, was classified as type III. The purple arrow indicates the right common iliac vein. The yellow arrow indicates the left common iliac artery after contrast enhancement. The blue arrow indicates the right common iliac artery. The green arrow indicates the left psoas. The orange arrow indicates the right psoas. (B) Coronal CTA: The positional relationship between the right common iliac vein (red marker) and the L5 vertebral body. The green arrow indicates the right psoas. The red arrow indicates the L5 vertebral body. (C) Lumbar sagittal CTA: The positional relationship between the right common iliac vein (red marker) and the L5 vertebral body. The red arrow indicates the L5 vertebral body. The yellow arrow indicates the right common iliac artery after contrast enhancement. CTA = computed tomography angiography.

mean age: 57.8 [range: 46–71] years). All patients had symptoms of low back pain pre-surgery, including 7 patients with low back and lower limb pain and 2 with low back pain and lower limb numbness. No patients complained of reduced lower limb muscle strength or dysfunction.

The requirement for informed consent by patients was waived because of the retrospective nature of this study.

2.3. Surgical method

We confirmed the location of the common iliac veins and arteries using computed tomography (Fig. 2) before surgery.

The approach was then selected according to the iliac vein and common iliac artery positions. The L5/S1 intervertebral disc (Fig. 1A and B) was identified under fluoroscopy, and an extension line was marked as a tangent of the L5/S1 intervertebral disc. An oblique line of 6 to 8 cm was drawn about 2 fingers laterally of the right anterior superior iliac spine. An incision was made, and blunt dissection of the external and internal oblique muscle, transverse abdominal muscle, and transverse fascia was performed. The surgical traction frame revealed the surgical field (Fig. 1C). The surgeon used their fingers to explore the lateral surface of the psoas muscle, blood vessels, and intervertebral disc. A frame retractor (DePuy Synthes Co. Spine, Paoli, PA) was used to pull the psoas muscle dorsally, push any soft tissue cranially and caudally, and carefully move the internal iliac vein ventromedially. Most patients displayed a “lumbar vein” in the L5/S1 segment, which was connected to the internal iliac vein (the affected side). The internal iliac vein was gently pulled away, and then the lumbar vein was either ligated or coagulated with a bipolar electrode, depending on the wall thickness of the internal iliac vein (Fig. 1D). The internal iliac artery and vein of the affected side were separated to reveal the L5/S1 segment. After discectomy, the intervertebral space was prepared and the intervertebral cage (Clydesdale spinal system; Medtronic, Minneapolis, MN; Wright Medical Technology Inc., Arlington, TN) filled with demineralized bone matrix was inserted. The wound was irrigated and sutured layer by layer. No drainage tube was placed.

For the percutaneous placement of the pedicle screw, the patient was placed in the prone position. After routine disinfection, a sterile surgical incision film was applied. Under the guidance of the spinal surgery robot, a guide wire was placed bilaterally through the L5 and S1 pedicles. After the C-arm confirmed the correct position, bilateral pedicle screws were inserted sequentially along the guide wire. The connecting rod was installed, and satisfactory fixation was confirmed under C-arm control. The incision was sutured layer by layer.

We recorded the operation time, intraoperative blood loss, and complications for each patient.

2.4. Perioperative management

Intravenous cefuroxime sodium (1.5 g) was administered 30 minutes before incision and 24 hours postoperatively as infection prophylaxis. The sutures were removed 2 weeks later. On postoperative day 2, patients were mobilized with waist protection and instructed to avoid bending over and lifting anything heavy in the first 3 months. After that, patients gradually resumed their normal daily activities.

2.5. Evaluation methods

Imaging examination and clinical evaluation were performed before surgery and 1 week and 6 months after surgery. All patients underwent lumbar spinal X-ray imaging and computed tomography. Intervertebral height and intervertebral foramen height and width were measured before surgery and at the last follow-up.

2.6. Clinical outcomes

The visual analog scale (VAS) was used to compare the preoperative with the postoperative pain. The VAS score ranges from 0 to 10. A score of 0 indicates no pain and 10 unbearable pain. The Oswestry disability index (ODI) was used to assess patients' quality of life. The ODI assesses pain, functioning, and individual comprehensive functions. Each item is scored on a scale of 0 to 5. The highest possible score is 50.

