学位論文

Indirect decompression of the central lumbar spinal canal by means of simultaneous bilateral transforaminal lumbar interbody fusion for severe degenerative lumbar canal stenosis with 3 years minimum follow-up

(重度変性脊柱管狭窄に対して同時左右経椎間孔椎体間固定術による正中脊柱管間接除圧、3年間以上経過観察)

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（武田直樹，石田直樹）

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Indirect decompression of the central lumbar spinal canal by means of simultaneous bilateral transforaminal lumbar interbody fusion for severe degenerative lumbar canal stenosis with 3 years minimum follow-up

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ABSTRACT

Study design: Given the drawbacks of direct decompression for LCS, indirect decompression techniques such as oblique lateral interbody fusion from anterior/lateral approaches are gaining popularity. However, anterior/lateral approaches to the spine have risks of their own.

We performed a retrospective analysis of a prospective cohort of LCS patients surgically treated in our facility.

Objectives: 1) Reduce the technical demands of indirect decompression for severe LCS;

2) Establish a reliable and simple indirect decompression technique for severe and extreme stenosis.

Methods: Sixty-eight spinal segments of 50 patients were operated for LCS with instability. Bilateral screw distractors were attached to pedicle screws and bilateral TLIF was performed. Laminae and ligamentum flavum were preserved. Forty-five segments with pre-op cross-sectional thecal sack area (CSA) below 100 mm^2 on T2 axial MRI were sampled for this study.

Results: Decompressed levels were L2/3 in 3 cases, L3/4 in 19 cases, L4/5 in 20 cases, L5/S in 3 cases.

There were no complications and no reoperations. Mean CSA increase was 75.8 mm^2 (166% increase, from 58.6 mm^2 pre-op to 134.4 mm^2 at follow-up, $p < 0.001$). Mean disk space height increase was 5 mm ($p < 0.001$). Mean lower extremity pain visual analog scale (VAS, 10 points) improvement was 4.9 ($p < 0.001$), mean lower extremity paresthesia VAS improvement was 3.8 ($p < 0.001$). Union rate was 96%.Minimum follow-up is 3 years post-op.

Conclusion: Posterior approach indirect decompression by bilateral TLIF is safe, effective for treatment of lower extremity symptoms of severe and extreme LCS, not technically demanding, and has high fusion rate.

1. Introduction

In 2000 Abumi et al. [1] for the first time described indirect decompression of the spinal canal from posterior approach for traumatic cervical intervertebral disk herniation that was made possible by the strength of pedicle screws.

Degenerative lumbar canal stenosis (LCS) is increasingly prevalent in ageing society and leads to significant morbidity and economic burden [2,3]. The definitive treatment is lumbar canal decompression, which is traditionally achieved through posterior approach by resecting ligamentum flavum (direct decompression). Direct decompression is accompanied by direct manipulation of nerve tissue with some risk of dural tear and/or nerve injury even in experienced hands [3]. Opening of spinal canal with exposure of thecal sack creates the possibility of postoperative deterioration in case of hematoma or infection.

Recently indirect decompression from anterior/lateral approaches has been gaining popularity. Anterior lumbar interbody fusion (ALIF), transpsoas lumbar interbody fusion (XLIF, LLIF, DLIF) and oblique lateral interbody fusion (OLIF) restore disk height thus reversing disk bulging and ligamentum flavum buckling [4]. There are risks associated with anterior/lateral approaches to the spine. Injury to retroperitoneal viscus and blood vessel injury are reported in literature [3,5]. There is no local bone for grafting. Facet joints cannot be resected and might impede restoration of disk height and segmental alignment. Intraoperative

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navigation and nerve monitoring is required in some cases [6]. For these reasons anterior/lateral fusion is more expensive than posterior approach surgery [7].

We performed posterior approach indirect decompression by means of bilateral transforaminal lumbar interbody fusion (TLIF) for severe LCS. Posterior approach is achieved through a midline incision in prone position. Indirect decompression is achieved by restoring the disk height [8–10]. Approach to intervertebral disk is through facetectomy [11].

2. Methods

2.1. Patient demographics

A retrospective analysis of a prospective LCS cohort was performed. Institutional review board approval was received for this study. All patients signed informed consent form.

LCS was confirmed on Magnetic Resonance Imaging (MRI).

All patients underwent conservative treatment for at least 6 months before surgery. Patients with severe debilitating neurologic claudication resistant to lifestyle modification, medication and rehabilitation were eligible for surgery.

One or two level fusion was performed in 68 lumbar spine segments of 50 patients. The indications for fusion were: instability and/or malalignment.

From this number 45 spinal segments of 34 patients with pre-op thecal sack cross-sectional area (CSA) below 100 mm [2] were sampled (17 males, 17 females, mean age 67 years old, 31 ~ 81 years old).

One hundred mm^2 is established in literature as a cut-off CSA value for LCS [12]. All stenotic segments were classified as Schizas grade C (severe) or D (extreme) [13].

