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Preoperative Design for the Posterolateral Approach in Full-Endoscopic Spine Surgery for the Treatment of L5/S1 Lumbar Disc Herniation

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Objective: Full-endoscopic spine surgery (FESS) is a relatively less invasive treatment for lumbar disc herniation (LDH). This study investigated the optimal operative route of the posterolateral approach (PLA) of FESS for the treatment of L5/S1 LDH.
Methods: Between June 2016 and November 2018, a total of 21 patients with leg pain due to L5/S1 LDH underwent PLA of FESS. According to the partial removal of the superior articular process (SAP) of the L5/S1 facet joint (FJ), we categorized these patients into 2 groups. LDH type, anatomical configurations (FJ, sacral ala [SA], and iliac crest [IC]), the presence or absence of spondylolysis, operation time, and operative outcome were compared between these 2 groups.
Results: Although the anatomical configuration of the FJ was the most important factor for the necessity of SAP removal, the configuration of the SA and IC did not restrict endoscope insertion and subsequent LDH removal. Even in intracanal LDH, the removal of SAP was not absolutely required depending on the FJ configuration. Furthermore, the presence of spondylolysis was a factor associated with the unnecessity of SAP removal.
Conclusion: Detailed radiological examination of the FJ configuration is an important preoperative investigation to determine the optimal operative route for PLA of FESS.

Keywords: Full-endoscopic spine surgery, Lumbar disc herniation, Posterolateral approach, Three-dimensional computed tomography, Minimally invasive

INTRODUCTION

In general, interlaminar approach (ILA) of full-endoscopic spine surgery (FESS) is the first choice of the intracanal lumbar disc herniation (LDH) at L5/S1 because of the wide interlaminar space. On the other hand, foraminal and extraforaminal LDH at L5/S1 can be treated by the posterolateral approach (PLA) of FESS.[1,2] However, the extent of the foraminoplasty (partial removal of the superior articular process [SAP], the inferior articular process, and the caudal pedicle) in this approach remains controversial. A high-speed drill or trephine reamer can be applied to the removal, but the significance of each procedure has not been clearly determined.[3,4] Furthermore, the preoperative design of the detailed operative procedure and simulation are currently only imagined in the operator's brain.[5,6]

To solve these problems, we calculated SAP cross-sectional area (mm^2),[7] entry angle, and entry distance for endoscope insertion, and determined the extent of the removal of SAP based on preoperative computed tomography (CT) and magnetic resonance (MR) images. Based on these calculations and determinations, we simulated the operative approach using omni-azimuth three-dimensional (3D) CT imaging of the corresponding facet joint (FJ) and neighboring structures. This preoperative consideration is not complicated and can provide information that can be shared between all operative staffs. The sharing of such information is especially important for the operative training and education of young spinal surgeons.

MATERIALS AND METHODS

1. Patient Selection

Between June 2016 and November 2018, 22 consecutive patients with L5/S1 LDH underwent PLA of FESS. A 7-mm diameter spinal full-endoscopic system (Richard Wolf GmbH, Knittlingen, Germany) was used in all cases. All patients had leg pain (L5 and/or S1 dermatome) that was resistant to medical treatment, epidural steroid injection, and/or nerve block. One case revealed Meyerding grade II spondylolisthesis and calcified LDH. As the operative approach of this case was quite different from that in the other cases, we excluded this case from this study. Similarly, we also excluded 4 cases of L5/S1 foraminal LDH treated by percutaneous endoscopic translaminar approach (PETA)[4] during this period. However, we did not exclude the recurrence cases (cases 3 and 9) in which posterior approaches (microendoscopic and open discectomy) had previously been performed.

