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—Lumbar Instrumentation and Fusion

Dynamic Stabilization for Degenerative Spondylolisthesis and Lumbar Spinal Instability

Tatsuya OHTONARI,¹ Nobuharu NISHIHARA,¹ Katsuyasu SUWA,¹ Taisei OTA,¹
and Tsunemaro KOYAMA²

¹*Department of Spinal Surgery, Brain Attack Center Ota Memorial Hospital,
Fukuyama, Hiroshima;*

²*Department of Spinal Surgery, Clinical Institute for Spinal Disorders, Otsu, Shiga*

Abstract

Lumbar interbody fusion is a widely accepted surgical procedure for patients with lumbar degenerative spondylolisthesis and lumbar spinal instability in the active age group. However, in elderly patients, it is often questionable whether it is truly necessary to construct rigid fixation for a short period of time. In recent years, we have been occasionally performing posterior dynamic stabilization in elderly patients with such lumbar disorders. Posterior dynamic stabilization was performed in 12 patients (6 women, 70.9 ± 5.6 years old at the time of operation) with lumbar degenerative spondylolisthesis in whom % slip was less than 20% or instability associated with lumbar disc herniation between March 2011 and March 2013. Movement occurs through the connector linked to the pedicle screw. In practice, 9 pairs of D connector system where the rod moves in the perpendicular direction alone and 8 pairs of Dynamic connector system where the connector linked to the pedicle screw rotates in the sagittal direction were installed. The observation period was 77–479 days, and the mean recovery rate of lumbar Japanese Orthopedic Association (JOA) score was 65.6 ± 20.8%. There was progression of slippage due to slight loosening in a case with lumbar degenerative spondylolisthesis, but this did not lead to exacerbation of the symptoms. Although follow-up was short, there were no symptomatic adjacent vertebral and disc disorders during this period. Posterior dynamic stabilization may diminish the development of adjacent vertebral or disc disorders due to lumbar interbody fusion, especially in elderly patients, and it may be a useful procedure that facilitates decompression and ensures a certain degree of spinal stabilization.

Key words: dynamic stabilization, instability, pedicle screw, posterior lumbar interbody fusion, spondylolisthesis

Introduction

In patients with degenerative spondylolisthesis or instability of the lumbar spine, lumbar interbody fusion is widely accepted if the patient is in the active age group, because the long-term outcome is stable.^{1–3)} In contrast, elderly patients have decreased activity and spinal mobility, and it is therefore often questionable whether it is truly necessary to

construct rigid fixation for a relatively short period of time. In reality, it is fairly common to experience adjacent vertebral or intervertebral disc disorders postoperatively.^{4–10)} On the other hand, it is still controversial that posterior simple decompression is actually tolerable to a recurrence or a deterioration of neurological symptoms by the progression of slippage or intervertebral rotation. Given this background, we have been performing decompression and posterior dynamic stabilization with pedicle screws that allows for specific movement either in the perpendicular or

sagittal direction according to the patient's condition, without having to perform lumbar interbody fusion in some elderly patients with degenerative spondylolisthesis or lumbar spinal instability. Here we present the outcome of this procedure.

Methods

I. Patient selection

Posterior dynamic stabilization using pedicle screws, connectors for dynamization, and rods was performed in 12 patients (6 men and 6 women, 70.9 ± 5.6 years old at the time of operation) with lumbar degenerative spondylolisthesis in whom % slip was less than 20% or instability with associated lumbar disc herniation presenting vacuum phenomenon of intervertebral disc between March 2011 and March 2013. The details of the diagnoses were: 7 patients with lumbar degenerative spondylolisthesis (6 patients at one level and 1 patient at two levels); 3 patients with instability associated with lumbar disc herniation; and 2 patients with each condition at adjacent intervertebral levels. Preoperative lumbar Japanese Orthopedic Association (JOA score, 0 [worst] –29 points [best])¹¹⁾ score was 14.7 ± 5.7 . At 9 intervertebral levels presenting slippage of 8 cases with degenerative lumbar spondylolisthesis, the mean preoperative % slip was 11.4% (range; 5.4–19.4%).

II. Implants and concept regarding dynamization

The implant system used was the KAPSS® (Robert Reid Inc., Tokyo). For pedicle screws, there are two types of monoaxial screws: the closed type (Fig. 1A) and the open type (Fig. 1B). The connector and rod are easier to install with the open type. However, the closed type has the advantage of having a low profile. Regarding the connector, which is the most important aspect to obtain dynamization, there is the D connector that allows rod movement in the perpendicular direction (Fig. 1C) and the Dynamic connector that allows pedicle screw movement in the sagittal direction (Fig. 1D). The first system was invented by Saito et al., who has reported the results of performing posterior lumbar interbody fusion (PLIF) with this system.^{12,13)} The latter system was invented by Suda.