2.2. Surgical technique

Patients were operated in prone position on four-point frame mounted onto a radiolucent table under surgical loupe magnification. Lumbar spine was approached through a midline incision above the tips of spinous processes. Back muscles were bilaterally separated from spinous processes, laminae and facet joints of the level to be fused.

Cranial level pedicle screws (PS) [14] were inserted according to pre-op computed tomography CT planning under C-arm image intensification.

Inferior articular processes on both sides were resected with a 5 mm chisel. Ligamentum flavum attachments were preserved. Caudal level PSs were then inserted.

Bilateral screw distractors (Pagoda Spinal System, TLIF Distractor, Ortho Development Corporation, Draper, Utah) were attached to the PS heads on both sides (right and left) as shown in Fig. 1A. The segment was distracted bilaterally until ligamentum flavum unbuckled as shown in Fig. 1B and Video 1. Superior articular processes were osteotomised and removed on both sides. Annulus was incised on both sides and degenerated nucleus pulposus was removed. Interbody release was achieved by twisting a Cobb elevator placed inside disk cavity to push endplates apart.

Morcellized bone from resected facet joints was grafted into disk cavity and inside the polyether ether ketone (PEEK) cages followed by cage insertion on both sides (left and right) as shown in Fig. 1C.

Intraoperative indirect decompression evaluation by myelography [15] was not necessary.

Titanium rods were attached to screw heads; compression applied to the cages and set screws torqued. Wound was tightly closed layer by layer with resorbable sutures. No drains were necessary.

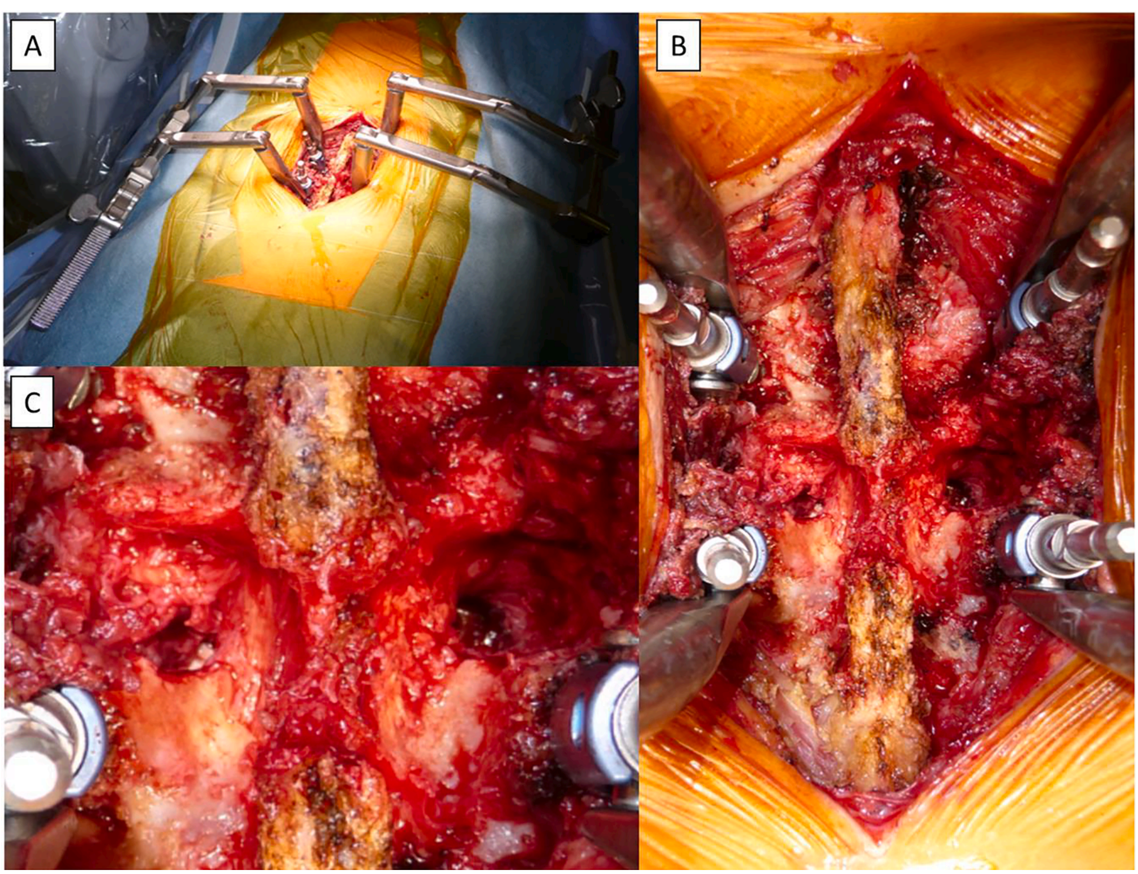

Fig. 1. A. Bilateral screw distractors attached to pedicle screw heads during L3/4 procedure. B. View of the operative field after bilateral TLIF cage insertion before distractor removal. C. The unbuckled ligamentum flavum are seen and PEEK cages are visible in the disk space bilaterally.