2.7. Statistical analysis

Data analysis was performed using SPSS Statistics for Windows, version 18.0 (SPSS Inc., Chicago, IL). Normally distributed data are expressed as mean ± standard deviation. Pre- and postoperative values were compared using the paired t test. A P-value $< .05$ was considered statistically significant.

3. Results

3.1. General results

Exclusively segment L5/S1 was fused in each of the 9 patients. The average surgical time was 152.8 ± 22.9 minutes. The intraoperative blood loss was 165 ± 27.5 mL. Since no drainage tube was placed in the surgical cavity, drainage volume was not measured after surgery. Low back pain, lower limb pain, numbness, and other neurological symptoms were significantly reduced postoperatively compared to those preoperatively (Table 2). The VAS and ODI scores were significantly lower at the last follow-up than those preoperatively (Table 2).

Table 2

VAS and ODI scores (n = 9).

Time	VAS	ODI score
Preoperatively	8.2 ± 0.8	42.6 ± 5.1
1 wk after surgery	5.3 ± 0.6	30.7 ± 3.9
Last follow-up	1.2 ± 0.5	15.2 ± 2.6

Data are expressed as mean ± standard deviation.
ODI = Oswestry disability index, VAS = visual analog scale.

3.2. Imaging evaluation

At the last follow-up, intervertebral height and intervertebral foramen height and width were significantly increased compared to the values preoperatively (Table 3).

3.3. Complications

Intraoperatively, 2 cases of internal iliac vein injury occurred that were closed with a titanium clip. During the postoperative follow-up period, no patient had internal fixation failure. No patient had complications such as abdominal organ, ureteral, or cauda equina injury.

4. Discussion

In this study, the ATP approach combined with posterior fixation was safe and effective for treating spondylolisthesis at L5/S1. The ATP approach was first proposed by Mayer[7] in 1997. In 2012, Silvestre et al[2] performed minimally invasive anterior retroperitoneal lumbar interbody fusion in 179 patients and officially introduced the OLIF concept. The original goal of the technique was to reduce retroperitoneal trauma by using the gap between the retroperitoneum and the psoas muscle as the access route. Later, lateral lumbar interbody fusion was used widely to treat lumbar degenerative disease, but this procedure damaged the psoas muscle and had a high risk of lumbar plexus injury in cases of neurophysiological monitoring.[8] Abe et al[9] reported on 155 patients who underwent OLIF, with 75 (48.3%) of them suffering complications that included endplate fractures or subsidence (18.7%), transient lumbar weakness and thigh numbness (13.5%), and segmental arterial injury (2.6%). Most of the consequences of these complications were temporary, but 3 patients had permanent damage (1 ureteral injury and 2

Table 3

L5/S1 imaging analysis.

Time	Intervertebral height, mm	Right intervertebral foramen height, mm	Right intervertebral foramen width, mm
Preoperatively	3.5 ± 1.7	9.5 ± 2.9	7.1 ± 1.8
Last follow-up	12.6 ± 2.1	14.7 ± 3.5	9.6 ± 2.1

Data are expressed as mean ± standard deviation.