Although the concept is one of dynamic stabilization, in degenerative spondylolisthesis at single intervertebral level, movement in the horizontal direction and rotation are suppressed, while movement in the perpendicular direction is allowed on the cranial side. For intervertebral instability at single level such as lumbar disc herniation which is presenting vacuum phenomenon of intervertebral disc, movements in the rotational and perpendicular

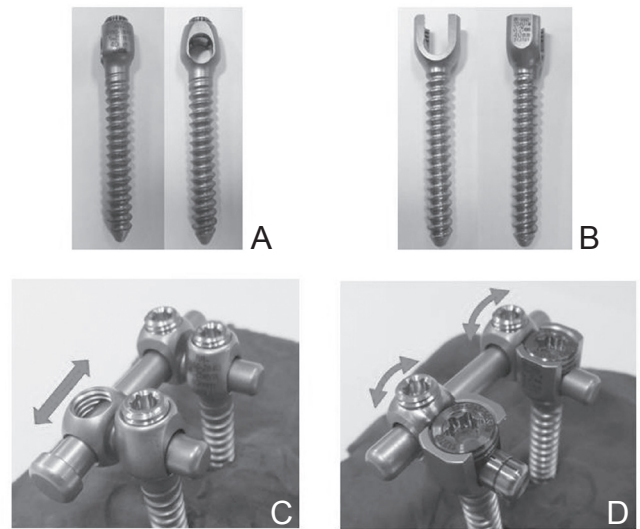


Fig. 1 KAPSS® (Robert Reid Inc., Tokyo) closed type (A) and open type (B) of monoaxial screw. The lower left picture (C) showing the D connector that allows rod movement in the perpendicular direction (a double-headed arrow) and the lower right picture (D) showing the Dynamic connector that allows pedicle screw movement in the sagittal direction (curved double-headed arrows).

directions are suppressed, while slight movement in the sagittal direction is allowed on the cranial and caudal sides.

Additionally, for degenerative spondylolisthesis and intervertebral instability accompanied with disc hernia at adjacent level, the pedicle screw and the rod at middle vertebra are rigidly fixed with common connector, the D connector for spondylolisthesis and the Dynamic connector for disc hernia complicated by intervertebral instability are used at adjacent levels, respectively. The following are detailed descriptions of representative examples. As seen in Fig. 2A, for degenerative spondylolisthesis at L4/5, the L5 pedicle screw and rod are rigidly fixed, and the L4 pedicle screw and rod allow for movement only in the perpendicular direction through the connector. By doing so, the aim is to suppress the progression of spondylolisthesis and to alleviate the sudden load in the perpendicular direction to the adjacent intervertebral disc or vertebral body.

In another example, when the deterioration of intervertebral instability is suspected after hernia excision, as seen in Fig. 2B, if, for instance, hernia excision is performed at L4/5, L4,5 pedicle screws are fixed to the rod with the connector that rotates 10 degrees each way in the sagittal direction. By doing so, the aim is to suppress the movement of the operated intervertebral disc in the rotational