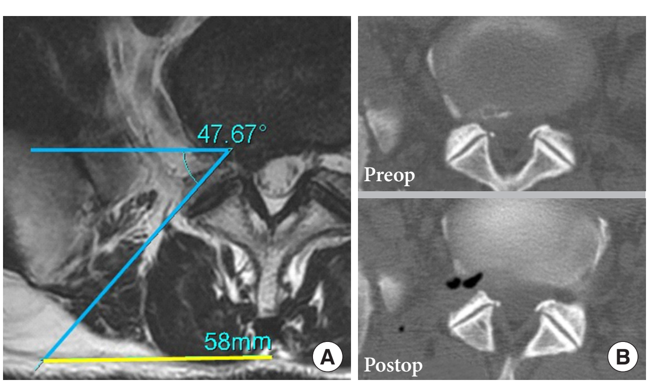

Fig. 1. (A) Preoperative measurement of the entry point. The entry angle (blue angle) and the distance of the skin entry point from the midline (yellow line) were calculated on axial magnetic resonance image at the L5/S1 disc level. (B) The exact area removed from the superior articular process was confirmed by comparison between the preoperative (preop) and postoperative (postop) computed tomography images.

2. Preoperative Measurement and Simulation

Preoperative CT and MR images were obtained to determine the endoscope entry angle. The entry angle was calculated on axial views (L5/S1 disc level) of the preoperative MR image (Fig. 1A). The angle was measured as the inclination of the line drawn between the lateral border of the herniated disc and the skin entry point against the horizontal axis. As we can use curved forceps, the exposure of lateral border of herniated disc is sufficient to remove the disc material. The skin entry point was located at the outermost position in which posterior iliac crest (IC) did not interfere. This line was drawn to avoid the sacral ala (SA) and posterior IC but not the SAP of the L5/S1 FJ. The lateral side of the SAP separated by this line indicated the area required for removal (Fig. 1A blue angle). The position of skin entry point was measured as the distance from the midline (Fig. 1A yellow line). The exact area removed from the SAP was confirmed by CT and was compared to the preoperative CT image (Fig. 1B).

To evaluate FJ hypertrophy, we measured the SAP area on axial T2-weighted MR imaging as described by An et al.[7] FJ hypertrophy was defined as cases with areas greater than 111 mm^2

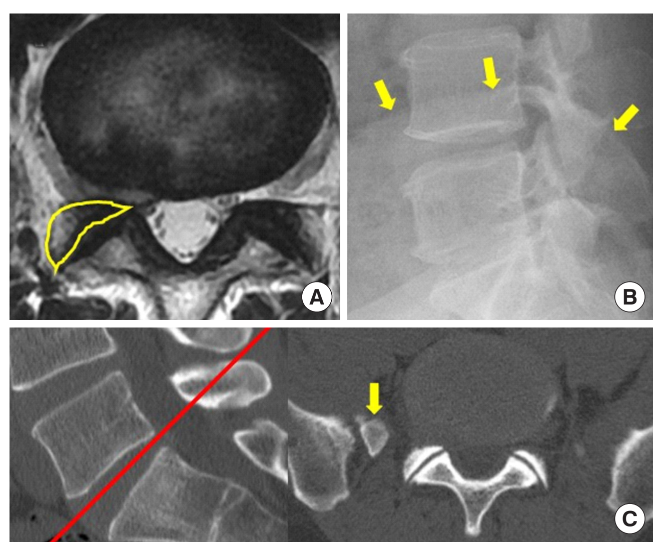

Fig. 2. (A) Preoperative measurement of anatomical configurations The superior articular process area on axial T2-weighted magnetic resonance image was measured as described by An et al.[7] (yellow polygon). (B) The high position of the iliac crest was defined when the iliac crest (arrows) was located at the L4/5 disc level on lateral plain X roentgen film. (C) Sacral ala hypertrophy was defined as observation of the sacral ala (yellow arrow on the right axial image) on axial computed tomography image at the L5/S1 disc level (the red line on the left sagittal image indicates the level of the right axial image).

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(Fig. 2A; case 6). Statistical analysis was performed using the Wilcoxon/Kruskal-Wallis equality of populations rank test for continuous variables. A p-value less than 0.01 was considered statistically significant. A high IC position was defined an IC located at the L4/5 disc level on lateral plain X roentgen film that was identical to Choi's classification type 6 (Fig. 2B; case 1).[8] SA hypertrophy was defined as SA observed at the L5/S1 disc level in axial CT imaging (Fig. 2C; case 6).[9]

