Predicting factors of adjacent segment degeneration after long-segment spinal fusion: spinopelvic parameters analysis

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Abstract
Purpose We investigated whether spinopelvic parameters are important prognostic factors for adjacent segment degeneration after long instrumented spinal fusion for degenerative spinal disease.

Methods This uncontrolled, randomized, single arm retrospective study included patients who underwent long instrumented lumbar fusion (fusion levels ≥ 4) in the past 5 years with follow-up for at least 2 years. The inclusion criteria included adult patients (≥40 years of age) with a diagnosis of spinal degeneration who underwent instrumented corrective surgery. The exclusion criteria included preexisting adjacent disc degeneration, combined anterior reconstructive surgery, and distal ASD. Clinical and operative characters were evaluated. Lumbar lordotic angle (LLA), sacral slope angle (SSA), pelvic tilt angle (PTA) and pelvic incidence angle (PIA) were compared preoperatively, postoperatively and at the final follow-up.

Results From 2009 to 2014, 60 patients (30 ASD and 30 non-ASD patients) were enrolled. The average age was 66.82 ± 7.48 years for the study group and 67.97 ± 7.81 years for the control group. There was no statistically significant difference in clinical and operative characteristics. Among all spinopelvic parameters, only pre-, post-operative and final follow-up PIA in ASD group (53.9±10.4[°], 54.6±14.0[°], 54.3±14.1[°]) and non-ASD group (60.3±13.0[°], 61.8±11.3[°], 62.5±11.2[°]) showed statistically significant differences (p<0.05).

Conclusion This study confirms that preoperative, postoperative and final follow-up PIA is a significant factor contributing to the development of adjacent segment degeneration after long instrumented spinal fusion.

Introduction
Decompression and long segmental instrumented fusion are mainstay treatments for adult degenerative scoliosis patients who need a full correction of deformity [1]. The major long-term concern for long segmental spinal fusion is adjacent segment degeneration (ASD). Various studies have proposed risk factors for ASD for short segmental fusion, including the aging process, scarifying posterior ligament complex or overdecompression during surgery and poor sagittal balance after lumbar fusion [2–3]. Sagittal plane imbalance on reconstructive spine surgery has become popular
and is an increasingly recognized cause of postoperative back pain [4–7]. The key concept is that normal sagittal alignment helps individuals remain in a stable posture with less energy consumption. The fused spine of a locked position may cause a loss of lumbar lordosis, a forward shift of the upper trunk [12–14] and subsequent adjacent degeneration.

Various spinopelvic parameters have been proposed to evaluate sagittal balance, including pelvic incidence angle (PIA) [16], sacral slope angle (SSA) [15], and pelvic tilt angle (PTA) [17]. These parameters are common measurements used to assess the morphology of the pelvis with adequate intraobserver and interobserver reliability [18]. The most commonly used parameter is pelvic incidence (PI), which is defined as the angle between the line perpendicular to the sacral endplate at its midpoint and the line connecting the middle axis of the bilateral femoral head to the midpoint, and PI is calculated as the algebraic sum of the SSA and the PTA. Boulay et al. demonstrated excellent the intraobserver and interobserver reliability of these measurements [19]. The C7 plumb line is another measurement useful in evaluating sagittal balance [20–22]. The horizontal distance between the posterosuperior corner of the sacrum and the plumb line drawn from the center of the C7 vertebra (C7 plumb line) is recorded, and the sagittal balance is indicated by the distance [22–24]. The relations between ASD and the spinopelvic parameters of short segmental fusion have been studied [1,2,4,14]. Postoperative flat back, including decreased lumbar lordotic angle (LLA), SSA and increased PTA, may have a negative impact on the adjacent segment [4].

To our knowledge, no existing research has addressed the effect of spinopelvic parameters on proximal ASD of long segmental spinal fusion. Our study is the first retrospective controlled study to determine whether spinopelvic and associated parameters are important prognostic factors for proximal ASD after long segmental spinal fusion.