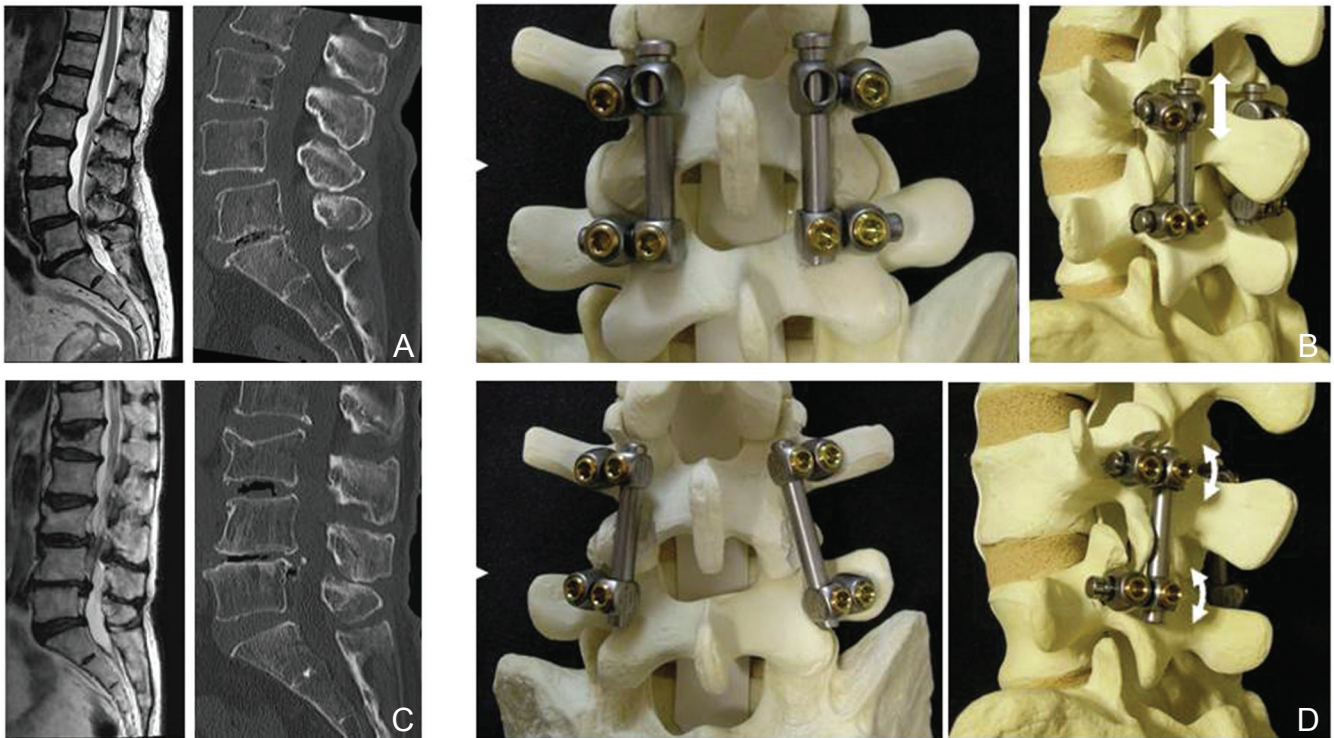


Fig. 2 Representative two patterns of dynamic stabilization. In L4/5 degenerative spondylolisthesis case (A), the L4 pedicle screw and rod allow for movement only in the perpendicular direction (a double-headed arrow) through the D connector (B). In L4/5 disc hernia case (C) accompanied with gas in the disc, L4,5 pedicle screws are fixed to the rod with the Dynamic connector that rotates 10 degrees each way (curved double-headed arrows) in the sagittal direction (D).

and perpendicular directions to a certain degree, to preserve slight movement in the sagittal direction, and disperse the load generated from sudden stress to the adjacent intervertebral disc or vertebral body. In a middle- or long term, while a decrease and a delay of adjacent vertebral or intervertebral disc disorders are expected with these dynamic stabilization systems, these effects should be examined seriously in future.

III. Surgery

Patients were placed on the surgical table in the prone position under general anesthesia. A midline skin incision was taken and posterior lumbar muscles were stripped in a subperiosteal plane in a usual manner. Fenestration or hernia excision was performed with a spinal process-splitting approach to the target level of the operation. Subsequently, pedicle screws of the aforementioned systems were installed using a navigation system under fluoroscopic support, with the height of the transverse process of the superior articular process as the insertion point. The rod was combined with either a D connector or a Dynamic connector, depending

on the patient, and fixed to the pedicle screw via the connector. Regarding undergoing dynamic stabilization with these implants, all patients gave consent prior to the operation.

Results

The results are summarized in Table 1. Nine each pairs of the D connector and Dynamic connector systems were installed. The follow-up period was 77–479 days, and postoperative JOA score and the recovery rate of JOA score was $24.3 \pm 2.9\%$ and $65.6 \pm 20.8\%$. There was progression of slippage due to the slight loosening of the cranial side screws in Case 6 with lumbar degenerative spondylolisthesis, but this did not lead to exacerbation of the low back pain or neurological symptoms. If the back out of these screws is confirmed and the slippage gradually progresses, intervertebral fusion will be necessary as a salvage step. However, if these loosened screws remain in the pedicle without remarkable motion and the slippage does not progress, the removal of implants or intervertebral fusion as a salvage surgery would not be absolute

Table 1 Summary of all 12 cases who underwent dynamic stabilization

Case	Age	Gender	Disease	Operated level	Utilized connector	Preoperative JOA score	Postoperative JOA score	Follow-up period (day)	JOA score recovery rate (%)
Case 1	66	M	L3/4 DS	L3–4	L3 D-connector	16	20	479	30.8
Case 2	67	M	L4/5 DS	L4–5	L4 D-connector	21	29	288	100
Case 3	75	M	L3/4 DS	L3–4	L3 D-connector	17	24	217	58.3
Case 4	67	F	L3/4/5 DS	L3–5	L3,5 D-connector	7	21	329	63.6
Case 5	61	M	L4/5 DS	L4–5	L4 D-connector	17	26	238	75
Case 6	76	F	L4/5 DS	L4–5	L4 D-connector	18	26	380	72.7
Case 7	75	M	L3/4 DS	L3–4	L3 D-connector	12	27	196	88.2
Case 8	67	M	L3/4 DH	L3–4	L3,4 Dynamic.	11	20	161	50.0
Case 9	79	F	L3/4 DS L4/5 DH	L3–5	L3 D-connector L5 Dynamic.	12	24	117	70.6
Case 10	69	F	L3/4 DS L4/5 DH	L3–5	(L3/4 PLF) L5 Dynamic.	17	23	114	50
Case 11	78	F	L3/4/5 DH	L3–5	L3,4,5 Dynamic.	24	26	77	40
Case 12	71	F	L4/5 DH	L4–5	L4,5 Dynamic.	4	26	336	88

DH: disc herniation, DS: degenerative spondylolisthesis, Dynamic.: Dynamic connector, JOA: Japanese Orthopedic Association, PLIF: posterior lumbar interbody fusion.