2.3. Evaluation of outcomes

Operation time, blood loss, time for bilateral screw distractors attachment, complications, bony union at 12 months post-op, disk height before and after surgery, segmental lordosis angle, CSA before surgery and at follow-up, Japanese Orthopedic Association Back Pain Evaluation Questionnaire (JOABPEQ) [16] efficiency ratios, back pain visual analog scale (VAS, 10 points) improvement, lower extremity pain VAS improvement, lower extremity paresthesia VAS improvement at follow-up were evaluated.

Disk height increase in % was calculated as.

$$\frac{Disk\ height\ after - Disk\ height\ before}{Disk\ \ height\ \ before} \times 100\% = Disk\ \ height\ \ increase\ \ in\ \ \%$$

Bony union was declared if there was no motion on functional X-rays at 12 months post-op as shown in Figure 2A and B, and a continuous fusion mass through a cage, no screw loosening, no vacuum phenomenon, no bony cyst formation on CT as shown in Fig. 2C.

CSA was measured on T2 axial MRI scans with Carestream Picture Archiving Communication System (Carestream Health, Rochester, New York) imaging software at the slice where spinal canal was most stenotic as shown in Fig. 3A, B, C, D as described in literature [17–19]. CSA increase in % was calculated as.

$$\frac{CSA\ \ after - CSA\ \ before}{CSA\ \ before} \times 100\% = CSA\ \ increase\ \ in\ \ \%$$

2.4. Statistical analysis

Paired *t*-test was performed in Excel (Microsoft, Redmond, Washington) to compare pre-op and post-op values. P values of 0.05 or less were considered statistically significant.

3. Results

Decompressed levels were L2/3 in 3 cases, L3/4 in 19 cases, L4/5 in 20 cases and L5/S in 3 cases.

Mean operation time was 159 min in one level and 233 min in two level surgeries. Mean intraoperative bleeding was 216 ml in one level and 450 ml in two level surgeries. Mean time required for bilateral screw distractors attachment by a single operator was 117 s (85 ~ 274 s).

There were no complications, no dural tears, no cerebrospinal fluid (CSF) leaks, no hematomas, no nerve injuries, and no infections.

In 22 segments distraction before facet osteotomy resulted in vacuum phenomenon in the disk space observed on image intensification as shown in Fig. 4A, B and Video 2. Among them were 15 cases with no gas in the disk space on pre-op CT scans.

In cases, where the disk was airtight after facetectomy, a sucking sound was heard in the moment of annulotomy under distraction.

There were two asymptomatic unfused segments at 12 months post-op (union rate 96%) and one asymptomatic unfused segment at last follow-up (union rate 98%).

Mean CSA increase was 75.8 mm^2 (from 58.6 mm^2 pre-op to 134.4 mm^2 at last follow-up, $p < .001$), average 166% increase. Mean disk space height increase was 5 mm (from 6 mm pre-op to 11.2 mm post-op, $p < .001$), average 192% increase. Mean instrumented segment lordosis angle was unchanged (average 11° lordosis pre-op and post-op).

JOABPEQ efficiency ratios were 65 % for low back pain, 38% for lumbar function, 53% for walking ability, 53% for social life function and 35% for mental health. Mean back pain VAS improvement was 2.8 (from 5 pre-op to 1.9 at follow-up, $p < .001$), mean lower extremity pain VAS improvement was 4.9 (from 6.1 pre-op to 1.0 at follow-up, $p < .001$), mean lower extremity paresthesia VAS improvement was 3.8 (from 5.7 pre-op to 1.9 at follow-up, $p < .001$).

All patients were followed for more than 36 months post-op (mean follow-up 46 months). There were no cases of insufficient decompression, no symptomatic residual stenosis, no reoperations, no failed back surgery syndrome cases, and no symptomatic adjacent segment disease during follow-up. Fig. 5.

3.1. Illustrative case 1 as illustrated in Figure 5A, B

Sixty-seven years old male was seen after several months of conservative treatment for degenerative LCS with persistent intermittent claudication of 5 min alleviated by rest in forward bent position. MRI revealed Schizas grade D (Extreme) lumbar canal stenosis with CSA of 32 mm^2 at L4/5 as shown in Fig. 5C, D. One level fusion was performed after a period of in-patient rehabilitation as shown in Fig. 5E, F.