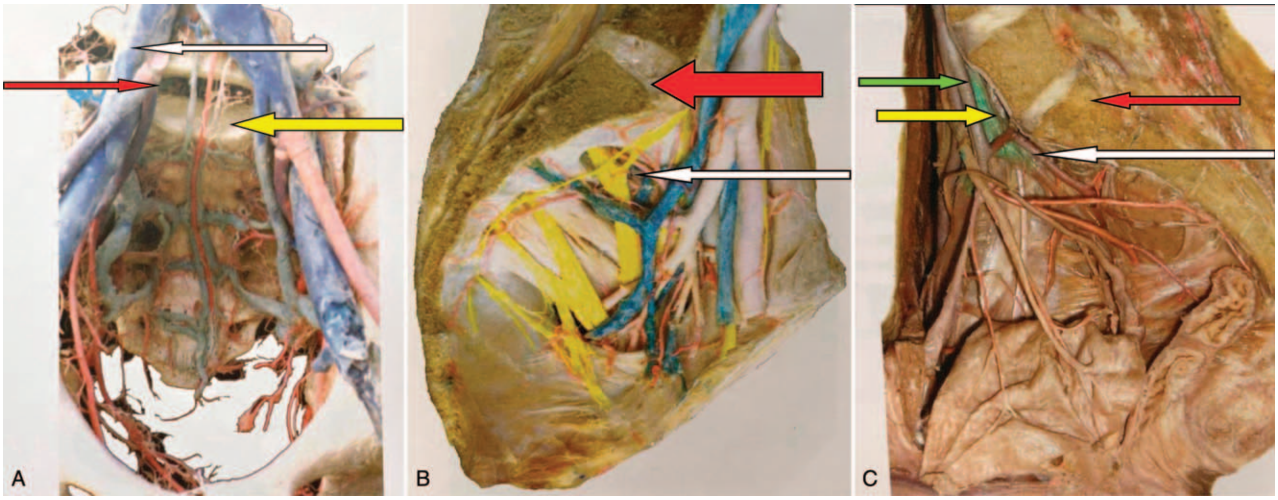

Figure 3. Autopsy shows important blood vessels around the L5/S1 segment. (A) Vascular cast. The positional relationship between the confluence of the iliac vein and the bifurcation of the iliac artery and L5/S1 is shown. The white arrow indicates the right iliac vein confluence. The red arrow indicates the right iliac artery bifurcation. The yellow arrow indicates the L5/S1 intervertebral space. (B) Sagittal anatomy of the sacrum in relation to the iliac-lumbar artery. The white arrow indicates the iliac-lumbar artery. Although veins are not shown, this area includes the iliac-lumbar vein. The red arrow indicates the L5/S1 disc. (C) Sagittal anatomy of the sacrum in relation to the internal iliac artery. The white arrow indicates the posterior branch of the internal iliac artery. Although veins are not shown, this area includes the posterior tributary of the internal iliac vein. The red arrow indicates the L5/S1 intervertebral disc. The yellow arrow indicates the internal iliac vein. The green arrow indicates the internal iliac artery.

neurological impairments). Long-term postoperative complications included surgical site infection (1.9%) and reoperation (1.9%). In our study, no patient suffered permanent nerve or ureteral damage.

Avoiding vascular injury is one of the challenges in spine surgery. Woods et al[10] reported a 2.9% rate of vascular injury during OLIF of the L2–S1 segments. However, when patients who underwent OLIF of L2–L5 were excluded, the vascular injury rate at L5/S1 increased to 4.3%: no vascular injuries occurred at L2–L5, but 4 at L5/S1. An iliac-lumbar vein injury occurred in the left common iliac vein in 2 patients, but hemorrhage was controlled with a blood vessel clamp. The other 2 patients had left common iliac vein injuries that were repaired at the time. The vascular injury rate for OLIF at L5/S1 was found to be higher than that for anterior lumbar interbody fusion (4.3% vs 3.3%).[10]

Chung et al[11] assessed left iliac vein anatomy in 65 patients in whom they performed OLIF of L5/S1. They distinguished type I, II, and III: Type I was defined as the medial edge of the iliac vein being located in either the lateral part of the middle third or the lateral third of the left half of vertebral body. Type II was defined as the medial edge of the iliac vein being located within one-third of the middle and lateral third of the vertebral body, with perivascular adipose tissue between the iliac vein and vertebral body. Type III was defined as the medial edge of the iliac vein being located within the middle and outer thirds of the half of the vertebral body, with no adipose tissue between the iliac vein and vertebral body. In their study,[11] 7 patients (10.8%) had left iliac vein injury, 5 had type III, and 2 had type II iliac vein injuries. There is a risk of iliac vein injury when performing fusion of L5/S1, with the risk being high for type III iliac vein. We; therefore, recommend evaluating the iliac vein anatomy before surgery. Of the 9 patients who underwent the ATP approach (Fig. 2) in our study, 2 suffered an iatrogenic injury to the segmental (L5/S1) veins (2/9, 22.2%) during surgery, but these were repaired promptly with sutures. There were no signs of vascular damage in the lower extremities.

