Minimally invasive anteroposterior combined surgery using lateral lumbar interbody fusion without corpectomy for treatment of lumbar spinal canal stenosis associated with osteoporotic vertebral collapse

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OBJECTIVE Various reconstructive surgical procedures have been described for lumbar spinal canal stenosis (LSCS) with osteoporotic vertebral collapse (OVC); however, the optimal surgery remains controversial. In this study, the authors aimed to report the clinical and radiographic outcomes of their novel, less invasive, short-segment anteroposterior combined surgery (APCS) that utilized oblique lateral interbody fusion (OLIF) and posterior fusion without corpectomy to achieve decompression and reconstruction of anterior support in patients with LSCS-OVC.

METHODS In this retrospective study, 20 patients with LSCS-OVC (mean age 79.6 years) underwent APCS and received follow-up for a mean of 38.6 months. All patients were unable to walk without support owing to severe low-back and leg pain. Cleft formations in the fractured vertebrae were identified on CT. APCS was performed on the basis of a novel classification of OVC into three types. In type A fractures with a collapsed rostral endplate, combined monosegment OLIF and posterior spinal fusion (PSF) were performed between the collapsed and rostral adjacent vertebrae. In type B fractures with a collapsed caudal endplate, combined monosegment OLIF and PSF were performed between the collapsed and caudal adjacent vertebrae. In type C fractures with severe collapse of both the rostral and caudal endplates, bisegment OLIF and PSF were performed between the rostral and caudal adjacent vertebrae, and pedicle screws were also inserted into the collapsed vertebra. Preoperative and postoperative clinical and radiographical status were reviewed.

RESULTS The mean number of fusion segments was 1.6. Walking ability improved in all patients, and the mean Japanese Orthopaedic Association score for recovery rate was 65.7%. At 1 year postoperatively, the mean preoperative Oswestry Disability Index of 65.6% had significantly improved to 21.1%. The mean local lordotic angle, which was −5.9° preoperatively, was corrected to 10.5° with surgery and was maintained at 7.7° at the final follow-up. The mean corrective angle was 16.4°, and the mean correction loss was 2.8°.

CONCLUSIONS The authors have proposed using minimally invasive, short-segment APCS with OLIF, tailored to the morphology of the collapsed vertebra, to treat LSCS-OVC. APCS achieves neural decompression, reconstruction of anterior support, and correction of local alignment.

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KEYWORDS osteoporosis; osteoporotic vertebral fracture; lumbar canal stenosis; minimally invasive surgery; lateral lumbar interbody fusion; anterior posterior combined surgery

The incidence of osteoporotic vertebral collapse (OVC) has been increasing with the aging population, with an estimated 1.4 million new OVC cases in the year 2000.1 Most patients with OVC can be treated conservatively, and clinical outcome has improved with the introduction of effective osteoanabolic agents such as teriparatide.2,3 In some cases, however, the posteriorly displaced fractured vertebra can encroach upon the lumbar
canal and compress neural elements. When lumbar spinal canal stenosis (LSCS) associated with OVC leads to severe low-back pain and/or neurological complications, surgical treatment is highly recommended.\(^4\) Posterior decompression surgery alone cannot sufficiently relieve symptoms in these patients because neurological symptoms are brought about by the retropulsed bony fragments and vertebral instability.\(^5\) Therefore, restoration of spinal stability is essential for surgical management of these patients.\(^6\)

Various reconstructive surgical procedures have been described for LSCS-OVC, each with its advantages and disadvantages, but the optimal procedure remains controversial.\(^2\)-\(^15\) Posterior surgery is reportedly the current mainstream method and performed in 60.6% of LSCS-OVC cases,\(^15\) and Hosogane et al.\(^16\) reported that 44.5% of posterior surgical procedures for LSCS-OVC were combined with vertebroplasty (VP). Anteroposterior combined surgery (APCS) can be used to reconstruct a stable anterior support structure, correct alignment with posterior instrumentation, and reduce the number of levels that require fusion.\(^7\) However, because APCS has longer operative time and increased intraoperative blood loss than other procedures, it is not commonly performed. In a previous systematic review, Sheng and Ren\(^15\) reported that APCS was performed in only 2.8% of LSCS-OVC cases. The introduction of minimally invasive lateral interbody fusion techniques, such as oblique lateral interbody fusion (OLIF) and extreme lateral interbody fusion, has made it possible to reduce the burden and morbidity associated with anterior surgery.\(^7\)-\(^9\) By fully utilizing the merits afforded by lateral interbody fusion techniques, we have applied OLIF\(^19\) and posterior instrumentation to treat LSCS-OVC since 2014. The purpose of our study was to introduce the technique, retrospectively evaluate clinical outcomes, and clarify any issues that should be resolved in the future.