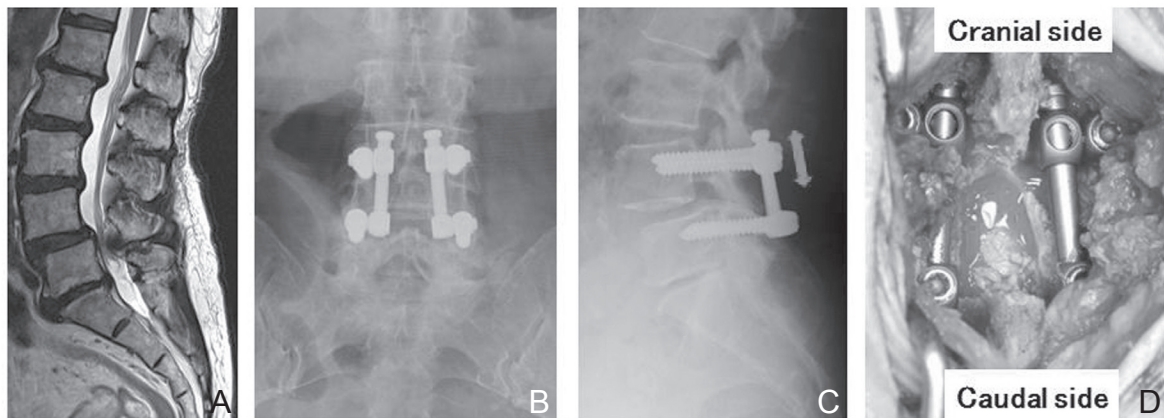


Fig. 3 Representative case of degenerative spondylolisthesis at one level on sagittal T₂-weighted magnetic resonance (MR) image (A). Postoperative lumbar anteroposterior (B) and lateral (C) radiographs are showing that the pedicle screw on the caudal side and the rod are rigidly fixed with a common connector, and a D connector that allows perpendicular movement (a double-headed arrow) of the rod is installed on the cranial side. Intraoperative photograph just after the placement of implants (D).

requirement. In another spondylolisthesis case, no progression of the slippage was confirmed in the follow-up period. Although the follow-up period was short- to medium term, no adjacent vertebral fractures and symptomatic adjacent intervertebral disorders were seen during this period.

The current series of dynamic stabilization procedures could be classified consequently into five patterns, along with the surgical strategy described

in the section *implants and concept regarding dynamization*:

Pattern 1: Six patients with degenerative spondylolisthesis at one level (Cases 1, 2, 3, 5, 6, and 7). The pedicle screw on the caudal side and the rod were rigidly fixed with a common connector, and a D connector that allows perpendicular movement of the rod was installed on the cranial side (Fig. 3).

Pattern 2: One patient with degenerative spondylolisthesis at two consecutive levels (Case 4). The L4 pedicle screw and the rod were rigidly fixed with the common connector, and a rod was installed with a D connector to the pedicle screws on the cranial and caudal sides (Fig. 4).

Pattern 3: Three patients with instability associated with lumbar disc herniation at one level (Cases 8, 11, and 12). Dynamic stabilization was added in all three patients due to the high probability that intervertebral instability would exacerbate after hernia excision. The pedicle screw on the craniocaudal

side was fastened to the rod through the Dynamic connector that allows the pedicle screw to move 10 degrees in the craniocaudal sagittal direction of the rod (Fig. 5).

Pattern 4: One patient with degenerative spondylolisthesis and instability associated with lumbar disc hernia at adjoining levels respectively (Case 9). The pedicle screw and the rod at L4 were rigidly fixed with a common connector. Rods were installed at L3/4, where there was degenerative spondylolisthesis, using an L3 pedicle screw with the D connector, and at L4/5, where there was concern

