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

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Research article

Keywords: adjacent segment degeneration, long-segment spinal fusion, pelvic incidence, pelvic tilt, sacrum slope

Posted Date: April 6th, 2020

DOI: https://doi.org/10.21203/rs.2.18590/v2

Abstract

Background We investigated whether spinopelvic parameters are important prognostic factors causing adjacent segment degeneration (ASD) 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. Angle of lumbar lordosis (LLA), sacral slope (SSA), pelvic tilt (PTA) and pelvic incidence (PIA) were compared preoperatively, postoperatively and at the final follow-up.

Results From 2009 to 2014, 60 patients (30 ASD and 30 non-ASD) 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 ASD 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 after short segmental fusion, including the aging process, sagittal imbalance after lumbar fusion and iatrogenic sacrifice of posterior ligament complex during decompression[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[8–10] and subsequent adjacent degeneration.

Various spinopelvic parameters have been proposed to evaluate sagittal balance, including pelvic incidence angle (PIA)[11], sacral slope angle (SSA)[12], and pelvic tilt angle (PTA)[13]. These parameters are common measurements used to assess the morphology of the pelvis with adequate intra-observer and inter-observer reliability[14]. Pelvic incidence angle (PIA), the most commonly applied parameters in spinal pelvic analysis, which is measured between the line perpendicular to the sacral endplate from its midpoint and the line connecting the middle axis of the bilateral femoral head to the midpoint; PIA is calculated as the algebraic sum of the SSA and the PTA. Boulay et al. demonstrated excellent the intra-observer and inter-observer reliability of these measurements[15]. The C7 plumb line is another measurement useful in evaluating sagittal balance[16–18]. The horizontal distance between the posterior superior corner of the sacrum and the vertical reference line from the center of the C7 vertebra (C7 plumb line) is defined , and the sagittal balance is indicated by the distance[15,17,19]. The relations between ASD and the spinopelvic parameters of short segmental fusion have been studied[1,2,5,10]. Postoperative flat back, including decreased lumbar lordotic angle (LLA), SSA and increased PTA, may have a negative impact on the adjacent segment[5].

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 parameters are important prognostic factors for proximal ASD after long segmental spinal fusion.

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 in our hospital. The waived requirement of informed consent of the patients was approved by the Chang Gung Medical Foundation Institutional Review Board (201600408B0) because of the retrospective cohort. The inclusion criteria included fusion levels≥4 and adult patients (≥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 fractures. 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. Thirty patients from the non-ASD group with potential matching criteria, including similar diagnosis, pathological levels (≤ 1 level difference), sex and age were included as the control group. Clinical characteristics, including sex, age, duration of follow-up and the pre-/ post-operative Oswestry Disability Index (ODI)[20,21] 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 over 4 mm; 2. adjacent segmental kyphosis over 10°; 3. adjacent disc space complete collapsed (Figure 1); 4. above Modic type 2 change of adjacent disc[22]. A patient without ASD was provided as figure 2.

Statistical analysis

A statistical software program (IBM SPSS Statistics v. 24.0 (Armonk, NY: IBM Corp.)) was used to analyze the preoperative and postoperative parameters in both groups. All data are presented as the mean ± standard deviation. The differences between the study and control groups in spinopelvic parameters and lumbar lordosis were evaluated using independent-T 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. The number of levels fused was 4.83± 0.23 in ASD group and 4.74± 0.21 in non-ASD group. The upper instrumented vertebrae above T12 was 7 patients (23.3%) in ASD group, and 5 (16.7%) in 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 ($p<0.05$). Pre-, post-operative and final follow-up SSA in ASD group and non-ASD group were 24.5±9.5°, 30.6±12.7°, 26.4±13.8°and 29.6±12.9°, 33.4±9.1°, 31.2±12.0°respectively; LLA in ASD group and non-ASD group were 17.7±14.2°, 21.9±11.5°, 17.1±11.3°and 24.1±11.8°, 26.2±12.6°, 21.8±13.2° respectively. There was no statistically significant difference of LLA, SSA and PTA in pre-, post-operative and final follow-up 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 inter-observer mistakes.