**Methods**

**Patients**

Between April 2014 and May 2019, 24 consecutive patients underwent surgery for LSCS-OVC at our institution. We excluded 4 patients (3 did not receive follow-up at our institution within 1 year after surgery, and 1 died of unrelated disease) and retrospectively reviewed the data of 20 patients (16 females and 4 males) who underwent minimally invasive APCS and received follow-up for more than 1 year. All patients had osteoporosis, were unable to walk without support owing to severe low-back and leg pain, and chose surgical treatment because conservative treatment provided no relief. This study received ethical approval from the Saiseikai Yokohamashi Tobu Hospital Institutional Research Board. We explained the purpose of the study, and written consent was obtained from all patients.

**Clinical Assessment**

The location and number of segments fused, operative time, intraoperative blood loss (total and per level), and perioperative complications were evaluated. The neurological status of each patient was assessed preoperatively and at 1 year postoperatively with an abridged 15-point Japanese Orthopaedic Association (JOA) score that included scores for subjective symptoms (9 points), clinical signs (6 points), and urinary bladder function (0 to −6 points).\(^10\) Walking ability was classified with an original scale: stage 1, able to walk without any support; stage 2, able to walk with a cane; stage 3, able to walk with two canes or a walker; and stage 4, difficult to stand without support. Low-back pain was evaluated with the Oswestry Disability Index (ODI) preoperatively, 1 year postoperatively, and at the final follow-up. To compare the surgical outcomes with those of other studies, we conducted a PubMed search with the terms (“osteoporotic vertebral collapse” OR “vertebral fracture”) AND (“anterior posterior combined surgery” OR “anteroposterior surgery”), and studies published in English before June 2020 were considered.

**Radiographic Assessment**

Cleft formation was identified on CT images of the affected vertebrae in all patients. The local lordotic angle (LLA) was measured on plain lateral-view radiographs between the cranial endplate of the upper vertebra and the caudal endplate of the lower vertebra preoperatively, postoperatively, and at the final follow-up, as indicated in Figs. 1A, 2A, and 3A. The correction angle (postoperative LLA − preoperative LLA), correction loss (postoperative LLA − LLA at final follow-up), and correction loss rate (correction loss/correction angle \(\times 100\%\) were calculated. To evaluate global sagittal alignment, lumbar lordosis (LL), pelvic tilt (PT), and sagittal vertical axis (SVA) were measured on standing whole-spine radiographs preoperatively, postoperatively, and at the final follow-up in the 13 patients who were able to stand preoperatively.

**Surgical Procedure**

Surgery was designed to be as short as possible, with anterior and posterior fusion procedures for only the affected segments. We classified the OVC morphology into three types according to the damage to the rostral and/or caudal endplates and determined the fusion segment as follows. In type A fractures with a collapsed rostral endplate and intact caudal endplate, combined monosegment OLIF and posterior spinal fusion (PSF) were performed between the affected and rostral adjacent vertebrae, with pedicle screws caudally inserted into the affected vertebra (Fig. 1). In type B fractures with a collapsed caudal endplate, combined monosegment OLIF and PSF were performed between the affected and caudal adjacent vertebrae, with pedicle screws inserted along the superior endplate of the affected vertebra (Fig. 2). In type C fractures with both rostral and caudal endplates that were severely collapsed or broken, bisegment OLIF and PSF were performed between the cranial and caudal adjacent vertebrae, with pedicle screws inserted into the affected vertebra as well (Fig. 3).