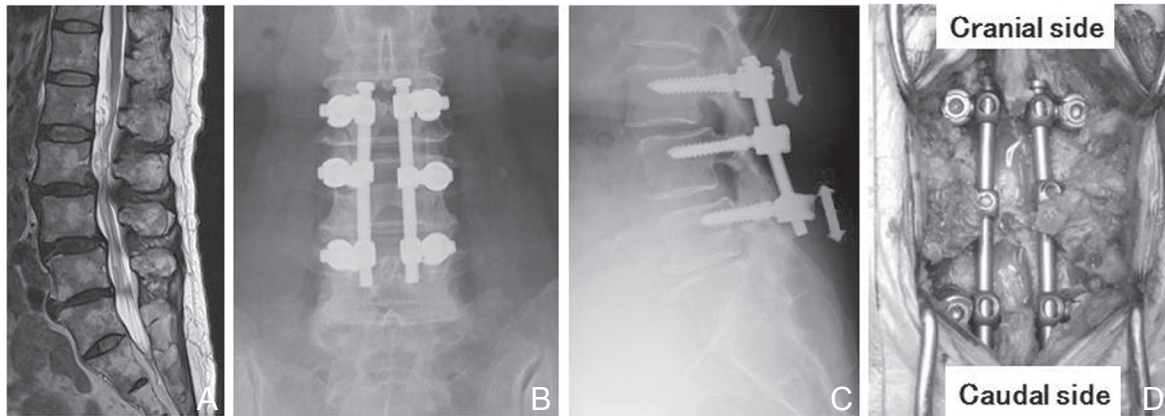


Fig. 4 A degenerative spondylolisthesis case at two adjacent levels (A) on sagittal T₂-weighted magnetic resonance (MR) image. Postoperative lumbar anteroposterior (B) and lateral (C) radiographs reveal that the L4 pedicle screw and the rod are rigidly fixed with a common connector, and a rod is installed with a D connector to the pedicle screws on the cranial and caudal sides. *Double-headed arrows* reveal the allowed perpendicular movement of the rod. Intraoperative photograph just after the placement of implants (D).

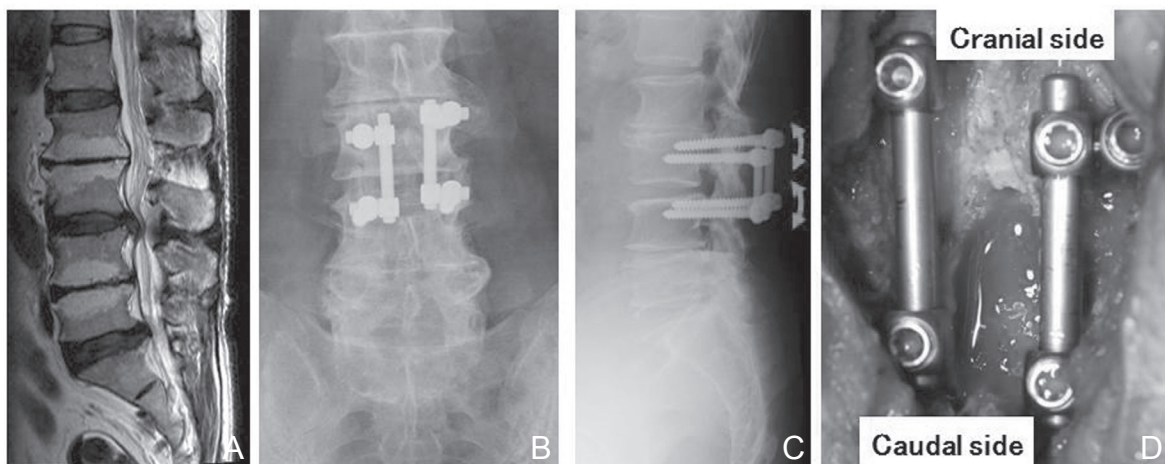


Fig. 5 Representative case with instability at one level on sagittal T₂-weighted magnetic resonance (MR) image (A). Postoperative lumbar anteroposterior (B) and lateral (C) radiographs show that the pedicle screw on the craniocaudal side is fastened to the rod through the dynamic connector that allows the pedicle screw to move 10 degrees in the craniocaudal sagittal direction (*curved double-headed arrows*) of the rod. Intraoperative photograph just after the placement of implants (D).

about intervertebral instability exacerbation after hernia excision, using an L5 pedicle screw with the Dynamic connector (Fig. 6).

Pattern 5: One patient with degenerative spondylolisthesis and instability associated with lumbar disc hernia at adjoining levels respectively (Case 10). Since this patient did not have osteoporosis and

preoperative % slip was greater than 20%, PLIF was performed at L3/4 where there was degenerative spondylolisthesis. At the caudal side, which was the adjacent L4/5 level, exacerbation of instability was expected after hernia excision; therefore, dynamic stabilization was added using a Dynamic connector at L5 (Fig. 7).