Discussion

The most common long-term complication of adult degenerative scoliosis patients who receive corrective surgery is ASD[23,24]. 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 biomechanical changes in the fused segment were risk factors[10,25,26], 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 fusion level was not a significant factor in contributing ASD, but only the distal intervertebral disc was compared. Faldini et al. proposed that clinical ASD could not be decided by levels of fusion because different operation methods were made: radiculopathy in short fusion group with more properly aligned spine versus spinal deformity related back pain in long fusion group[28]. Gillet et al. included patients with five or more fusion levels and found that the risk of ASD was not increased [29]. However, in our studies, the number of levels fused was 4.83± 0.23 in ASD group and 4.74± 0.21 in non-ASD group without significant difference 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[29]. In our study, the upper instrumented vertebrae above T12 was 7 patients (23.3%) in ASD group, and 5 (16.7%) in non-ASD group without significant difference which means extending the fusion level to the thoracic spine did not alter the risk of ASD; thus, “rib cage protection” had no effect because sagittal alignment has a more profound influence than structural anatomical protection.

The potential for variations in spinal curves is associated with two coordinating pelvic positional parameters. PIA (morphological) is calculated as the algebraic sum of the SSA (positional) and the PTA (positional) which means SSA and PTA could adjust reversely to keep PIA constant[3031]. Faldini et al analyzed changes in spino-pelvic parameters after surgery of high-grade lumbar isthmic spondylolisthesis in 41 patients and found that failure of instrumentation was significantly correlated with higher post-operative PTA[32]. In contrast, we found that lower PIA patients may be a contributing factor to the development of ASD after long spinal fusion (Table 2). The different finding maybe resulted from different diagnosis and operations. Many studies[25,33–38] have focused on how to correct the sagittal profile, including increased LLA, reduced normal C7 plumb line and PTA, but our results showed that there was no significant significant difference between the incidence of ASD with the correction of all spinopelvic parameters (Table 3). Only preoperative, postoperative and follow-up PIA were responsible for the progression of ASD. The PIA, 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 PIA thus implies the relative angle of 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, which is compatible with our results. The SSA and LLA in non-ASD group were larger than in ASD group in pre-, post-operative and follow-up measurements. 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[43,44]. A decreased LLA resulting from the lesser postoperative and final follow-up PIA may lead to an anterior shift of the upper body trunk[4346]. The patient would have to spend more energy in maintaining sagittal balance, which may cause the adjacent level to sustain more compressive load[47]. Eventually, the back muscle fatigues, and ASD develops. Preservation of back muscle plays a more important role than anatomical correction in preventing ASD in low PIA patients.

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 follow-up PIA is a significant factor contributing to 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

PIA pelvic incidence angle

LLA Lumbar lordotic angle

SSA sacral slope angle

PTA pelvic tilt angle

Declarations

Ethics approval and consent to participate:

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

Consent to publish

The consent form must state that the details/images/videos will be freely available on the internet and may be seen by the general public.

Availability of data and materials

The data supporting the findings of this study were available from Chang Gung Memorial Hospital without publicly availability. However, the data belonging to Chang Gung Memorial Hospital are accessible under reasonable request through the corresponding author.

Competing Interests:

The authors declare that there is no conflict of interest.

Funding:

This work was supported by Chang Gung Memorial Hospital (grant No. CMRPG3F2051), which participated in the design of the study and collection, and interpretation of analytical data.

Authors' contributions:

PYC, FCK and MKH participated in the study design, data collection, the statistical analysis and manuscript writing. PLL, WJC, and TTT provided conceptualization, funding acquisition and validity of data. TTT and CWY used the plagiarism software to confirm the originality. MKH and CWY assisted in the final writing editing and supervision.