In our experience, the most difficult aspect of the ATP approach is securing with vascular structures around the L5/S1 disc. With narrow blood veins or traffic tributaries, the treatment is electrocoagulation in case of injury and bleeding. However, with large veins, it is possible that the venous blood flow from the lower limbs or pelvic organs is affected after suturing. Therefore, detailed knowledge of the local anatomy is a prerequisite when using the ATP approach.

The common iliac vein on either side is usually located in front of the sacroiliac joint and formed by the confluence of the internal and external iliac veins. The distance between the common iliac vein confluence and the common iliac artery bifurcation was 2.98 ± 0.12 cm and 3.16 ± 0.10 cm on the left and right side, respectively (Fig. 3).[12] The outer diameter of the external iliac vein was 13.15 ± 0.23 mm and 13.72 ± 0.17 mm on the left and right side, respectively.[12] The outer diameter of the internal iliac vein was 11.68 ± 0.22 mm and 11.99 ± 0.23 mm on the left and right side, respectively.[12]

The veins of the pelvic organs initially form bundles and then several stems, accompanied by the respective artery, and merge into the internal iliac vein. Notably, the venous plexus draining into the gonadal veins have sex-specific differences, but this does not apply to the tributaries of the internal iliac vein.[13] This may be the anatomical explanation for the lack of significant consequences after ligation of the internal iliac vein.

Intervertebral cage displacement can lead to a decrease in intervertebral fusion rates, a loss of height of the intervertebral space and intervertebral foramen, and, more importantly, direct compression of the nerve root resulting in a recurrence of clinical symptoms.[14] Many authors have reported that the incidence of interbody cage retropulsion is higher at L5/S1 than that in other intervertebral spaces.[15–17] There were no cases of cage retropulsion among our 9 patients. We believe that the ATP approach protects the integrity of the posterior longitudinal ligament and posterior annulus of the vertebral body, which is the most important factor in avoiding cage retropulsion. Buttermann et al[18] reported that a “good” tension of the annulus could