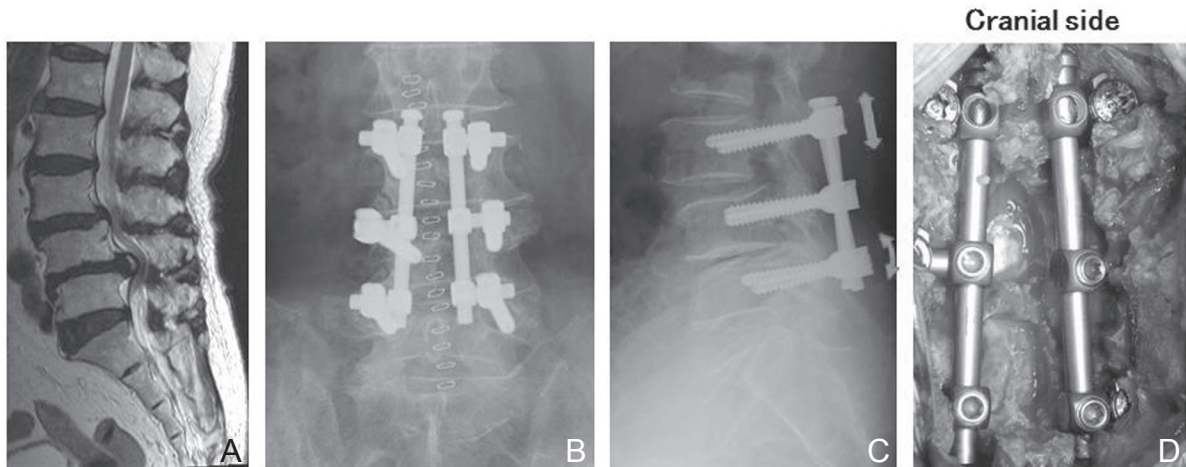


Fig. 6 Sagittal T₂-weighted magnetic resonance (MR) image is showing a case with degenerative spondylolisthesis and instability associated with lumbar disc hernia at adjacent levels respectively (A). Postoperative lumbar anteroposterior (B) and lateral (C) radiographs demonstrate that the pedicle screw and the rod at L4 are rigidly fixed with a common connector. Rods are installed at L3/4, where there was degenerative spondylolisthesis, using an L3 pedicle screw with the D connector, and at L4/5, where there was concern about intervertebral instability exacerbation after hernia excision, using an L5 pedicle screw with the dynamic connector. Each *double-headed arrow* is revealing the feature of motion with the connector. Intraoperative photograph just after the placement of implants (D).

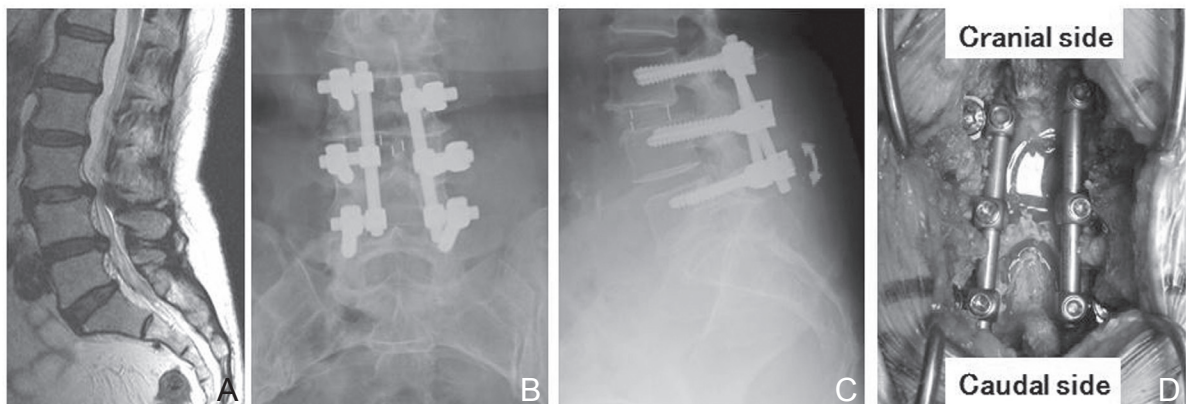


Fig. 7 Sagittal T₂-weighted magnetic resonance (MR) image reveals a case with degenerative spondylolisthesis and instability associated with lumbar disc hernia at adjacent levels respectively (A). Postoperative lumbar anteroposterior (B) and lateral (C) radiograph show that posterior lumbar interbody fusion is performed at L3/4 where there is degenerative spondylolisthesis, and that dynamic stabilization is added at L4/5 using a dynamic connector at L5 where exacerbation of instability is expected after hernia excision. *Curved double-headed arrow* is showing the feature of motion with Dynamic connector. Intraoperative photograph just after the placement of implants (D).

Discussion

For patients with neurological symptoms and low back pain that are associated with lumbar degenerative spondylolisthesis or lumbar spinal instability, lumbar interbody fusion is known to resolve these issues in the active age group and is reported to have a stable long-term outcome.¹⁴⁻¹⁷⁾ Indeed, an adjacent intervertebral disorder is a problem with lumbar interbody fusion.¹⁸⁻²¹⁾ However, relatively long-term vigorous activity is continued if interbody fusion can be obtained. In contrast, elderly patients often develop adjacent vertebral or intervertebral disc disorders before benefiting from any mid- to long-term effects of the lumbar interbody fusion, and adverse effects are fairly common in those who undergo rigid lumbar interbody fusion. While lumbar interbody fusion is inevitable in elderly patients with marked intervertebral instability, instability itself may not necessarily be the primary cause of the condition, because the patients' activity and spinal mobility are decreased to begin with. Nonetheless, if only conventional decompression is performed for lumbar degenerative spondylolisthesis or lumbar spine instability, a high rate of exacerbation of spondylolisthesis or instability is observed in the long-term regardless of the aggravation of neurological symptoms.²²⁾ This is the dilemma in deciding on the surgical strategy for elderly patients with lumbar degenerative spondylolisthesis or lumbar spinal instability. In such circumstances, the procedure of dynamic stabilization was evaluated as one approach to resolve this dilemma. Furthermore, the possibility that degenerative spondylolisthesis does not affect the outcome and the postoperative slippage with microsurgical unilateral laminotomy with bilateral decompression is also reported.²³⁾ Which strategy is better for various types of degenerative spondylolisthesis should be examined further in future.