To determine the 3D relationship between the SAP and surrounding bony structures, the acquired CT data were anonymized and collected in the DICOM (Digital Imaging and Communications in Medicine) format. The data were further analyzed using AZE VirtualPlace Fuji Raijin 370 imaging analysis software (AZE Inc., Tokyo, Japan). We first dorsally observed the 3D CT image and then tilted the image according to the angle determined by the axial MR images. The ipsilateral IC and SA covered the L5/S1 disc space in some cases. It is easy to resolve the overlapping by cranially tilting within 15° (Fig. 3A). This cranial tilting is within the allowable range during the operation because the skin entry point moves to permit the tilting of the endoscope. In the next step of the simulation, the SAP is erased in the 3D image to expose the entry point on the L5/S1 disc surface (Fig. 3B arrowheads). During this step, we can also confirm the removal area with a scale (Fig. 3C). From these erased images, we can image the operative view after removal of the corresponding SAP. This simulation can also be compared to the exact area removed from the SAP (Fig. 3D) and can be observed from multiple directions and edited as a video clip (Supplementary video clip 1).

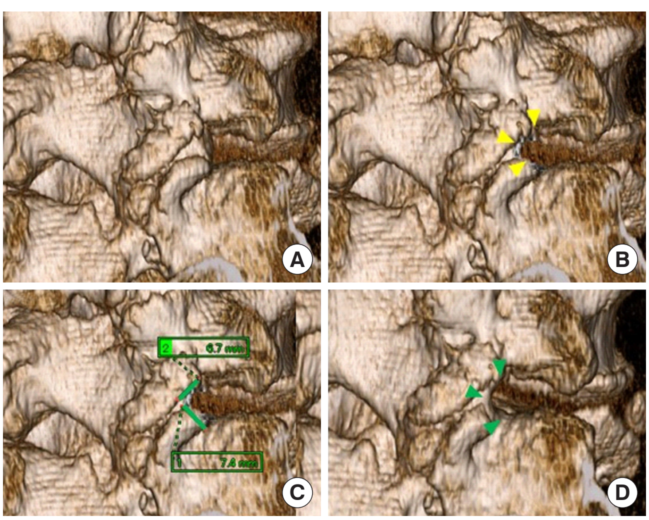

Fig. 3. Three-dimensional (3D) relationship between the superior articular process (SAP) and surrounding bony structures. The SAP and surrounding bony structures were observed in 3D computed tomography image according to the determined entry angle. (A) The overlapping of the ipsilateral iliac crest and sacral ala in the L5/S1 disc space disappeared with cranial tilting of the image. (B) In the next step of the simulation, the SAP is erased on the 3D image to expose the entry point on the L5/S1 disc surface (yellow arrowheads). (C) During this step we can also confirm the area for the removal using a scale. The exact area removed from the SAP (D, green arrow heads) can be compared to the simulated area (B, yellow arrowheads).

3. Surgical Procedure

The basic operative procedure was described previously.[10] Eight-millimeter skin and fascial incisions were made approximately 75 mm lateral from the midline (Tables 1, 2) towards the corresponding SAP under fluoroscopic guidance (lateral view). In addition to the basic FESS procedure, the SAP removal method is described below.

First, the endoscope sheath was placed on the lateral surface of the L5/S1 FJ and tilted toward the SAP to center the area requiring bone removal within the endoscopic visual field. The SAP was removed using a high-speed drill with a diameter of 3.5 mm (NSK-Nakanishi Japan, Tokyo, Japan). Although there are no important structures underneath the caudal part of the SAP, it is possible to perforate toward the L5/S1 vertebral disc. To avoid bleeding from epidural fat tissue, we recommend careful removal of the ventral cortex of the SAP. A small Kerrison rongeur (VITAL Co. Ltd., Tokyo, Japan) is a useful tool for the removal of the residual thin layer of the SAP. After exposing the surface of the L5/S1 vertebral disc, the protruding vertebral disc was separated from the surrounding normal vertebral disc with a small (3 mm) dissector. Finally, the protruding nucleus pulposus was removed with several kinds of forceps (VITAL Co. Ltd., Tokyo, Japan) (Supplementary video clip 2).

This study was approved by ethics committee of the Iwai Medical Foundation, and informed consent was obtained from the patients for publication of this study and any accompanying images.