Materials And Methods
This study is a controlled, open-labeled, randomized, single center retrospective study. From August 2009 to July 2014, 5575 patients with degenerative lumbar scoliosis underwent surgery at our institution. The Chang Gung Medical Foundation Institutional Review Board approved this study (201600408B0) and waived the requirement for informed consent due to the retrospective nature of
this study. The inclusion criteria included fusion levels $\geq 4$ and adult patients ($\geq 40$ years of age) with a diagnosis of spinal degeneration who underwent instrumented corrective surgery. The exclusion criteria included preexisting disc degeneration, spondylolisthesis or junctional kyphoscoliosis of the proximal adjacent segment, combined anterior reconstructive surgery, distal ASD and proximal adjacent level vertebral compression fracture.

Thirty ASD and 30 non-ASD patients were included with a minimal follow-up of 2 years. Pairwise, retrospective, case-control matching was performed between these two groups. Thirty patients from the ASD group were randomly selected as the study group. Another computer-generated thirty patients from the non-ASD group with potential matching criteria, including similar diagnosis, pathological levels ($\leq 1$ level difference), sex and age were included as the control group.

Clinical characteristics, including sex, age, duration of follow-up and the preoperative and postoperative Oswestry Disability Index (ODI) [14], were assessed. Operative data, including the number of levels fused and upper instrumented vertebrae (UIV) above T12, were also evaluated.

Radiographic evaluation

The investigator measured the LLA, SSA, PTA, and PIA preoperatively, postoperatively and at the final follow-up. Radiographic ASD was defined as follows: 1. adjacent segment spondylolisthesis $\geq 4$ mm, 2. adjacent segmental kyphosis $\geq 10^\circ$, 3. complete collapse of adjacent disc space (Figure) or 4. Modic type 2 or 3 adjacent degenerative discs.

Statistical analysis

A statistical software program (SPSS for Windows, version 12.0; SPSS Inc., Chicago, IL) was used to analyze the preoperative and postoperative parameters in both groups. All data are presented as the mean $\pm$ standard deviation. The differences between the study and control groups in spinopelvic parameters and lumbar lordosis were evaluated using Fisher’s exact test and the Mann-Whitney U test. We compared the clinical and spinopelvic parameters at the preoperative, postoperative, and follow-up periods. The statistical significance for all tests was set at a $p$ value of less than 0.05.

Results

The clinical and operative characteristics of both groups are shown in Table 1. A total of 60 patients
were analyzed in this study (53 females and 7 males), of which the 30 patients who developed ASD during follow-up were included in the study group and the other 30 patients were included in the control group. The average age was 66.82 ± 7.48 years for the study group and 67.97 ± 7.81 years for the control group. All patients received clinical and radiographic follow-up for a minimum of 24 months, with an average follow-up of 48 ±22 months in the ASD group and 52 ±26 months in the non-ASD group. No statistically significant differences were detected with respect to age, sex, follow-up period, mean pre- and postoperative ODI, number of levels fused and UIV above T12.

The details of these radiographic spinopelvic parameters are listed in Table 2. The preoperative, postoperative and final follow-up LLA, PIA, SSA, and PTA were calculated on standing lateral X-ray images. Pre-, post-operative and final follow-up PIA in ASD group and non-ASD group were 53.9±10.4, 54.6±14.0, 54.3±14.1 and 60.3±13.0, 61.8±11.3, 62.5±11.2 respectively. The patients in the ASD group showed significantly lower pre-, post-operative and final follow-up PIA values than those in the non-ASD group (p<0.05). There was no statistically significant difference in other parameters between the groups.

The corrected radiographic parameters, defined as the postoperative angle minus the preoperative angle and the final follow-up angle minus the preoperative angle, are listed in Table 3. There was no statistically significant difference in other parameters between the groups. The value of corrected PIA was less than 5 degrees, which was in the range of interobserver mistakes.

**Discussion**

The most common long-term complication of adult degenerative scoliosis patients who receive corrective surgery is ASD. According to previous studies, the reasons and risk factors for ASD after long segmental spinal surgery remain controversial. Some reports have indicated that aging and mechanical and biomechanical changes in the fused segment were risk factors [14,25,26], but unrandomized controlled patient characteristics, preoperative surgical data, and mixed short and long segmental spinal fusions generated doubtful results.

Whether the possibility of ASD increases as more motion segments are included in spinal fusion remains unclear. Dehnokhalaji et al. [27] found that the length of fusion was not significant in
developing ASD, but only the distal intervertebral disc was discussed. Bassani et al. [28] proposed that patients with single-level fusions were more likely to have clinical ASD than those with multilevel fusions [29]. Gillet et al. included patients with 5 or more fusion levels and found that the risk of ASD was not increased [30]. However, in our studies, no significant difference in the number of fusion levels suggested that the adjacent degeneration was not affected by the fusion levels.