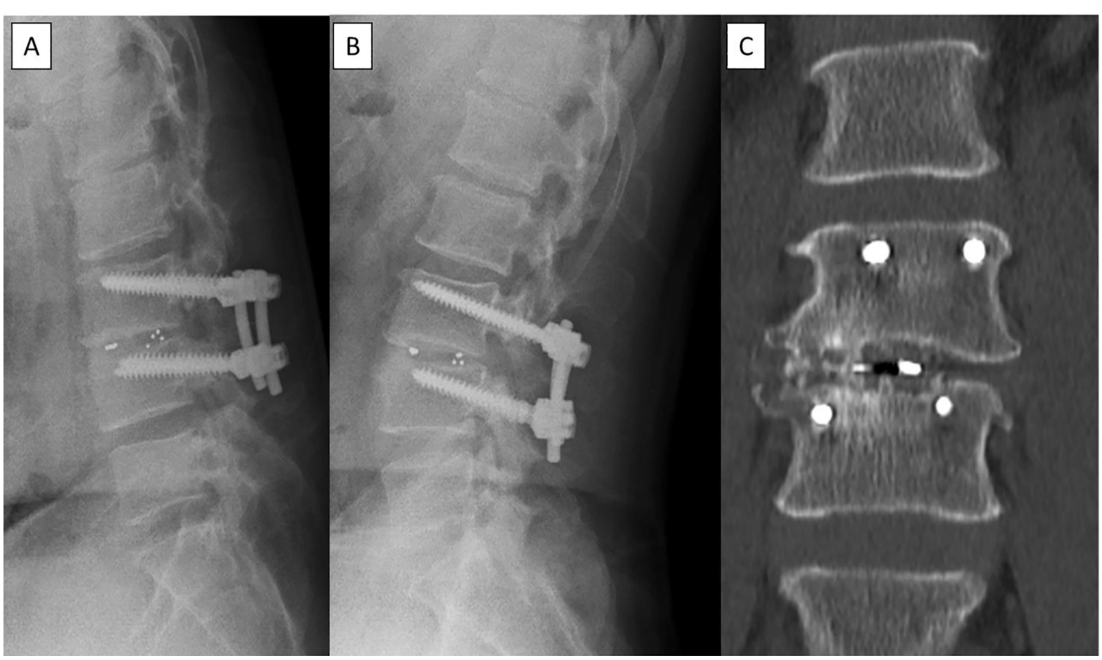

Fig. 2. Bony union at 12 months after L3/4 fusion. A, B. No motion is observed on functional X-rays. C. Continuous bone mass through the cage as well as no screw loosening, no vacuum phenomenon, no bony cyst formation is seen on coronal CT scan.

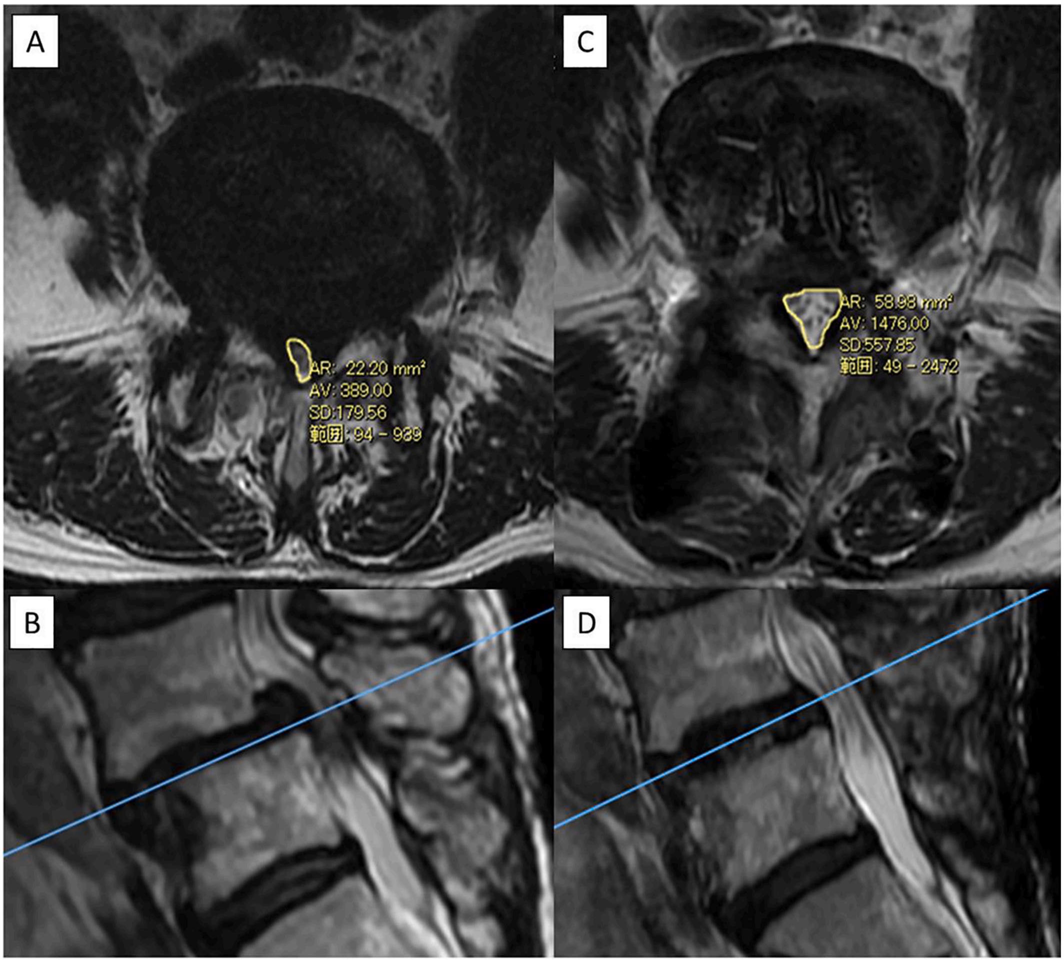

Fig. 3. Thecal sack CSA measured on axial MRI in L4/5 LCS patient. A, B. Before surgery. C, D. At follow-up.