The movements of the dynamic stabilization performed in this report do not use a mechanism involving an artificial disc that constantly moves in conjunction with the movement of the spine. Rather, functioning with a slight load share during accidental movements or falls is anticipated, and we consider it acceptable even if the fusion at the stabilized level occurs over the long term. Nevertheless, the load on the adjacent intervertebral disc is postulated to be significantly less compared to rigid lumbar interbody fusion that is completed in one day is performed. It is necessary in future studies to verify the actual long-term adjacent intervertebral disc disorders.

Saito et al., who invented the D connector, performed PLIF using a dynamization rod (D-PLIF group) and

the conventional rigid PLIF (PLIF group), investigated the rate of fusion, changes in disc height, loosening of the screw, and changes in the alignment of the fixed level.^{12,13)} In the dynamization used in the D-PLIF group, the rod end on the cranial side has stopper, and the intervertebral spacer is stabilized by applying compression as usual. The D connector is then used such that the rod on the cranial side can slide only to the cranial side in reference to the pedicle screw. This report showed that there were no differences in the rate of fusion 1 year postoperatively between the two groups in patients who were ≤ 60 years old. However, in those who were ≥ 60 years old, the rate of fusion was significantly higher in the D-PLIF group (D-PLIF group: 99.1%, PLIF group: 85.2%), and screw loosening was also significantly lower in the D-PLIF group (D-PLIF group: 1.1%, PLIF group: 13.7%). In addition, this report evaluated the adjacent intervertebral disc disorders using % slip, slip angle, and disc height ratio ≥ 7 years postoperatively, and they showed that the changes in each of these parameters were less in the D-PLIF group, indicating less development of adjacent intervertebral disc disorders.

In dynamic stabilization using the D connector, movement remained between the connector made of titanium and the rod, and this may have caused metallosis. However, as mentioned previously, the movement between the D connector and the rod is thought to occur only when a strongly accidental external force is applied. Additionally, constant movement of the connecting part in conjunction with spinal movement is rarely observed even under postoperative dynamic X-ray imaging. Therefore, we believe that the development of metallosis caused by friction is of little concern. The system was invented with the assumption that movement between the connector itself and the rod will remain, and the inventors, Saito et al., have not reported severe metallosis at the time of screw removal after completion of interbody fusion thus far.

The titanium elution and accumulation into the surrounding tissues or various organs is concerned also in the correction surgery for scoliosis, which is not necessary same to dynamic stabilization, for the long fixation with the titanium implants and the long-term their consequences in the body. Regarding this problem, Uchimura et al. measured hair titanium concentrations after surgery in 64 patients who underwent this surgery, and reported the comparison with 36 unaffected volunteers. This investigation suggested that the mean concentrations of titanium elution due to implant wear during mean of 41.3 months after surgery was extremely small, and the restoring rate increased less than

36 months after surgery compared to volunteers. However, the restoring rate indicated no statistical significant differences after this period between the two groups. With these results, they concluded that the effect to human body by the titanium elution from implants was small.²⁴⁾ We also have not encountered problematic changes in muscular signals caused by metallosis on postoperative magnetic resonance imaging. Now, we are preparing to measure hair titanium concentrations of patients more than 2 years after dynamic stabilization under the approval of ethical committee in our hospital, and we are going to present this outcome in future.

Conclusion

Dynamic stabilization with a pedicle screw, connector, and rod that allow movement has the possibility to decrease the development of adjacent vertebral or intervertebral disc disorders, especially in elderly patients, and it may be a useful procedure that facilitates decompression and ensures a certain degree of spinal stabilization. In the present report, dynamic stabilization that allowed slight movement only in the perpendicular direction for mild spondylolisthesis and only in the sagittal direction for suspected instability after hernia excision was performed, and satisfactory short-term outcomes were obtained. Nevertheless, it is necessary in the future to verify which dynamic factor is better to maintain and preserve.

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Conflicts of Interest Disclosure

The authors report no conflict of interest (COI) concerning the materials or methods used in this study or the findings reported in this paper. In addition, authors who are members of The Japan Neurosurgical Society (JNS) have registered online Self-reported COI Disclosure Statement Forums through the website for JNS members.