The rib cage provides a stabilizing effect and may balance the detrimental effect of long-level fusion in the development of ASD. These findings may be attributed to the bracing effect of the rib cage. Thus, the recommended length of fusion should be extended to the thoracic area when treating patients with ASD proximal to a prior fusion [30]. In our study, extending the fusion level to the thoracic spine did not increase the risk of ASD (p>0.05); thus, “rib cage protection” had no effect because sagittal alignment has a more profound influence than structural anatomical protection.

PI is a morphological parameter that plays a key role in the regulation of positional pelvic and spinal factors [14,31]. The potential for variations in spinal curves is associated with variations in pelvic positional parameters. For the same PI, SS and PT can vary, with the following relation among them:

\[
\text{PI (morphological)} = \text{SS (positional)} + \text{PT (positional)}
\]

PI creates different lordosis values to allow conditions conducive to standing posture and gait, according to the principle of biomechanical economy [14]. In contrast, we found that lower PIA patients may be a contributing factor to the development of ASD after long spinal fusion (Table 2). Many studies [32–38] have focused on how to correct the sagittal profile, including increased LLA, reduced normal C7 plumb line and PTA, but our results show that there was no significant significant difference between the incidence of ASD with preoperative and postoperative spinopelvic parameters, except for PIA. The PI, or pelvic base angle, is a useful descriptive terminology and an extremely important parameter for determining the global spinal balance of an individual [39,40]. The PI thus determines the relative position of the sacral plate with respect to the femoral head and the amount of lumbar lordosis required to maintain an erect posture [39–42]. In summary, higher PIA was always accompanied by higher LLA due to higher SSA, which decreased the adjacent segment facet pressure and reduced the energetic consumption of erect muscle. The accepted postoperative sagittal profile did not indicate proper preservation of an
erect back muscle. One study [43] found significant geometrical reductions of erector spinae by approximately 26 and 14% at the L5-S1 and L4-L5 levels, respectively, after posterior lumbar surgery. Another study [44] found that fusion generated a 12% reduction in the total multifidus muscle force during erect standing, and 10.5% reductions were produced during 20° flexion. In our study, muscle weakness may be one of the major causes of adjacent level degeneration.

Although the PIA is an anatomical indicator of sagittal balance and is simple to estimate, the correlation between the PIA and ASD has not been determined. Our study revealed that the lower preoperative PIA contributed to the development of ASD after long segmental fusion maybe result from the suspicious of lower amount of back erect muscle. A decreased LLA resulting from the lesser postoperative and final follow-up PIA may lead to an anterior shift of the upper body trunk. The patient would have to spend more energy in maintaining sagittal balance, which may cause the adjacent level to sustain more compressive load [45]. Eventually, the back muscle fatigues, and ASD develops.

Limitations of the study
A prospective study with the same allocation criteria and more patients should be included to establish a more powerful design model. Geographic results, such as magnetic resonance scanning of erector spinae, should be compared to indicate the final results. Studies conducted in multiple centers could decrease the selection bias.

Conclusion
A lower preoperative, postoperative, and final follow-up PIA is a significant factor contributing to the development of ASD after long instrumented spinal fusion for degenerative spinal disease. Compared with other anatomical parameters, lower PIA with possible long-term decreased erector spinae have a synergistic impact on adjacent degeneration.

Abbreviations
ASD adjacent segment degeneration
PI pelvic incidence
PIA pelvic incidence angle
LLA Lumbar lordotic angle
SSA sacral slope angle

PTA pelvic tilt angle

Declarations

**Ethics approval and consent to participate:**

The Chang Gung Medical Foundation Institutional Review Board approved this study (201600408B0) and waived the requirement for informed consent due to the retrospective nature of this study.

**Availability of data and materials**

The data supporting the findings of this study are available from Chang Gung Memorial Hospital, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. However, the data are available from the corresponding author upon reasonable request and with permission from Chang Gung Memorial Hospital.