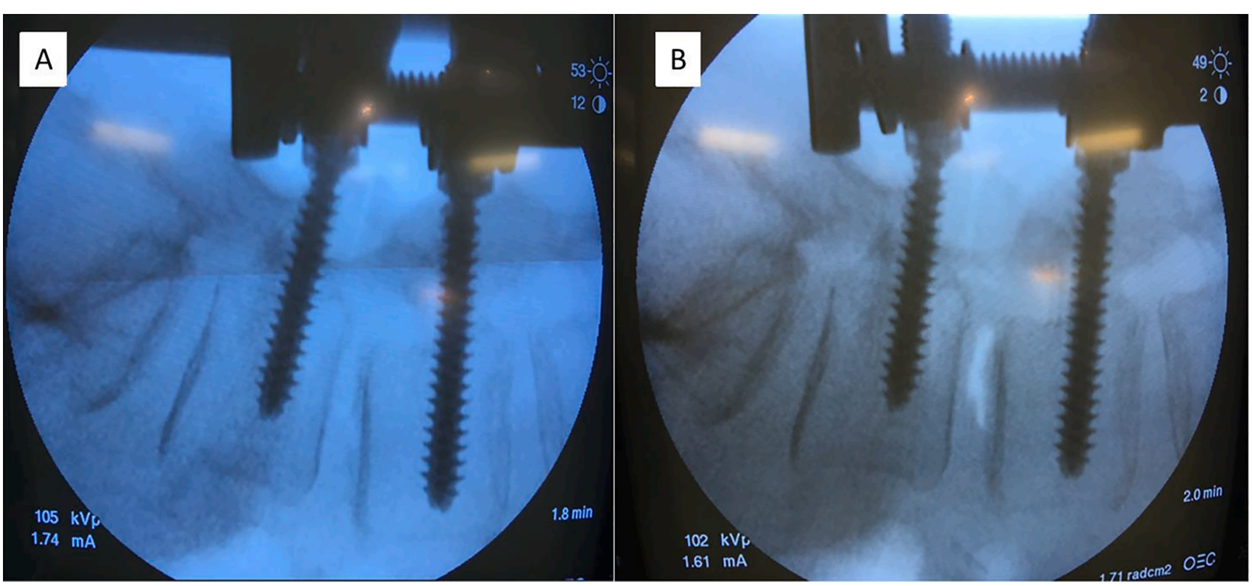

Fig. 4. Vacuum phenomenon inside the L4/5 disk space observed during bilateral TLIF procedure in L4/5 LCS patient with no vacuum phenomenon on pre-op CT. A. No vacuum inside disk before distraction. B. Obvious vacuum inside disk on image intensification after bilateral distraction before annulotomy.

Symptoms were relieved after surgery. CSA increased to 147 mm^2 (359% increase) as shown in Fig. 5G, H. Fusion was confirmed at 12 months post-op as shown in Fig. 5I. There is no need for medication and the patient is full time employed. Fig. 6.