Acknowledgments:

The authors wound like to thank the statistical assistance and acknowledge the support of the Maintenance Project of the Center for Big Data Analytics and Statistics (Grant CLRPG3D0046) at Chang Gung Memorial Hospital for statistical consultation and data analysis.

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Tables

Table 1 Clinical and operative characteristics of both groups

Character	ASD group (n=30)	Non-ASD group (n=30)	*P* value
Gender (female/male)	27/3	26/4	0.992
Age (mean ± SD)	66.82 ± 7.48	67.97 ± 7.81	0.796
Follow-up (mean ± SD)	48 ±22 months	52 ±26 months	0.872
Mean preop ODI (mean ± SD)	28.93 ± 7.69	30.57 ± 7.59	0.706
Mean final follow-up ODI (mean ± SD)	32.97 ± 10.69	26.13 ± 8.69	0.388
No. of levels fused	4.83± 0.23	4.74± 0.21	0.993
UIV above T12	7 (23.3%)	5 (16.7%)	0.067

No. of levels fused: number of levels fused

ODI: Oswestry Disability Index

UIV: upper instrumented vertebrae

Table 2 Radiographic parameters of both groups

Radiographic parameters	ASD group (n=30)	Non-ASD group (n=30)	*P* value
LLA preoperative	17.7±14.2	24.1±11.8	0.072
postoperative	21.9±11.5	26.2±12.6	0.181
Final F/U	17.1±11.3	21.8±13.2	0.152
PIA preoperative	53.9±10.4	60.3±13.0	0.020*
postoperative	54.6±14.0	61.8±11.3	0.042*
Final F/U	54.3±14.1	62.5±11.2	0.019*
SSA preoperative	24.5±9.5	29.6±12.9	0.102
postoperative	30.6±12.7	33.4±9.1	0.345
Final F/U	26.4±13.8	31.2±12.0	0.169
PTA preoperative	28.5±6.6	29.2±9.1	0.796
postoperative	23.0±6.8	27.4±6.2	0.063
Final F/U	23.0±6.8	30.4±8.1	0.290

All data are given as the mean ± SD unless otherwise indicated.

*Statistical significance was defined as $p<0.05$.

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	0.557
Final-pre	-0.6±11.3	-2.3±10.6	0.573
PIA post-pre	4.1±8.5	3.7±13.3	0.433
Final-pre	1.8±10.1	1.5±17.1	0.943
SSA post-pre	-3.8±8.1	-1.2±11.6	0.384
Final-pre	-0.4±9.5	1.5±11.8	0.515
PTA post-pre	2.0±10.1	2.5±14.3	0.881
Final-pre	2.1±18.2	3.4±15.2	0.777