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**Authors’ contributions:**

P-YC, F-CK and M-KH participated in the study design, data collection, the statistical analysis and manuscript writing. P-LL, W-JC, and T-TT participated in the study design. T-TT and C-WY used the iThenticate report to assist in ensuring that the correct attribution to the original source was made. F-CK and M-KH advised and assisted the manuscript writing. All authors read and approved the final manuscript.

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**Conflicting interests:**

The authors declare that there is no conflict of interest.

**Consent for publication**
Written informed consent for publication were obtained

References

1. Aebi M. The adult scoliosis. Eur Spine J 2005;14:925-948.

2. Wen-Jer Chen, Po-Liang Lai, Lih-Huei Chen: Adjacent Instability after Instrumented Lumbar Fusion. Chang Gung Med J 2003;26:792-8.

3. Ploumis A, Transfeldt EE, Gilbert TJ, et al. Degenerative lumbar scoliosis: radiographic correlation of lateral rotatory olisthesis with neural canal dimensions. Spine (Phila Pa 1976) 2006; 31:2353-2358.

4. Le Huec JC, Faundez A, Dominguez D, Hoffmeyer P, Aunoble S. Evidence showing the relationship between sagittal balance and clinical outcomes in surgical treatment of degenerative spinal diseases: a literature review. Int Orthop. 2015; Jan;39(1):87-95.

5. Yan C, Gao X, Sun Y, Dong Z, Shen Y. The preoperative predictors for subsequent degeneration in L5-S1 disc after long fusion arthrodesis terminating at L5 in patients with adult scoliosis: focus on spinopelvic parameters. J Orthop Surg Res. 2018; Nov 13;13(1):285.

6. O'Shaughnessy BA, Ondra SL. Measuring, preserving, and restoring sagittal spinal balance. Neurosurg Clin N Am 2007;18:347 – 356

7. Lih-Huei Chen, Po-Liang Lai, Ching-Lung Tai, et al. The effect of interspinous ligament integrity on adjacent segment instability after lumbar instrumentation and laminectomy--an experimental study in porcine model. Biomed Mater Eng. 2006;16(4):261-7

8. Lazennec JY, Ramare S, Arafati N, et al. Sagittal alignment in lumbosacral fusion: relations between radiological parameters and pain. Eur Spine J 2000;9:47 – 55

9. Godde S, Fritsch E, Dienst M, Kohn D. Influence of cage geometry on sagittal alignment in instrumented posterior lumbar interbody fusion. Spine (Phila Pa 1976)
10. Goldstein JA, Macenski MJ, Griffith SL, et al. Lumbar sagittal alignment after fusion with a threaded interbody cage. Spine (Phila Pa 1976). 2001; 26:1137 – 1142.

11. Ghandhari H, Ameri Mahabadi M, Nikouei F, et al. The Role of Spinopelvic Parameters in Clinical Outcomes of Spinal Osteotomies in Patients with Sagittal Imbalance. Arch Bone Jt Surg. 2018; 6(4):324-330.

12. Wen-Jer Chen, Po-Liang Lai, Ching-Lung Tai, et al. The effect of sagittal alignment on adjacent joint mobility after lumbar instrumentation--a biomechanical study of lumbar vertebrae in a porcine model. Clinical Biomechanics 2004; 19.763–768

13. Wen-Jer Chen, Po-Liang Lai, Chi-Chien Niu, et al. Surgical Treatment of Adjacent Instability After Lumbar Spine Fusion . Spine (Phila Pa 1976). 2001; 26:E519-E524.

14. Hsieh MK, Kao FC, Chen WJ, et a. The influence of spinopelvic parameters on adjacent-segment degeneration after short spinal fusion for degenerative spondylolisthesis. J Neurosurg Spine. 2018 Oct; 29(4):407-413.

15. Okuda T, Fujita T, Kaneuji A, et al. Stage-specific sagittal spinopelvic alignment changes in osteoarthritis of the hip secondary to developmental hip dysplasia. Spine (Phila Pa 1976). 2007 Dec 15; 32(26):E816-9.

16. Roh HS, Cho WJ, Ryu WJ, et al. The change of pain and lumbosacral sagittal alignment after sling exercise therapy for patients with chronic low back pain. J Phys Ther Sci. 2016 Oct; 28(10):2789-2792.