RESULTS

Twenty-one patients were registered for this study; 11 underwent the PLA of FESS without SAP removal (SAP removal (-): cases 1–11) and 10 underwent the PLA of FESS with SAP removal (SAP removal (+): cases 12–21). The LDH type, recurrence, anatomical configurations (FJ hypertrophy, SA hypertro-

Table 1. Summary of the detailed features of the 21 cases of L5/S1 lumbar disc herniation (LDH)

Case No.	Age (yr)	Sex	Type of LDH	Location	Recurrence	Hypertrophy			High iliac crest	Spondylolysis	Entry		Operation time (min)	Follow-up period (mo)	NRS		POD
						SAP cross-sectional area (mm^2)	SAP	Sacral ala			Angle (°)	Distance from midline (cm)			Preoperation	Postoperation	
SAP removal (-)																	
1	42	M	Extraforaminal	R	(-)	80	(-)	(+)	(+)	(-)	53.4	86	40	31	3	0	(-)
2	44	F	Foraminal	R	(-)	60	(-)	(-)	(+)	(+)	50.7	92	36	26	8	3	(-)
3	33	F	Intracanal	L	(+)	103	(-)	(+)	(-)	(-)	43.5	78	50	25	10	3	(-)
4	62	F	Intracanal-foraminal	R	(-)	83	(-)	(+)	(+)	(+)	51.7	90	62	24	4	0	(-)
5	51	M	Foraminal	L	(-)	99	(-)	(+)	(+)	(+)	51.9	78	26	19	7	3	(+)
6	43	M	Intracanal-foraminal	R	(-)	87	(-)	(+)	(+)	(-)	46.5	65	54	13	7	2	(+)
7	62	M	Extraforaminal	R	(-)	94	(-)	(+)	(-)	(-)	55.9	74	34	12	8	7	(+)
8	82	F	Intracanal-foraminal-extraforaminal	L	(-)	81	(-)	(-)	(-)	(-)	55.9	74	42	11	8	0	(-)
9	53	M	Intracanal	L	(+)	96	(-)	(-)	(+)	(-)	40.5	85	31	4	9	1	(-)
10	45	F	Intracanal	R	(-)	88	(-)	(+)	(-)	(-)	40.5	75	26	3	10	2	(-)
11	49	M	Foraminal	R	(-)	88	(-)	(-)	(+)	(+)	57.1	81	33	17	4	1	(-)
SAP removal (+)																	
12	68	M	Extraforaminal	R	(-)	116	(+)	(+)	(+)	(-)	64.2	59	64	25	9	1	(-)
13	70	M	Foraminal-extraforaminal	R	(-)	99	(-)	(-)	(-)	(-)	44.3	87	60	24	7	0	(-)
14	59	M	Foraminal-extraforaminal	R	(-)	225	(+)	(+)	(-)	(-)	43.4	91	88	13	8	0	(-)
15	56	M	Extraforaminal	R	(-)	107	(-)	(+)	(+)	(-)	51.5	65	40	4	5	1	(-)
16	40	M	Intracanal-foraminal	R	(-)	134	(+)	(+)	(-)	(-)	50.5	71	43	4	5	0	(-)
17	63	F	Intracanal-foraminal	L	(-)	121	(+)	(-)	(-)	(-)	49.4	90	39	4	8	3	(-)
18	42	M	Intracanal-foraminal	R	(-)	100	(-)	(+)	(+)	(-)	47.7	58	48	3	8	0	(-)
19	45	M	Intracanal-foraminal	R	(-)	120	(+)	(+)	(+)	(-)	49.5	60	42	2	8	1	(-)
20	71	M	Foraminal-extraforaminal	L	(-)	237	(+)	(+)	(+)	(-)	57.1	72	60	2	4	1	(-)
21	57	M	Extraforaminal	L	(-)	128	(+)	(+)	(+)	(-)	59.4	62	53	2	8	2	(-)

SAP, superior article process; NRS, numerical rating scale; POD, postoperative dysesthesia; R, right; L, left; (-), absence; (+), presence.