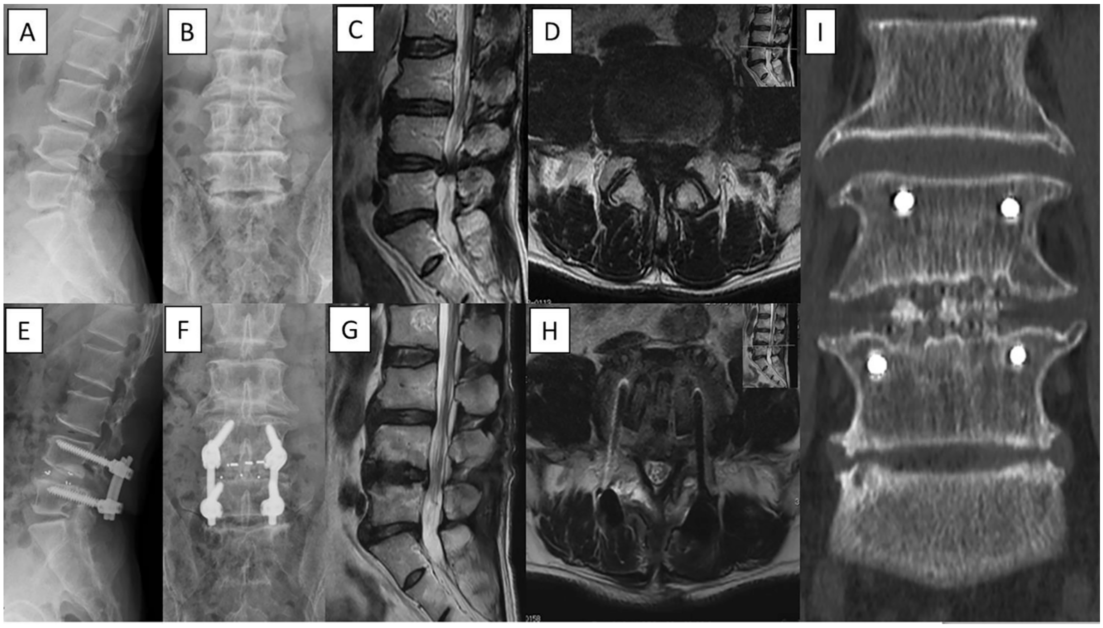

Fig. 5. Illustrative case 1. A, B. Alignment on standing X-rays before surgery. C, D. MRI scans indicating extreme stenosis. E, F. Alignment at 12 months post-op on standing X-rays. G, H. MRI scans at follow-up showing successful decompression. I. Evidence of bony ingrowth within the cage on CT scan 12 months post-op.

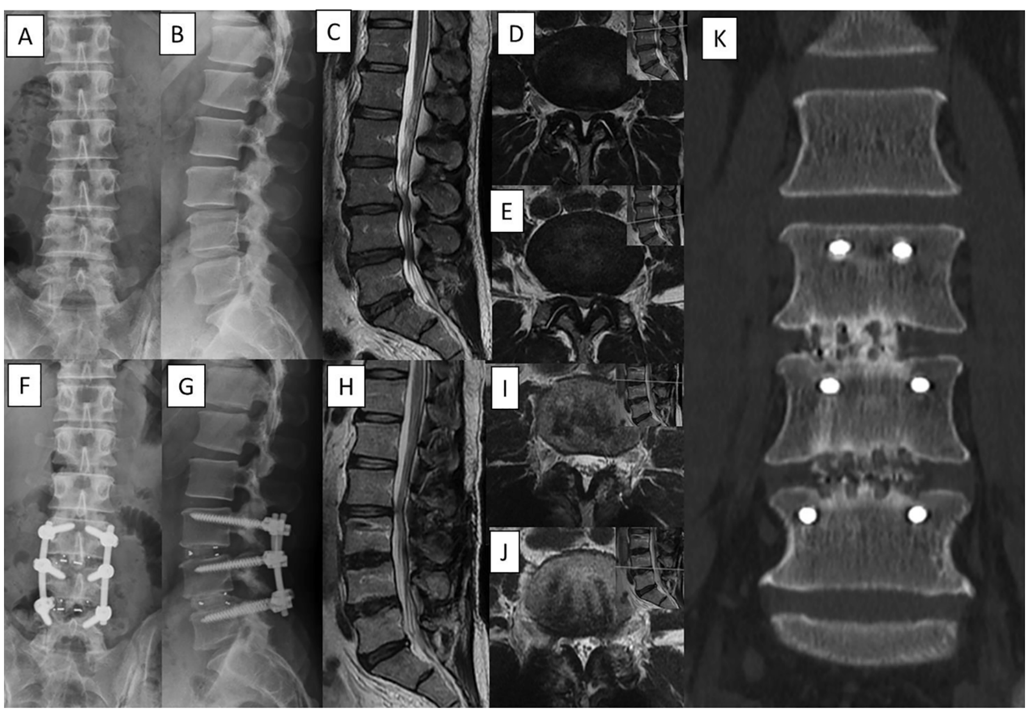

Fig. 6. Illustrative case 2. A, B. Alignment on standing X-rays before surgery. C, D, E MRI scans indicating severe stenosis. D. L3/4. E. L4/5. F, G. Alignment at 12 months post-op on standing X-rays. H, I, J. MRI scans at follow-up showing successful decompression. I. L3/4. J. L4/5. K. Evidence of bony ingrowth within the cage on CT scan 12 months post-op.

3.2. Illustrative case 2 as illustrated in Figure 6A, B

Fifty-six years old male with back pain, lower extremity pain, paresthesia and intermittent claudication at 10 m alleviated when bent forward was conservatively treated for 6 months without relief. MRI revealed Schizas grade C (Severe) LCS with spinal canal area of 56 mm^2 at L3/4 and 60 mm^2 at L4/5 as shown in Fig. 6C, D, E. L3/4/5 fusion was performed with relief of symptoms as shown in Fig. 6F, G. CSA was restored to 162 mm^2 (189% increase) at L3/4 and 124 mm^2 (106% increase) at L4/5 as shown in Fig. 6H, I, J. Fusion was confirmed at 12 months post-op as shown in Fig. 6K. The symptoms gradually resolved and the patient is full time employed.