17. Zeng Z, Hai Y, Bi Y, et al. Characteristics of sagittal spinopelvic alignment in asymptomatic Han Chinese adults. Exp Ther Med. 2018 Nov; 16(5):4107-4113.

18. Jackson RP, Phipps T, Hales C, et al. Pelvic lordosis and alignment in spondylolisthesis. Spine. 2003; 28:151-160.

19. Boulay C, Tardieu C, Hecquet J, et al. Anatomical reliability of two fundamental
radiological and clinical pelvic parameters: incidence and thickness. Eur J Orthop Surg Traumatol. 2005;15:197-204.

20. Hanson DS, Bridwell KH, Rhee JM, et al. Correlation of pelvic incidence with low- and high-grade isthmic spondylolisthesis. Spine.2002;27:2026-2029.

21. Huang RP, Bohlman HH, Thompson GH, et al. Predictive value of pelvic incidence in progression of spondylolisthesis. Spine.2003;28:2381-2385; discussion 2385.

22. Gong H, Sun L, Yang R, et al. Changes of upright body posture in the sagittal plane of men and women occurring with aging - a cross sectional study. BMC Geriatr. 2019 Mar 5;19(1):71.

23. Po-Liang Lai, Lih-Huei Chen, Chi-Chien Niu, et al. Effect of Postoperative Lumbar Sagittal Alignment on the Development of Adjacent Instability. J Spinal Disord Tech 2004;17:353-357

24. Boulay C, Tardieu C, Hecquet J, et al. Sagittal alignment of spine and pelvis regulated by pelvic incidence: standard values and prediction of lordosis. Eur Spine J 15:415-422, 2006

25. Legaye J, Duval-Beaupere G. Sagittal plane alignment of the spine and gravity: a radiological and clinical evaluation. Acta Orthop Belg 71:213-220, 2005

26. Bassani T, Casaroli G, Galbusera F. Dependence of lumbar loads on spinopelvic sagittal alignment: An evaluation based on musculoskeletal modeling. PLoS One. 2019 Mar 18;14(3):e0207997.

27. Dehnokhalaji M, Golbakhsh MR, Siavashi B, et al. Evaluation of the Degenerative Changes of the Distal Intervertebral Discs after Internal Fixation Surgery in Adolescent Idiopathic Scoliosis. Asian Spine J. 2018 Dec;12(6):1060-1068.

28. Ghiselli G, Wang JC, Bhatia NN, et al. Adjacent segment degeneration in the lumbar spine. J Bone Joint Surg Am 2004;86:1497-503.

29. Faldini C, Di Martino A, Borghi R, et al. Long vs. short fusions for adult lumbar degenerative
scoliosis: does balance matters? Eur Spine J. 2015 Nov;24 Suppl 7:887-92.

30. Gillet P. The fate of the adjacent motion segment after lumbar fusion. J Spinal Disord Tech 2003;16:338-45.

31. Schwarz F, Burckhart M, McLean AL, et al. Risk Factors for Adjacent Fractures After Cement-Augmented Thoracolumbar Pedicle Screw Instrumentation. Int J Spine Surg. 2018 Oct 15;12(5):565-570.

32. Kumar MN, Baklanov A, Chopin D: Correlation between sagittal plane changes and adjacent segment degeneration following lumbar spine fusion. Eur Spine J 10:314-319, 2001

33. Marty C, Boisaubert B, Descamps H, et al. The sagittal anatomy of the sacrum among young adults, infants, and spondylolisthesis patients. Eur Spine J 11:119-125, 2002

34. Boulay C, Tardieu C, Hecquet J, et al: Sagittal alignment of spine and pelvis regulated by pelvic incidence: standard values and prediction of lordosis. Eur Spine J 15:415-422, 2006

35. Legaye J. The femoro-sacral posterior angle: an anatomical sagittal pelvic parameter usable with dome-shaped sacrum. Eur Spine J 16:219-225, 2006

36. Legaye J, Duval-Beaupere G. Sagittal plane alignment of the spine and gravity: a radiological and clinical evaluation. Acta Orthop Belg 71:213-220, 2005

37. Lee SH, Lim CW, Choi KY, et al. Effect of Spine-Pelvis Relationship in Total Hip Arthroplasty. Hip Pelvis. 2019 Mar;31(1):4-10.