OLIF was performed with the patient in the lateral decubitus position under fluoroscopic control, as previously described.\(^19\) Removal of the intervertebral discs and cartilaginous endplates was performed carefully so as not to damage the bony endplates, which were fragile due to os-
teoporosis. The size of the interbody cage was determined intraoperatively by increasing the size of the trial cage until a snug fit was confirmed, not by measurement of the height of the intervertebral space with preoperative CT. Accurate sizing of the cage based on preoperative imaging is difficult because the central region of the vertebral body is collapsed while the height of the lateral cortices is maintained in most cases (Figs. 1B and 3C). In all patients, OLIF was performed without any direct manipulation of the affected vertebra with procedures such as VP, vertebral osteotomy, or corpectomy. The OLIF cage was filled with autologous cancellous bone harvested from the iliac crest. After the lateral procedure, the patient was positioned prone and PSF surgery was performed. The kyphotic deformity was mainly corrected with postural reduction on the operating table. Pedicle screws that were as long as possible (range 40–55 mm) were inserted into the vertebrae, including the collapsed vertebra. Posterior neural decompression of the spinal canal and/or foraminal stenosis was performed, as preoperatively deemed necessary. After instrumentation was completed, the laminae and facet joints were decorticated and grafted with local autologous bone. Patients were allowed to sit up in bed and ambulate with the help of a thoracolumbar orthosis from 1 day postoperatively.

Statistical Analysis
All values are expressed as the mean ± SD. The preoperative and postoperative JOA scores, ODI scores, LLA, and spinopelvic parameters were compared with the paired t-test. Independent variables were compared among fracture types with the unpaired t-test or Mann-Whitney U-test. All statistical analyses were performed with IBM SPSS software version 22.0 (IBM Corp.), and a p value < 0.05 was considered statistically significant.

Results
The mean age at surgery was 79.6 ± 5.5 years. Dual-energy x-ray absorptiometry confirmed osteoporosis in all patients: the mean bone mineral density of the femoral neck was 0.609 ± 0.1 g/cm², and the mean T-score of the femoral neck was −2.4 ± 0.8. Nine patients demonstrated severe osteoporosis with a T-score < −2.5, and 8 patients registered a T-score within the range of −1.5 to −2.5. At the time of injury, osteoporosis was being treated with bisphosphonates in 4 patients, teriparatide in 2 patients, and denosumab in 1 patient. After diagnosis of OVC in the outpatient clinic, a more assertive osteoporosis treatment regimen with teriparatide was recommended to all patients not prescribed teriparatide treatment. Two of 4 patients taking bisphosphonates decided to change to teriparatide, and 10 patients not receiving medication chose to begin treatment with teriparatide. The patient prescribed denosumab elected to continue treatment, and 3 patients opted not to begin osteoporosis treatment. Therefore, at the time of surgery, osteoporosis treatment was being con-
ducted with teriparatide in 14 patients, denosumab in 1 patient, and bisphosphonates in 2 patients, whereas 3 patients continued to not receive medication.

The mean duration from onset of symptoms to surgery was 4.5 ± 2.8 months. The mean follow-up period was 38.6 ± 18.1 months, and 15 patients received follow-up for more than 2 years. The distribution of the collapsed vertebrae and the breakdown of the fracture types are outlined in Table 1. Three patients had involvement of multiple vertebrae. Minimally invasive anteroposterior surgical procedures were performed on 1 segment in 10 patients, 2 segments in 9 patients, and 3 segments in 1 patient. The mean number of fusion segments was 1.6 ± 0.6, the mean operative time (including time required to change the operative position) was 218 ± 41 minutes (154 ± 45 min/level), and the mean intraoperative blood loss was 171.5 ± 87.7 ml (119.9 ± 69.6 ml/level).