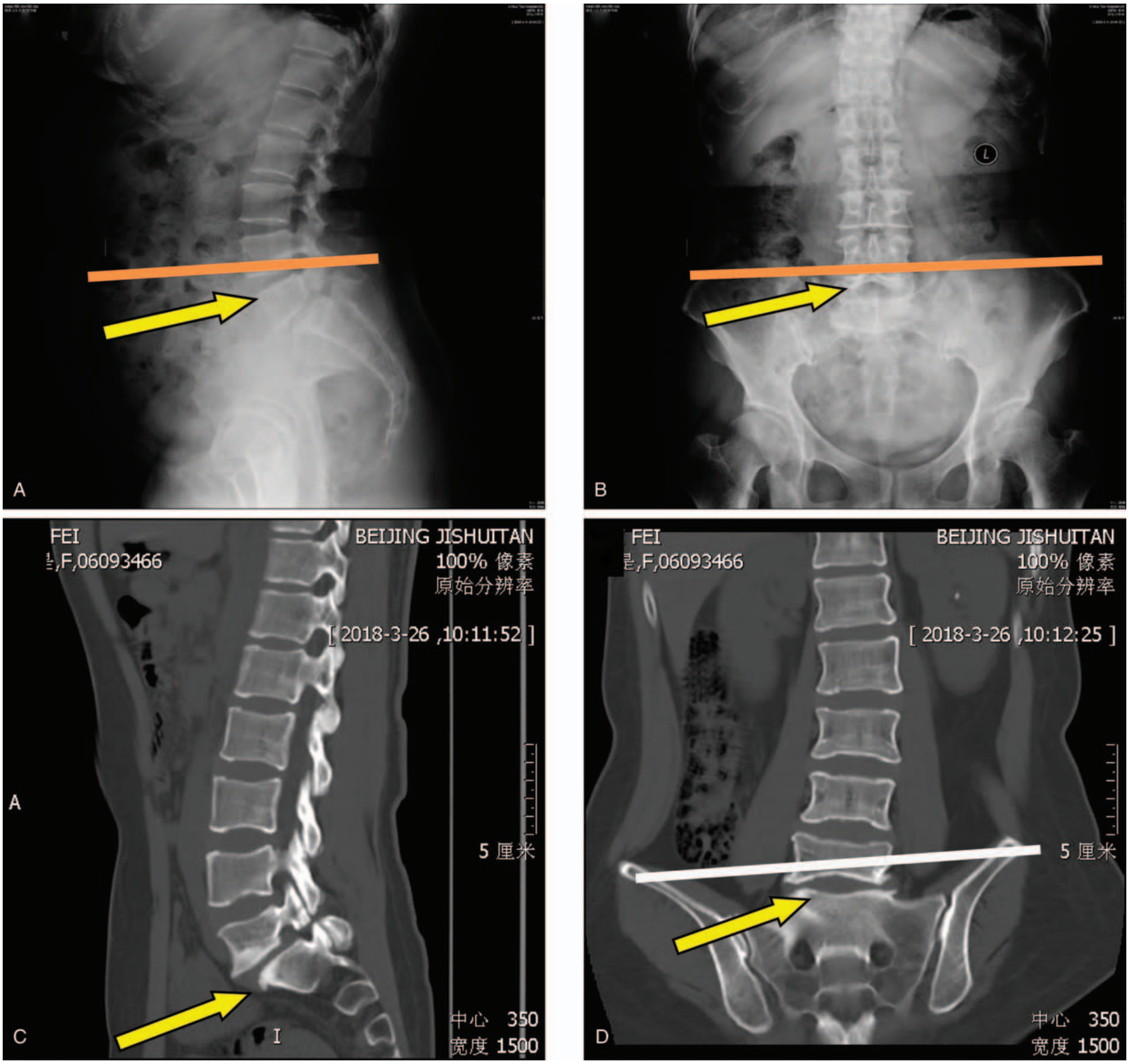

Figure 4. Preoperative lumbar spine X-ray and computed tomography. (A) Preoperative lumbar lateral X-ray shows the highest point of the iliac crest (orange line) is higher than the L4/5 level (yellow arrow). (B) Preoperative lumbar anteroposterior X-ray shows that connection of the highest points of the iliac crest on both sides (orange line) is higher than the L4/5 level (yellow arrow). (C) Preoperative lumbar sagittal CT: sacral tilt angle is large. Intervertebral space is narrow (yellow arrow). (D) Preoperative lumbar coronal CT: Connection of the highest points of the iliac crest on both sides (white line). L5/S1 intervertebral space (yellow arrow). CT = computed tomography.

reduce the incidence of cage retropulsion. The interbody cage used in the ATP approach has a larger cross-sectional area (length 50 mm, width 18 mm, cross-sectional area 900 mm^2) than a conventional TLIF interbody cage (length 26 mm, width 10 mm, cross-sectional area 260 mm^2), meaning that it results in more "efficient" bone fusion of the intervertebral space and lower rates of collapse of the interbody cage. Tohmeh et al[19] reported that a 50-mm cage was more likely to result in severe cage collapse >4 mm (P=.012) than a 60-mm cage.

There are 2 main features of the intervertebral space in degenerative lumbar spondylolisthesis at L5/S1 (Fig. 4). First, the sacral tilt angle is large, and the intervertebral height is low. Conventional TLIF and MI-TLIF do not provide direct visualization of the L5 inferior and S1 superior endplate, resulting in endplate damage. Xu et al[20] reported that because of the inability to treat the endplates under direct visualization, the rate of endplate damage was 48% when using the foramen path, whereas it was only 4% when using the lateral approach. Second, the height of the L5/S1 intervertebral space is significantly lower than that of other segments, and most patients included were middle-aged and elderly with moderate-to-severe osteoporosis. Cage placement is difficult in traditional TLIF and MI-TLIF. Due to the small cross-sectional area of the cage, the local pressure is high and may easily cause the cage to collapse into the vertebral body postoperatively. However, these 2 problems are avoided when using the ATP approach (Fig. 5).