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Table 2. Comparative radiological findings and surgical outcome of 11 cases without SAP removal and 10 cases with SAP removal

Variable	Without SAP removal (n = 11)	With SAP removal (n = 10)	p-value
Age (yr)	51.5	57.1	0.26
Sex			
Male	6	9	
Female	5	1	
Type of LDH			
Intracanal	3	0	
Foraminal	3	0	
Extraforaminal	2	3	
Combined*	3	7	
Location			
Right	7	7	
Left	4	3	
Recurrence			
(+)	2	0	
(-)	9	10	
SAP hypertrophy			
SAP cross-sectional area (mm^2)	87.9	138.7	0.0002
Sacral ala hypertrophy			
(+)	7	8	
(-)	4	2	
High iliac			
(+)	7	6	
(-)	4	4	
Spondylolysis			
(+)	4	0	
(-)	7	10	
Entry			
Angle (°)	49.8	51.7	0.81
Distance from midline (cm)	79.8	71.5	0.09
Operation time (min)	39.5	53.7	0.024
Follow-up period (mo)	16.8	8.3	0.037
NRS score			
Preoperation	7.1	7	0.88
Postoperation	2	0.9	0.17
POD	3	0	

SAP, superior article process; NRS, numerical rating scale; POD, postoperative dysesthesia; R, right; L, left; (-), absence; (+), presence.
*Lumbar disc herniation (LDH) type which arose beyond the single region.

phy, and IC position), presence or absence of spondylolysis, operation time, operative outcome based on numerical rating scale scores, and complications for each case are shown in Table 1.

The combined type of LDH was frequently observed in the SAP removal (+) group, but all types of LDH (intracanal, foraminal, and extraforaminal) were distributed in both groups. Similarly, hypertrophy of the SA and high IC were also observed in both groups. SAP removal was not eliminated by these factors. Four cases with spondylolysis were treated without SAP removal and the presence of spondylolysis may be one factor associated with the unnecessity of SAP removal. The 3D CT findings of the cases with spondylolysis support this idea (Fig. 4). Postoperative dysesthesia (POD)[10] was the only observed postoperative complication in this study and completely disappeared within 4 months after the operation. All three cases of POD were observed in SAP removal (-) group (Tables 1 and 2).

Comparisons between the 2 groups revealed that the average SAP cross-sectional area (mm^2) in the SAP removal (-) group was significantly smaller than that in the SAP removal (+) group (87.9 vs. 138.7 mm^2, p = 0.0002). The SAP hypertrophy was one

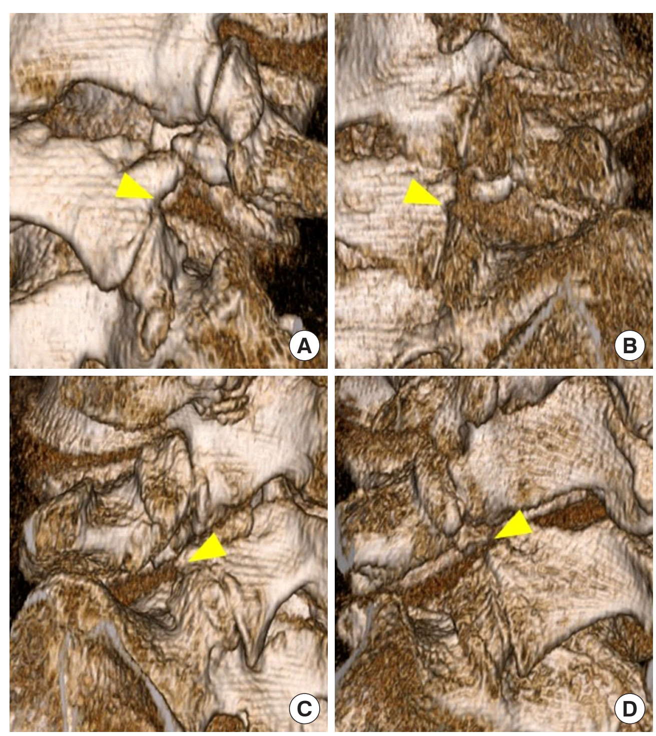

Fig. 4. Three-dimensional computed tomography images of cases combined with spondylolysis. Four cases with spondylolysis could be treated without superior articular process (SAP) removal (A, case 2; B, case 4; C, case 5; D, case 11). The arrowheads indicate the narrowed cranial portion of the SAP and exposed entry point on the L5/S1 disc surface.