Post-pre: Postoperative angle minus preoperative angle

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

Figures

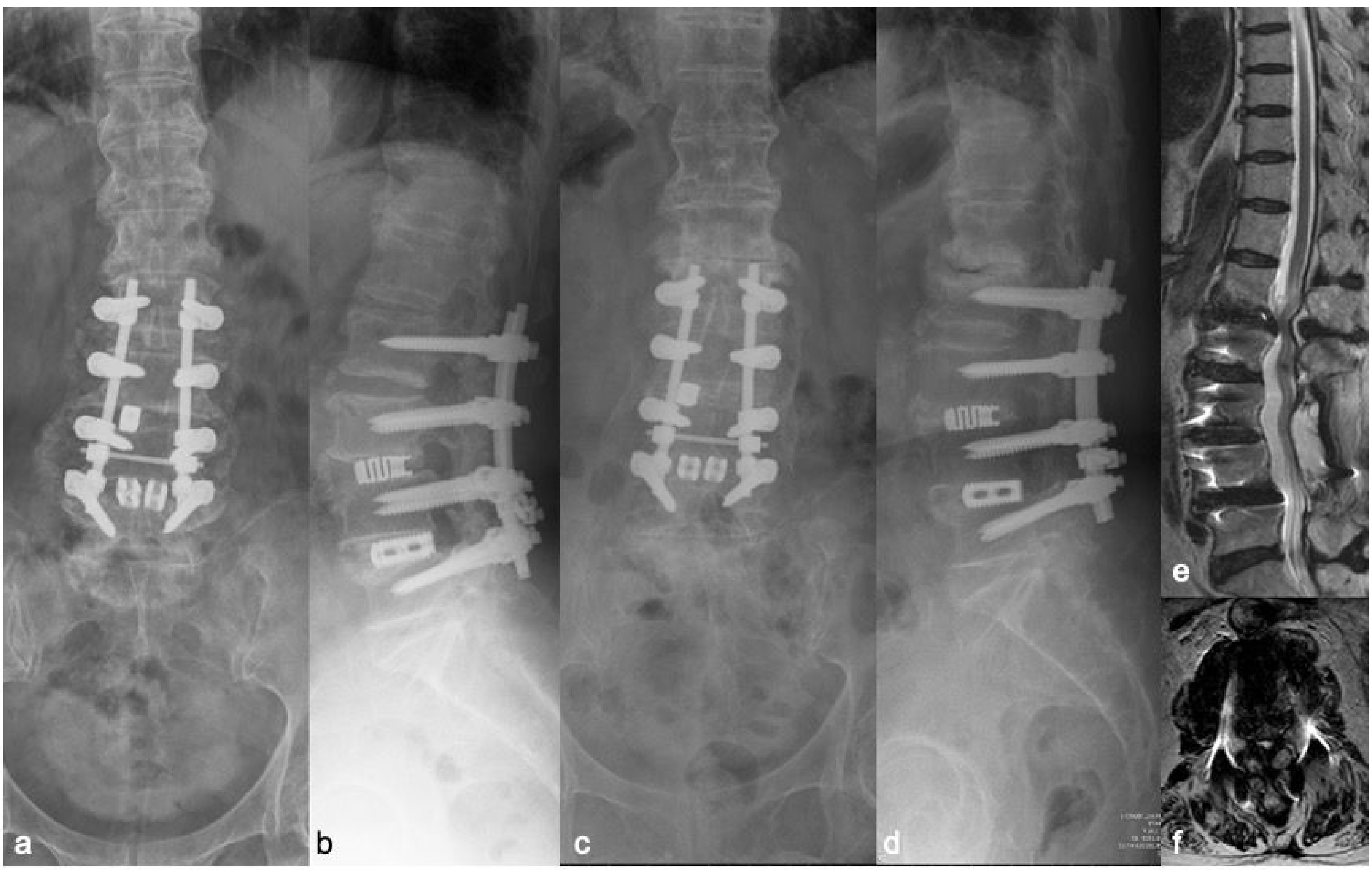

Figure 1

A 59 years-old male 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). The pre-operative, post-operative and follow-up values of LLA, PIA, SSA, PTA were 14.6, 13.0, 9.2; 43.4, 45.5, 51.1; 17.7, 25.1, 23.1; 25.7, 20.3, 28.0, respectively. Magnetic resonance scanning in the final follow-up revealed canal stenosis and disc protrusion over L1-2 (e, f). Lower than average PIA wound be the reason why adjacent segment degeneration eventually developed.