All patients progressed favorably after surgery, and walking ability improved by at least one stage (Fig. 4). The mean preoperative JOA score of 6.6 ± 1.4 improved to 12.1 ± 1.4 postoperatively (p < 0.0001), indicating a mean recovery rate of 65.7%. The mean ODI, which was 16.4 ± 7.4%, improved to 21.7 ± 11.7% (p = 0.005) and 86.9 ± 69.6 mm (p = 0.0004), respectively. Postoperatively, LL and SVA significantly improved to 21.7° ± 11.7° (p = 0.005) and 86.9 ± 69.6 mm (p = 0.0004), respectively, but PT was unchanged (27.4° ± 8.0°, p = 0.649). At final follow-up, there were no significant differences in the LL (15.1° ± 18.9°, p = 0.795) or PT (32.1° ± 12.1°, p = 0.064) compared with the preoperative parameters. Although postoperative SVA deteriorated to 101.4 ± 56.4 mm, it remained significantly different from preoperative SVA (p = 0.043) (Table 3). There were no significant differences in clinical or radiographic outcomes between the different OVC types.

There were no complications associated with OLIF and PSF, such as massive bleeding, neural deficit, bowel injury, ureter injury, or surgical site infection. One patient experienced delirium but quickly recovered. All patients initially had pain related to iliac bone harvesting, but it was not observed at discharge. There was no significant implant...
dislodgement over the course of the follow-up period. Subsequent OVC occurred postoperatively at other levels in 4 patients. One patient underwent balloon kyphoplasty, and 3 patients were treated conservatively. No revision surgery was required for the segments fixed with APCS in this study.

Discussion

In this study, we report the clinical and radiographic

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<td>A</td>
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<tr>
<td>L3</td>
<td>B</td>
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<tr>
<td>L4</td>
<td>C</td>
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FIG. 3. Type C fracture of L3 and surgical procedure for a 74-year-old female patient. A: Type C fracture in which both the rostral and caudal endplates are fractured (left). Two-level OLVF and PSF were performed between the cranial and caudal adjacent vertebrae, and pedicle screws were also inserted into the collapsed vertebra (right). The upper and lower dotted lines indicate the LLA. B: Preoperative lateral radiograph showing severe collapse of L3. C–F: Preoperative CT myelograms showing severe collapse of L3 with intravertebral cleft formation and canal stenosis at L2–3 (E) and L3–4 (F). G and H: Radiographs showing the results of two-level APS without corpectomy. I and J: Dynamic radiographs obtained 3 years after surgery showing rigid stabilization of L2–4 after intervertebral fusion.

* Type A fractures had a collapsed rostral endplate and intact caudal endplate. Type B fractures had a collapsed caudal endplate. Type C fractures had both rostral and caudal endplates that were severely collapsed or broken.

FIG. 4. Preoperative and postoperative walking ability according to our own classification scale. Stage 1 indicates ability to walk without any support; stage 2, ability to walk with a cane; stage 3, ability to walk with two canes or a walker; and stage 4, difficult to stand without support.

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outcomes of using our proposed less invasive, short-segment APCS that utilized OLIF and PSF without corpectomy to treat 20 patients with LSCS-OVC. To the best of our knowledge, this is the first report on the use of this minimally invasive method and surgical strategy based on collapsed vertebra morphology to treat patients with LSCS-OVC. Numerous reported OVC classifications are useful for the description of fracture morphology, prediction of prognosis, and determination of surgical indication. However, conventional classifications are not useful for determining the segments to be fused or the trajectory for screw insertion. In particular, the type B fracture described with our classification does not correspond to any fracture type described with conventional fracture classifications. Therefore, we felt that it was necessary to develop our own original fracture classification to convey our surgical strategy.

The surgical options for the treatment of LSCS-OVC include PSF,25 PSF combined with VP,9,26 posterior lumbar interbody fusion (PLIF),3,14,27 spinal shortening (spinal osteotomy),6,7 anterior spinal fusion (ASF),28–30 and APCS,7 though each technique has its respective advantages and disadvantages.

PLIF27 and posterior spinal shortening6 allow for direct neural decompression by resection of the retropulsed vertebral fragment and correction of kyphotic deformity. Machino et al.14 reported the usefulness of PLIF for LSCS-OVC, but they excluded patients with type C fractures with both superior and inferior endplate involvement. PLIF often requires partial resection of the posterior corner of the vertebral body to access the interbody space, and spinal shortening for a three-column osteotomy; both are invasive procedures with a high risk of intraoperative blood loss and neural tissue damage.