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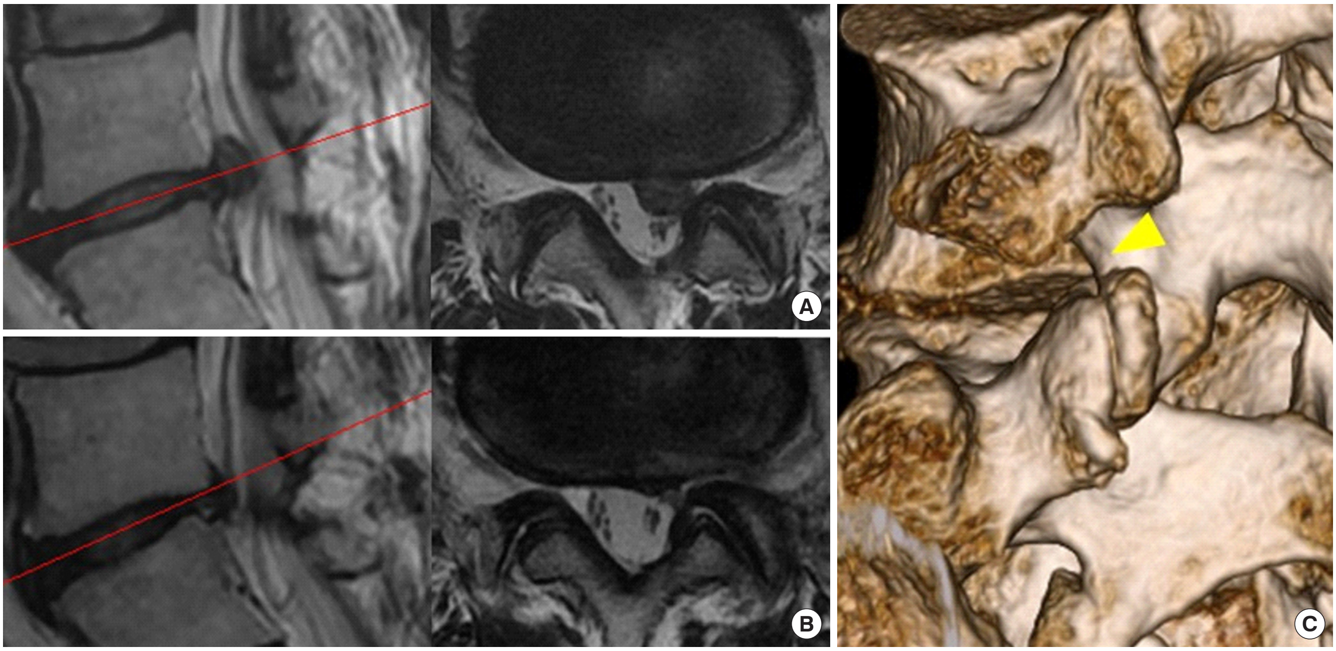

Fig. 5. Representative case without superior articular process (SAP) removal. Preoperative (A) and postoperative (B) magnetic resonance (MR) images of case 9. Sagittal (left) and axial (right) T2-weighted MR images are shown (the red line on the left sagittal image indicates the level of the right axial image). (C) Three-dimensional computed tomography finding of case 9. This case has no SAP hypertrophy; consequently, the entry point on the L5/S1 disc surface is exposed (arrowhead).

of the distinct factors associated with the necessity of SAP removal. The operation time in SAP removal (-) group was shorter than that in the SAP removal (+) group, but there was no significant difference (39.5 vs. 53.7 min, $p = 0.024$). Furthermore, there was no significant difference between the 2 groups in age, calculated entry point, follow-up periods and operative outcome.

A representative case from the SAP removal (-) group (case 9) is shown in Fig. 5. This 53-year-old man presented with left leg pain (S1 dermatome) that had started 5 months prior to visiting our outpatient clinic. This patient had received an open discectomy at the same level 10 years before. Neurological examination revealed slight (manual muscle test [MMT] 4/5) muscle weakness of left gastrocnemius. Lumbar T2-weighted MR imaging revealed a left intracanal L5/S1 LDH (Fig. 5A). Immediately after the operation (Supplementary video clip 3), the patient's leg pain disappeared. Postoperative MR imaging revealed the disappearance of the LDH (Fig. 5B). Preoperative 3D CT scans showed enough space for endoscope insertion at the ventrolateral side of the corresponding SAP (Fig. 5C arrowhead).