38. Faundez AA, Richards J, Maxy P, et al. The mechanism in junctional failure of thoraco-lumbar fusions. Part II: Analysis of a series of PJK after thoraco-lumbar fusion to determine parameters allowing to predict the risk of junctional breakdown. Eur Spine J. 2018 Feb;27(Suppl 1):139-148.

39. Sparrey CJ, Bailey JF, Safae M, et al. Etiology of lumbar lordosis and its pathophysiology: a review of the evolution of lumbar lordosis, and the mechanics and
biology of lumbar degeneration. Neurosurg. Focus 2014; 36:E1.

40. Terran J, Schwab F, Shaffrey CI, Smith JS, Devos P, et al. The SRS-schwab adult spinal deformity classification: Assessment and clinical correlations based on a prospective operative and non-operative cohort. Neurosurgery 2013; 73: 559-568.

41. Yamada K, Abe Y, Yanagibashi Y, et al. Mid- and long-term clinical outcomes of corrective fusion surgery which did not achieve sufficient pelvic incidence minus lumbar lordosis value for adult spinal deformity. Scoliosis 2015; 10: S17.

42. Ailon T, Smith JS, Shaffrey CI, et al. Degenerative spinal deformity. Neurosurgery 2015; 77: S75-S91

43. Ghiasi MS, Arjmand N, Shirazi-Adl A, et al. Cross-sectional area of human trunk paraspinal muscles before and after posterior lumbar surgery using magnetic resonance imaging. Eur Spine J. 2016 Mar; 25(3): 774-82.

44. Kim YE, Choi HW. Does stabilization of the degenerative lumbar spine itself produce multifidus atrophy? Med Eng Phys. 2017 Nov; 49: 63-70.

45. Rohlmann A, Zander T, Bergmann G. Spinal loads after osteoporotic vertebral fractures treated by vertebroplasty or kyphoplasty. Eur Spine J 2006; 15: 1255-1264.

Tables

Table 1 Clinical and operative characteristics of both groups

| Character                          | ASD group (n=30) | Non-ASD group (n=30) |
|-----------------------------------|-----------------|----------------------|
| Gender (female/male)              | 27/3            | 26/4                 |
| Age (mean ± SD)                   | 66.82 ± 7.48    | 67.97 ± 7.81         |
| Follow-up (mean ± SD)             | 48 ±22 months   | 52 ±26 months        |
| Mean preop ODI (mean ± SD)        | 28.93 ± 7.69    | 30.57 ± 7.59         |
| Mean final follow-up ODI (mean ± SD) | 32.97 ± 10.69  | 26.13 ± 8.69         |
| No. of levels fused               | 4.83± 0.23      | 4.74± 0.21           |
| UIV above T12                      | 7 (23.3%)       | 5 (16.7%)            |

No. of levels fused: number of levels fused

ODI: Oswestry Disability Index

UIV: upper instrumented vertebrae

Table 2 Radiographic parameters of both groups
Table 3 Corrected radiographic parameters

| Radiographic parameters | ASD group (n=30) | Non-ASD group (n=30) | P value |
|-------------------------|------------------|----------------------|---------|
| LLA post-pre            | 4.2±10.0         | 2.6±9.7              | >0.05   |
| Final-pre               | -0.6±11.3        | -2.3±10.6            | >0.05   |
| PIA post-pre            | 4.1±8.5          | 3.7±13.3             | >0.05   |
| Final-pre               | 1.8±10.1         | 1.5±17.1             | >0.05   |
| SSA post-pre            | -3.8±8.1         | -1.2±11.6            | >0.05   |
| Final-pre               | -0.4±9.5         | 1.5±11.8             | >0.05   |
| PTA post-pre            | 2.0±10.1         | 2.5±14.3             | >0.05   |
| Final-pre               | 2.1±18.2         | 3.4±15.2             | >0.05   |

Post-pre: Postoperative angle minus preoperative angle

Final-pre: Final F/U angle minus preoperative angle

Figures
A patient underwent long segmental spinal instrumented fusion from L2 to L5. Postoperative images (a,b) revealed adequate implantation without adjacent degeneration. Solid fusion was achieved after 26 months, but symptomatic adjacent segment degeneration L1-2 developed (c,d). Magnetic resonance scanning revealed canal stenosis and disc protrusion over L1-2 (e,f).

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