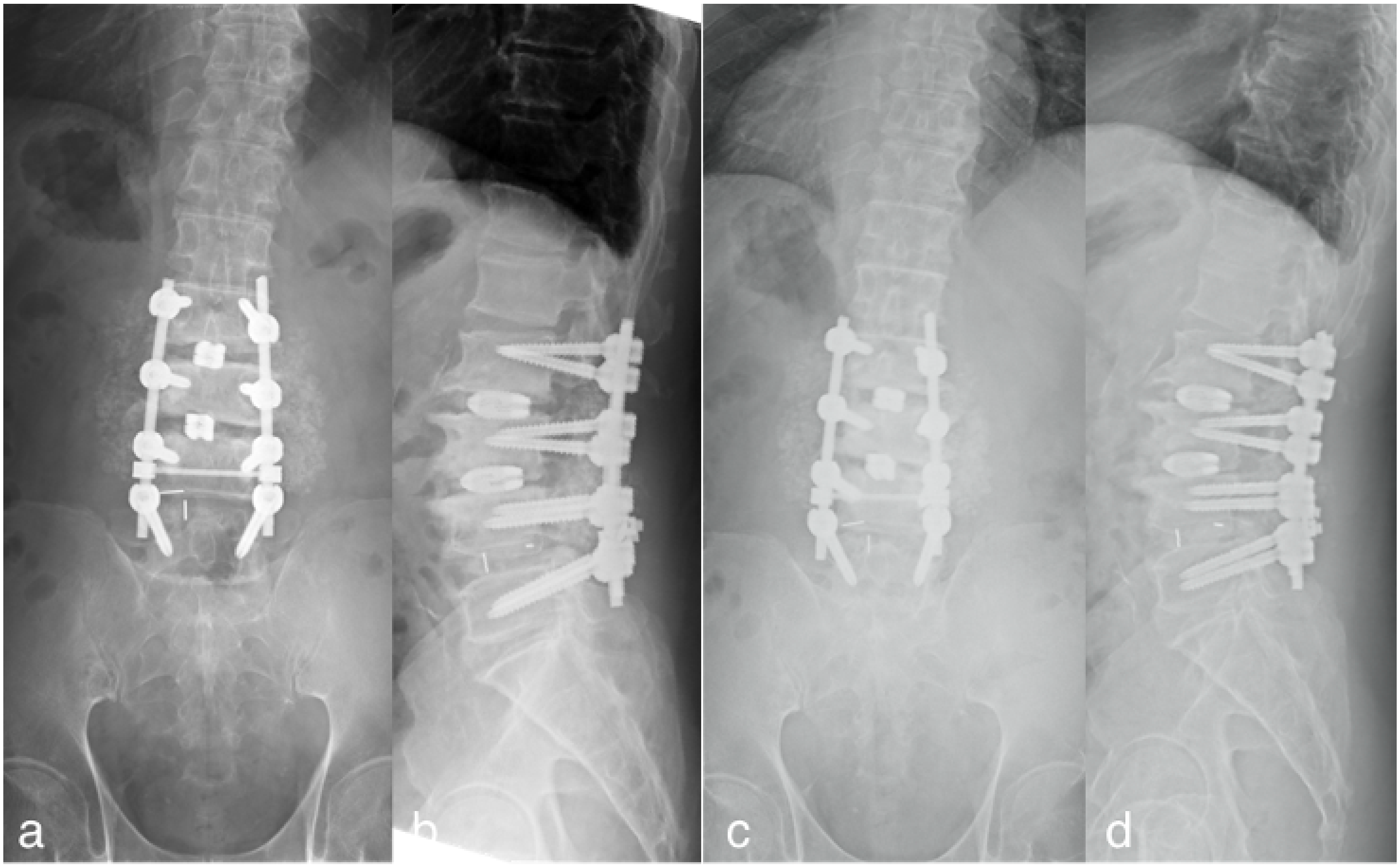

Figure 2

Long segmental spinal instrumented fusion from L2 to L5 was performed in a 62-year-old female. Adequate implantation without proximal adjacent segment destruction post-operatively was showed on image (a, b). Solid fusion was achieved after 25 months without radiographic or clinical proximal adjacent segment degeneration (c, d). The values of LLA, PIA, SSA, PTA pre-operatively, post-operatively and at final follow-up were 26.0, 35.1, 23.2; 68.3, 67.8, 64.6; 40.8, 37.2, 30.0; 27.5, 30.6, 34.6, respectively.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- STROBEassupplementarydata2.doc
- 586TemplateESJslides.pptx
- Rawdataassupplemenattydata1.xlsx