4. Discussion

4.1. Problems of traditional posterior decompression

Traditional posterior decompression carries a risk of dural tears and nerve injury. Intraoperative complications display a learning curve that leads to significant reduction in the incidence of dural tear and nerve injury, however, even experienced surgeons using microscope continue to report complications [20,21]. During conventional TLIF the traversing nerve root and the exiting nerve root are at risk and should be protected by nerve root retractors.

It is widely accepted that restoring disk height leads to improvement in alignment and spinal canal diameter [1,3,4,10,13,15,17]. Such indirect decompression through anterior/lateral approaches became popular in recent years [15].

Also, recurrent disc herniation is widely accepted as an indication for fusion [22,23], so indirect decompression with fusion as an index surgery may be considered as a way to prevent recurrent stenosis, multiple operated back (MOB) and failed back surgery syndrome.

4.2. Problems of indirect decompression from anterior/lateral approaches

Disk height restoration in anterior/lateral approaches relies on anterior release. Endplates are pushed apart after anterior or lateral annulus incision. Endplate violation may result and insufficient disk height restoration might lead to residual stenosis [24].

Lack of local bone for grafting increases costs of treatment [7].

There are some risks of viscus or large vessel injury. Some surgeons prefer to perform indirect decompression procedures in large facilities with vascular surgery, general surgery and urology support.

4.3. Posterior approach indirect decompression with bilateral TLIF

Abumi et al. described indirect decompression from posterior approach for traumatic cervical disk herniation [1] two decades ago. We applied Abumi's technique to the treatment of degenerative LCS with instability.

We utilize PSs during the surgery to attach bilateral distractors and distract the spinal segment with following advantages:

1) Immediate decompression of the thecal sack because of ligamentum flavum unbuckling, which reduces the risk of nerve tissue impingement during operation;

2) Access to the optimal superior articular process osteotomy site without having to remove any lamina bone or cut into the pedicle even in cases with 1 mm disk height pre-op;

3) Facilitating removal of the osteotomised superior articular process;

4) Assuring lateral recess thecal sack and traversing nerve root is located inside spinal canal by keeping ligaments and dura mater taut during disk space preparation;

5) Creating safe distance between exiting nerve root and annulotomy site;

6) Stabilizing vertebral segment during endplate preparation to prevent intraoperative nerve injury by repeated disk space collapse and distraction;

7) Maintaining parallel endplate alignment during endplate preparation for better X-ray visualization and prevention of endplate violation.

4.4. Proposed mechanism of bilateral TLIF

Exact measurements of negative pressure generated inside disk space under bilateral distraction were not performed. However, vacuum phenomenon observed under distraction during surgery on image intensification in patients who had no vacuum phenomenon on CT scans pre-op as shown in Fig. 4A, B and the sucking sound heard in the moment of annulotomy under distraction suggest that the pressure might be below atmospheric.

Achieving a below atmospheric pressure inside the disk would work to reduce herniated material and disk bulging together with ligamentotaxis until annulus incision. This effect certainly disappears after annulus is incised and disk space is not airtight anymore. Negative pressure was reported during endoscopic decompression in disks with vacuum on pre-op images [25]. To our knowledge our report is the first paper to report any evidence of negative pressure created inside intervertebral disks distracted during surgery.

Ebata et al. demonstrated that ligamentum flavum unbuckling plays an important role in indirectly decompressing thecal sack during OLIF [26].

Our observations suggest that decrease of intravertebral disk pressure under distraction might help to decompress the spinal canal together with ligamentotaxis and ligamentum flavum unbuckling.

Bilateral screw head distractors are easy to place by a single operator. Once placed they are easy to operate with one hand, do not interfere with the operation field view and TLIF corridor, are sufficiently strong to restore and maintain good alignment of degenerated spinal segment. Ligamentum flavum and thecal sack are kept taut so that no nerve root retractors are needed to prevent nerve injury during endplate preparation, bone grafting and cage insertion.

Resection of facet joints produces additional release of the spinal segment, creates wide view of ligamentum flavum and generates abundant local bone for grafting as shown in Fig. 7A, B.

Preservation of laminae with spinous process and ligamentum flavum means that the spinal canal is not opened. The thecal sack is thus protected so, even if post-op hematoma or abscess formed, no neurologic deterioration will ensue. This allowed us to forgo post-op drain insertion which further reduced cost and invasiveness.

Preserved laminae and spinous processes provide a perfect surface for back muscle reattachment and if additional posterior bone grafting is desired.

If a revision surgery would be needed in the future, the preserved posterior elements of the spinal column will protect the neural tissue during exposure, so a reoperation approach is no more dangerous than for the index procedure.

4.5. Effectiveness of indirect decompression

Outcomes of indirect decompression from anterior/lateral approaches for LCS are reported in literature as follows: average 7 ~ 143% CSA increase [10,15,17,27], average disk height increase of 61% [15], 14.3% postoperative psoas weakness [17], 21% reoperation rate for insufficient indirect decompression [15], 36% complication rate [24].