Another representative case in the SAP removal (+) group (case 16) is shown in Fig. 6. This 40-year-old man presented with right leg pain (L5 and S1 dermatome) that worsened 1 month prior to his visiting our outpatient clinic. Neurological examination revealed slight (MMT 4/5) muscle weakness of the extensor hallucis longus. Lumbar T2-weighted MR imaging revealed a right foraminal and intracanal L5/S1 LDH which was caudally sequestrated (Fig. 6A). Immediately after the operation (Supplementary video clip 2), the patient's leg pain disappeared. Postoperative MR imaging revealed complete disappearance of the LDH (Fig. 6B). Comparison of the preoperative and postoperative 3D CT images indicated appropriate bone removal of the corresponding SAP which exposed the entry point on the L5/S1 disc surface (Fig. 6D).

DISCUSSION

We previously reported the extent of minimal laminectomy of the ILA of FESS for the treatment of intracanal L5/S1 LDH.[11] We also reported the significance of PETA for foraminal stenosis of L5/S1.[4] Not only foraminal stenosis but also foraminal L5/S1 LDH can be treated by PETA.[12] However, the treatment of foraminal L5/S1 LDH extending to extraforaminal region is somewhat difficult by ILA of FESS and PETA because of the necessity for wider bone removal. In contrast, PLA of FESS with foraminoplasty seems to be an appropriate strategy for such cases.[8,13-15] To clarify the requirement for foraminoplasty, we di-

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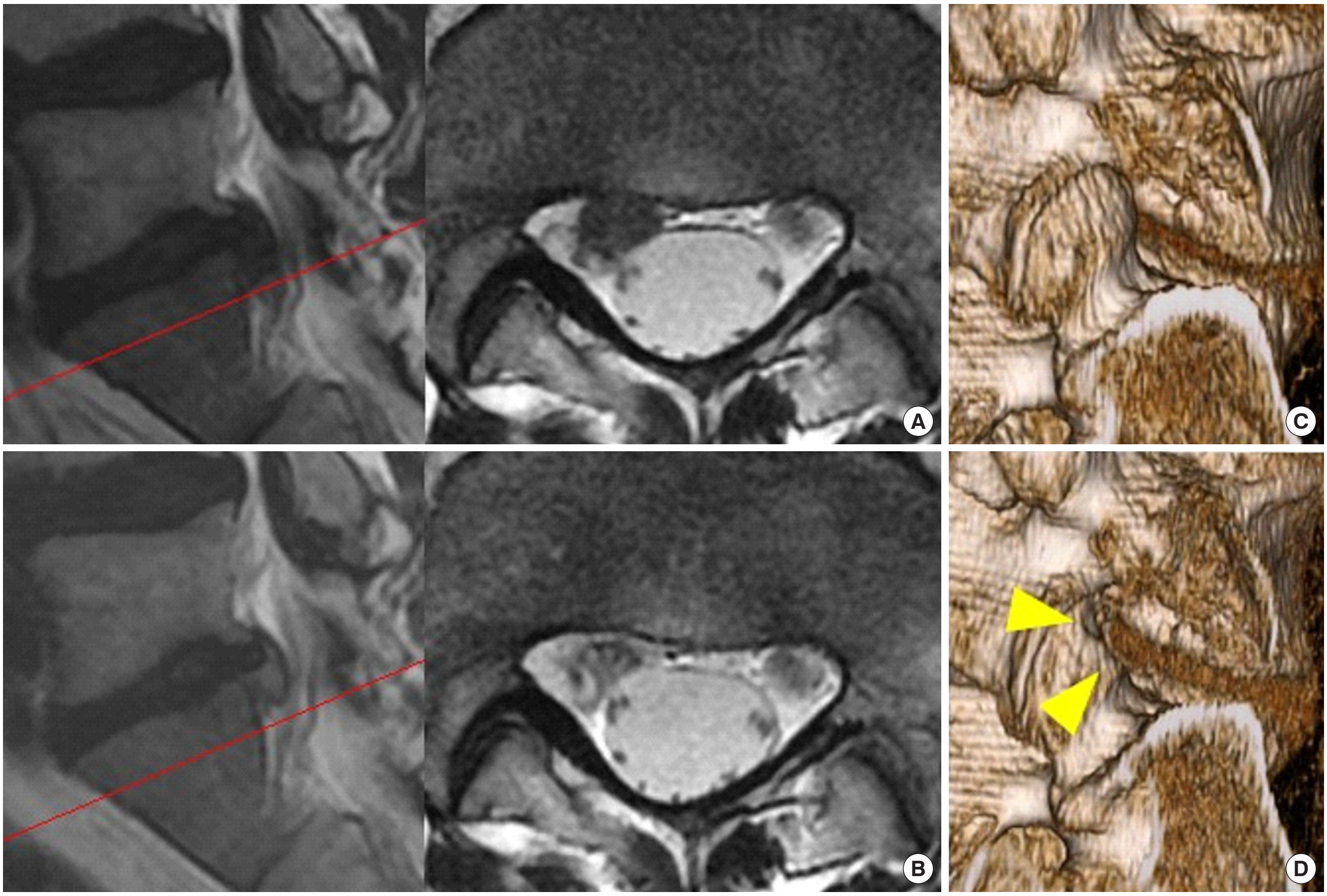