ASF is often performed with cylindrical titanium cages; however, cage subsidence and loss of correction are causes for concern because of the fragile, osteoporotic endplates.29,30 Smith et al.32 reported that expandable, wide-footprint titanium cages resist radiographic subsidence, but conceded that corpectomy required ligation of the segmental vessels and profuse bleeding from the vertebral body may be encountered often. Although ASF makes short-segment fusion possible by reconstruction of anterior support,28 the procedure by itself is often inadequate for correction and maintenance of alignment.11,12,33

PSF combined with VP is reportedly the most common surgery for LSCS-OVC,9,13,15,16 but comparison studies demonstrate that results may vary. Kashii et al.9 compared patients who underwent ASF, PSF, and PSF with VP to treat LSCS-OVC, and they reported no significant differences in improvement of neurological deficits or function level in activities of daily living. The VP group had significantly decreased blood loss and shorter operative times than the ASF and PSF groups. The VP group also had increased correction loss, but this was not associated with function in activities of daily living. Nakashima et al.13 compared patients who underwent APCS to patients who underwent PSF with VP, and they reported that APCS-treated patients had shorter fusion segments (2.4 vs 3.1 intervertebral levels) but superior stability with less pedicle screw loosening, nonunion, pedicle screw cut-out, and loss of correction. Because the VP group demonstrated significantly higher rates of correction loss, implant-related complications, and pseudarthrosis, they concluded that APCS is preferable. APCS is preferred by some surgeons because of its rigid stability, but the invasiveness of the surgery is often considered too high for medically compromised elderly patients.13 We believe that our APCS procedure is substantially less invasive than conventional APCS and has a lower threshold when considering APCS for elderly patients.

Many factors have been implicated in correction loss after fusion surgical procedures, including subsequent vertebral fractures within the fusion construct, cage subsidence, breakage of anterior support such as fragmented calcium phosphate cement, and pedicle screw loosening due to osteoporosis.3 Intervertebral disc can be a major source of correction loss, not only because of residual disc motion between instrumented vertebrae, but also because the injured vertebral endplate is highly associated with injury to the adjacent intervertebral disc that eventually leads to disc narrowing and collapse.24 PSF with VP stabilizes the collapsed vertebra, but the untreated injured intervertebral disc later collapses and leads to pedicle screw loosening and correction loss. Multilevel PSF is often required to prevent pedicle screw loosening and loss of correction.8 Therefore, our strategy to perform OLIF with anterior reconstruction of the intervertebral segments adjacent to the injured vertebral endplates makes sense. Our APCS procedure provides 360° fixation and rigid stability with a short fusion segment in a less invasive manner, thereby reducing implant failure and preventing correction loss as well as revision surgery. In fact, none of the segments fixed with our less invasive APCS procedure required revision surgery through the follow-up period.

### Table 2. Changes in neurological status and low-back pain after surgery

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<th>1 Yr Postop</th>
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<td>ODI score</td>
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Boldface type indicates statistical significance (p < 0.05).

### Table 3. Changes in radiographic measurements, LLA, and global sagittal alignment

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<tr>
<td>LLA, °</td>
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<td>PT, °</td>
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<td>SVA, mm</td>
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Boldface type indicates statistical significance (p < 0.05).
In addition, our method has the following advantages over conventional procedures. First, the OLIF procedure allows for minimally invasive access to the affected vertebral body and adjacent disc. Second, OLIF is an intervertebral procedure that does not require manipulation of the affected vertebra or segmental vessel ligation; therefore, it is less invasive than conventional APCS and three-column osteotomy. Snug-fit insertion of the OLIF cage into the interbody space compresses the intervertebral cleft from outside the affected vertebra, provides stability, and reconstructs anterior support by establishing bone-cage-bone continuity (Fig. 1A and B), and use of a wide interbody cage spanning the lateral borders of the apophyseal ring minimizes the risk of cage subsidence.35,36 Third, the selective fusion procedure based on our original classification of fracture morphology allows for the shortest fusion structure via anterior support reconstruction and placement of sufficient posterior anchors in consecutive segments. It is noteworthy that half the patients in this study were treated with monosegment surgery. Particularly for type C fractures, placement of a long pedicle screw into the remaining collapsed vertebral body increased the stability of the construct compared with the stability achieved with conventional APCS. This is illustrated by the low correction loss of 2.8° (18%) and the absence of significant cage subsidence or implant dislodgement, even though APCS was performed on elderly patients with poor bone quality. As shown in Table 4, our procedure provided shorter fusion segments, decreased correction loss, shorter operative time, and decreased intraoperative blood loss than other APCS procedures.7,12–14