Our results of 166% average increase in CSA, average disk height increase of 192% and no complications compare favorably with reports of other authors. There were no cases of insufficient decompression and no reoperations, a result that exceeds those of indirect decompression from other approaches.

It should be mentioned, that while we were able to achieve sufficient indirect decompression in this series, removal of the hypertrophic ligamentum flavum should be considered in each case if possibility of insufficient indirect decompression was suspected during surgery. Removal of the hypertrophic ligamentum flavum in such cases would be a powerful tool of traversing root decompression without causing istability.

Both options of anterior indirect decompression and bilateral TLIF should be given consideration in each case because indirect decompression from lateral and anterior approaches is an excellent option in skillful hands especially for patients with coronal deformity.

Bilateral TLIF is different from unilateral TLIF because unlike unilateral TLIF it can be an indication for extreme central canal stenosis and osteoporosis cases for which TLIF is contraindicated [3]. This is because bilateral facetectomy in bilateral TLIF allows for excellent bilateral ligamentum flavum unbuckling, while bilateral access to disk space gives an opportunity for additional cage insertion to distribute the weight and prevent cage sinking. In our practice we were able to insert as many as 5 PEEK cages into one disk space to prevent sinking in severe osteoporosis (unpublished data).

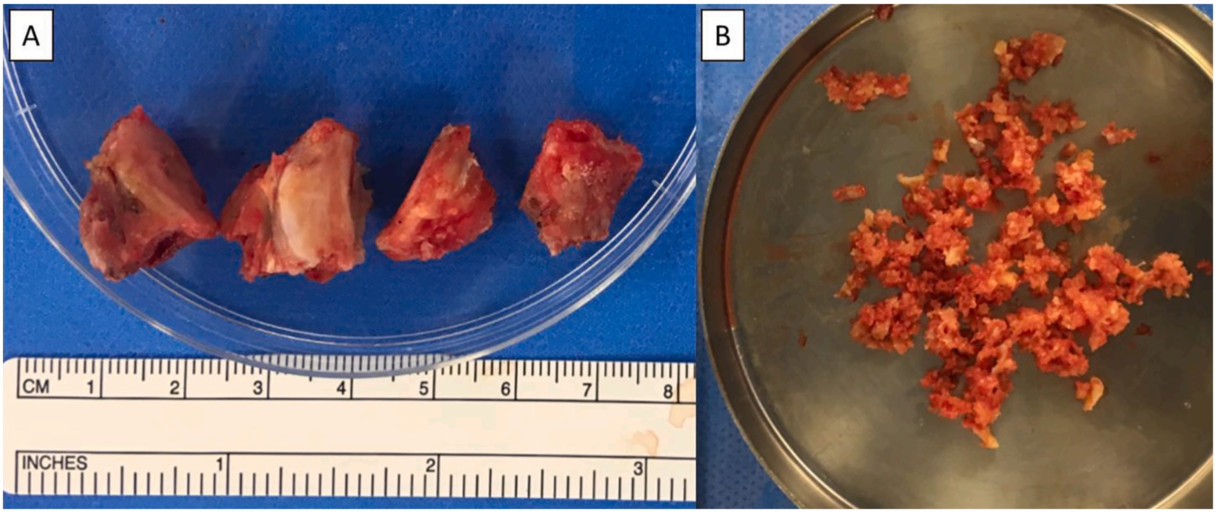

Fig. 7. Local bone graft. A. Bilateral inferior articular processes and superior articular processes removed during L3/4 procedure. B. Same local bone morcellized and ready for grafting.

Powerful bilateral distraction with bilateral release by bilateral facetectomy allowed us to successfully apply bilateral TLIF for cases of Pfirrmann grade Vdisk degeneration [28] with complete intervertebral disk collapse (unpublished data) which would be prohibitive for monolateral TLIF.

In summary, bilateral TLIF is similar to traditional TLIF in technique but has different indications.

Bilateral TLIF is a good indication for severe and extreme central stenosis cases, for which any other indirect decompression technique would be contraindicated because only in bilateral TLIF are both facet joints removed.

Limitations. This study is limited by a small number of subjects. The follow-up study will require a larger sample size and should include evaluation of sagittal balance on standing X-rays.

5. Conclusions

We report outcomes of indirect decompression from posterior approach with bilateral TLIF for severe degenerative LCS. Minimum follow-up was 3 years.

Bilateral TLIF appears to be safe, effective for treatment of lower extremity neurologic symptoms of LCS, has high fusion rate, is not technically demanding, can be performed by a single operator with basic spine surgery training in a standard orthopedic facility. We conclude that bilateral TLIF has a potential to be established as an accessible and safe procedure even for patients with severe stenosis for which other indirect decompression techniques might be contraindicated.

Funding

No funding was received for this research.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Author contribution

Ivan Sekiguchi wrote and prepared the manuscript, and all the authors participated in the study design. All authors have read, reviewed, and approved the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.inat.2022.101614.

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