Fig. 6. Representative case with superior articular process (SAP) removal. Preoperative (A) and postoperative (B) magnetic resonance (MR) images of case 16. Sagittal (left) and axial (right) T2-weighted MR images are shown (the red line on the left sagittal image indicates the level of the right axial image). Preoperative (C) and postoperative (D) 3-dimensional computed tomography (3D CT) findings of case 16. (C) Preoperative 3D CT revealed SAP hypertrophy. (D) After removal of the SAP tip, the entry point on the L5/S1 disc surface is exposed (arrowheads).

vided L5/S1 LDH treated by PLA of FESS into 2 groups based on SAP removal and compared the anatomical configurations.

The results of the present study showed that the SA and IC do not disturb endoscopic insertion. The SAP only eliminates endoscope insertion. Several investigators reported that a high IC disturbed the transforaminal approach (TFA) in L5/S1 LDH.[8,16,17] The entry angle of TFA is generally 25°–35°, and the skin entry point is 10–13 cm from the midline. In contrast, the entry angle of PLA (also known as the extraforaminal approach) is around 50° and the skin entry point is 6–9 cm from the midline.[18] These differences may explain the discordance between our results and those of previous reports. Compared to the report of Choi and Park,[8] SAP removal was performed more frequently our study (19 of 100 [19%] vs. 11 of 21 [52%]). SAP removal remains a minimally invasive optional procedure for PLA of FESS because of the minimum elimination of SAP removal (cranial tip of the SAP).

We observed POD in three cases in SAP removal (-) group (Tables 1 and 2). These cases did not reveal SAP hypertrophy, but revealed dorsal displacement of the affected L5 nerve root due to relatively large foraminal LDH. Further examinations for the LDH type and size are required to prevent POD for PLA of FESS.

CONCLUSION

The preliminary results obtained from a small sample show that PLA of FESS is feasible for the treatment of foraminal L5/S1 LDH extending to extraforaminal region. Although minimal SAP removal can allow enucleation of intracanal L5/S1 LDH, PLA is still technically more difficult than ILA as the deep and narrow surgical field.

CONFLICT OF INTEREST

The authors have nothing to disclose.

ACKNOWLEDGMENTS

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SUPPLEMENTARY MATERIALS

Supplementary video clips 1, 2, and 3 can be found via
https: //doi.org/10.14245/ns.1836316.158.v1,
https://doi.org/10.14245/ ns.1836316.158.v2,
https://doi.org/10.14245/ns.1836316.158.v3.

Supplementary video clip 1. Simulation of superior articular process removal: The erased 3D CT image can be observed from multiple directions.

Supplementary video clip 2. Intraoperative video in a case with superior articular process removal (case 16).

Supplementary video clip 3. Intraoperative video in a case without superior articular process removal (case 9).

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