Patients with severe canal stenosis require direct posterior neural decompression during correction of the kyphotic deformity through postural reduction and anterior cage insertion. Kashii et al.9 recommended short-segment PSF with VP, but they acknowledged the need for more invasive procedures such as APCS when neurological deficits are caused by retropulsed bony fragments and not instability. Nakajima et al.5 also recommended direct nerve decompression and reconstruction of the spinal column in patients with instability. These patients are prime candidates for our procedure, which achieves nerve decompression and reconstruction of a stable spine in a minimally invasive manner. Percutaneous placement of posterior instrumentation is possible, but we recommend posterior bone grafting because it is often difficult to achieve solid interbody fusion in patients with OVC; the irregular surface of the fractured endplate is a poor graft site, especially because the central cortex is often depressed. We usually perform the OLIF procedure, but the extreme lateral interbody fusion procedure can also be performed in a similar manner.18,36

The widening of the intervertebral disc space adjacent to the fractured OVC endplate raises the concern that the height of the cage may be insufficient to reconstruct the anterior support, especially in cases of severe collapse. Although the central region of the vertebral body is often collapsed, the height of the lateral cortices is maintained; hence, careful evaluation of preoperative CT images is necessary. With insertion of a wide cage that spans the lateral borders of the vertebral body, sufficient stability can be obtained in most cases. Suk et al.7 described the goals of surgery for LSCS-OVC as improvement of neurological deficits due to neural decompression, restoration of normal alignment by correction of the deformity, and stabilization of the spinal column with arthrodesis. We believe that our procedure achieves these goals with the shortest possible fusion structure in a minimally invasive manner. The high preoperative SVA dramatically improved after our short-segment surgery (illustrated in Fig. 2B and G), suggesting that high SVA in patients with LSCS-OVC does not necessarily reflect global sagittal malalignment that requires long fusion procedures as in patients with degenerative spinal deformity.5 In addition to the correction of LLA brought about by our short-segment surgery, the improvements in postoperative LL and SVA may be attributed to the increase in lumbar extension that was possible owing to the pain relief yielded by the stabilization of the collapsed vertebrae. Especially for elderly and frail patients, we believe that surgical management of LSCS-OVC should not be too biased toward improving radiological parameters, and instead the strategy should focus on improving patient-reported outcome measures with the least stress for patients. The increase in postoperative PT over the follow-up period can be interpreted as a compensatory change to maintain SVA despite the degenerative decrease in LL. Because the patients are elderly and have osteoporosis, there is a high risk of subsequent fractures that could cause deterioration of global sagittal alignment; therefore, treatment of osteoporosis should be considered mandatory.

The limitations of this study are its small sample size, insufficient and limited follow-up, and retrospective single-center study design. Longer follow-up is needed to determine the durability of improved alignment after APCS. A multicenter prospective study is needed to compare the

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Values reported as means unless indicated otherwise.
long-term outcomes of our minimally invasive APCS with those of conventional surgical procedures and to demonstrate the benefits of APCS. However, because long-term follow-up of elderly patients may be difficult, we believe that this study with a mean follow-up of over 3 years demonstrates the value of our minimally invasive procedure as a treatment of LSCS-OVC.

Conclusions

Our surgical procedure, which combines OLIF and PSF, produced satisfactory clinical outcomes. Although APCS has the disadvantage of intraoperatively changing the patient’s position, it resolves the drawbacks of conventional procedures and achieves neural decompression, reconstruction of anterior support, and correction of local alignment in a minimally invasive manner.

References


Disclosures
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions
Conception and design: Fukuda. Acquisition of data: Takahashi, Kitamura, Ikeda. Analysis and interpretation of data: Fukuda. Drafting the article: Fukuda. Reviewed submitted version of manuscript: Katoh, Kitamura.

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