Our study showed that the ATP approach led to less trauma and fewer complications with short-term curative effects. This approach can achieve effective indirect decompression, complete lumbar interbody fusion, and avoid disturbance of the spinal

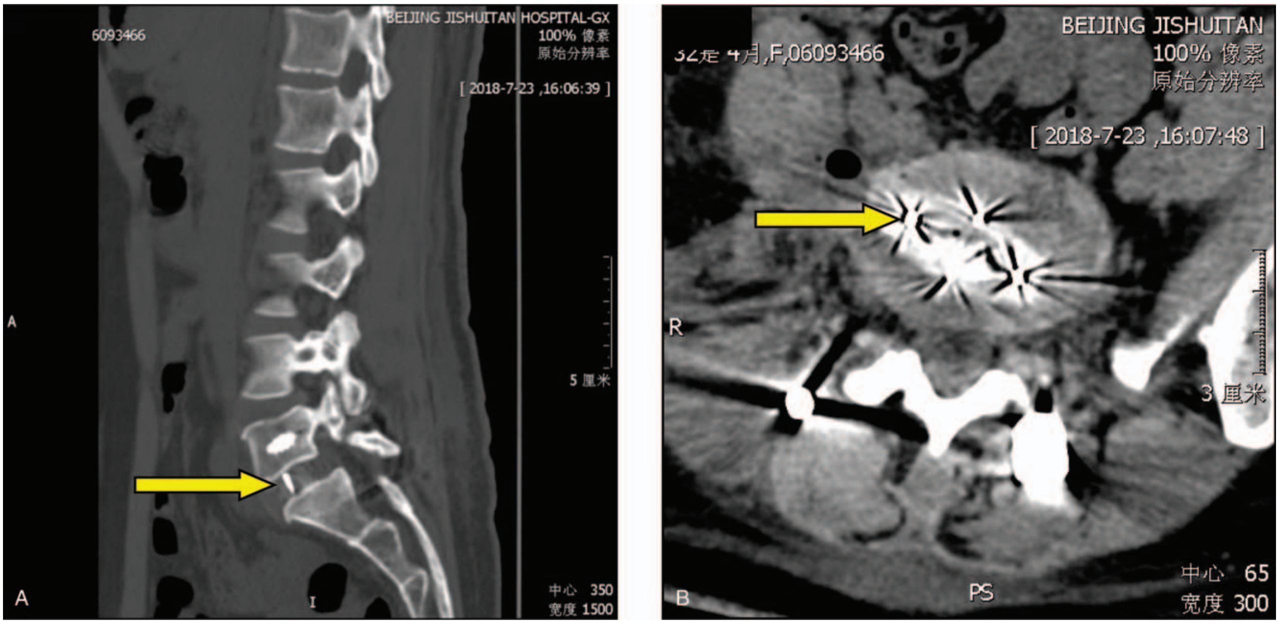

Figure 5. Postoperative lumbar computed tomography. (A) Postoperative lumbar sagittal CT: the interbody fusion cage marker. (B) Postoperative lumbar cross section CT: 4 markers of the interbody fusion cage. CT = computed tomography.

canal structures. It does not damage the structure of the paravertebral muscles, anterior and posterior longitudinal ligaments, and psoas muscle.

The limitations of this research were the small sample size, lack of a control group, and short follow-up time. It would be more convincing if more cases can be included by expanding the study time frame. Multicenter randomized controlled trials with large sample sizes are needed to further evaluate our findings and assess the long-term efficacy of the ATP approach.

We conclude that the ATP approach should be considered as a surgical option for treating L5/S1 spondylolisthesis. Compared with the results of other surgical methods reported in previous studies, it results in better recovery of the intervertebral height. We recommend that surgeons identify all relevant vessels and either secure or ligate them during surgery.

Our findings have immediate practical implications. First, because we analyzed the anatomy of the vessels around the L5/S1 segment to gain a deeper understanding of their significance in the ATP approach, surgeons can stop fearing vascular damage. Second, the ATP approach allows for the use of a wider cage compared to TLIF or MI-TLIF. Therefore, the collapse rate of the cage is lower. Third, the ATP approach can be performed intuitively and does require direct visualization of the endplate. Hence, the injury rate of the endplate is low.

Author contributions

Wei He analyzed the work, interpreted data, draft the work and revised it. Da He performed the operation and verified the methods. Wei Tian contributed to the conception or design of the work. All authors provided critical feedback and helped shape the research, analysis and manuscript. All the authors approved the final draft of the manuscript.

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