References

- 1) Ohwada T, Ohkouchi T, Yamamoto T: [Long-term results of PLIF with Steffee VSP system for degenerative spondylolisthesis.] *Spine & Spinal Cord* 17: 193–200, 2004 (Japanese)
- 2) Trouillier H, Birkenmaier C, Rauch A, Weiler C, Kauschke T, Refior HJ: Posterior lumbar interbody

- fusion (PLIF) with cages and local bone graft in the treatment of spinal stenosis. *Acta Orthop Belg* 72: 460–466, 2006
- 3) Yamamoto T, Ohkouchi T, Ohwada T: Clinical and radiological results of PLIF for degenerative spondylolisthesis. *J Mus Res* 2: 181–195, 1998
- 4) Kaito T, Hosono N, Mukai Y, Makino T, Fuji T, Yonenobu K: Induction of early degeneration of the adjacent segment after posterior lumbar interbody fusion by excessive distraction of lumbar disc space. *J Neurosurg Spine* 12: 671–679, 2010
- 5) Cheh G, Bridwell KH, Lenke LG, Buchowski JM, Daubs MD, Kim Y, Baldus C: Adjacent segment disease following lumbar/thoracolumbar fusion with pedicle screw instrumentation: a minimum 5-year follow-up. *Spine* 32: 2253–2257, 2007
- 6) Park P, Garton HJ, Gala VC, Hoff JT, McGillicuddy JE: Adjacent segment disease after lumbar or lumbosacral fusion: review of the literature. *Spine* 29: 1938–1944, 2004
- 7) Hambly MF, Wiltse LL, Raghavan N, Schneiderman G, Koenig C: The transition zone above a lumbosacral fusion. *Spine* 23: 1785–1792, 1998
- 8) Leong JC, Chun SY, Grange WJ, Fang D: Long-term results of lumbar intervertebral disc prolapse. *Spine* 8: 793–799, 1983
- 9) Nakai S, Yoshizawa H, Kobayashi S: Long-term follow-up study of posterior lumbar interbody fusion. *J Spinal Disord* 12: 293–299, 1999
- 10) Seitsalo S, Schlenzka D, Poussa M, Osterman K: Disc degeneration in young patients with isthmic spondylolisthesis treated operatively or conservatively: a long-term follow-up. *Eur Spine J* 6: 393–397, 1997
- 11) Izumida S, Inoue S: [Assessment of treatment for low back pain.] *J Jpn Orthop Assoc* 60: 391–394, 1986 (Japanese)
- 12) Saito T, Matsuya H, Adachi T, Ishihara M, Tani S, Nakagawa T, Ogawa K: [Posterior lumbar interbody fusion using dynamization rod system.] *J Spine Res* 19(2): 228, 2008 (Japanese)
- 13) Saito T, Kushida T, Ishihara M, Adachi T, Tani Y, Iida H: [Degenerative change of adjacent segment in lumbar spine after PLIF using dynamization rod.] *J Spine Res* 20(2): 484, 2009 (Japanese)
- 14) Bridwell KH, Sedgewick TA, O'Brien MF, Lenke LG, Baldus C: The role of fusion and instrumentation in the treatment of degenerative spondylolisthesis with spinal stenosis. *J Spinal Disord* 6: 461–472, 1993
- 15) Kaneda K, Kazama H, Satoh S, Fujiya M: Follow-up study of medial facetectomies and posterolateral fusion with instrumentation in unstable degenerative spondylolisthesis. *Clin Orthop Relat Res* 159–167, 1986
- 16) West JL, Bradford DS, Ogilvie JW: Results of spinal arthrodesis with pedicle screw-plate fixation. *J Bone Joint Surg Am* 73: 1179–1184, 1991
- 17) Zdeblick TA: A prospective, randomized study of lumbar fusion. Preliminary results. *Spine* 18: 983–991, 1993

- 18) Cunningham BW, Kotani Y, McNulty PS, Cappuccino A, McAfee PC: The effect of spinal destabilization and instrumentation on lumbar intradiscal pressure: an in vitro biomechanical analysis. *Spine* 22: 2655–2663, 1997
- 19) Lee CK, Langrana NA: Lumbosacral spinal fusion. A biomechanical study. *Spine* 9: 574–581, 1984
- 20) Lee CK: Accelerated degeneration of the segment adjacent to a lumbar fusion. *Spine* 13: 375–377, 1988
- 21) Lehmann TR, Spratt KF, Tozzi JE, Weinstein JN, Reinartz SJ, el-Khoury GY, Colby H: Long-term follow-up of lower lumbar fusion patients. *Spine* 12: 97–104, 1987
- 22) Lombardi JS, Wiltse LL, Reynolds J, Widell EH, Spencer C: Treatment of degenerative spondylolisthesis. *Spine* 10: 821–827, 1985
- 23) Chang HS, Fujisawa N, Tsuchiya T, Oya S, Matsui T: Degenerative spondylolisthesis does not affect the outcome of unilateral laminotomy with bilateral decompression in patients with lumbar stenosis. *Spine* 39: 400–408, 2014
- 24) Uchimura R, Yamazaki K, Murakami H, Yoshida S, Shimamura T, Sera K: Serum and hair titanium concentration after scoliosis surgery. *NMCC Annual Report* 17: 252–259, 2010

Address reprint requests to: Tatsuya Ohtonari, MD, PhD, Department of Spinal Surgery, Brain Attack Center Ota Memorial Hospital, 3-6-28 Okinogami, Fukuyama, Hiroshima 720-0825, Japan.
e-mail: ohtonari@shouwa.or.jp