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ORIGINAL ARTICLE

Long vs. short fusions for adult lumbar degenerative scoliosis: does balance matters?

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Abstract
Purpose Surgery of adult scoliosis was based upon coronal plane radiographical analysis using Cobb angle measurements, but recently it has been demonstrated that sagittal spinopelvic alignment plays a critical role in determining the final outcome. The aim of this paper is to compare the clinical and radiological results of 81 patients affected by adult scoliosis, treated with short or long fusions, and followed for 2–5 year follow-up.
Materials and methods 81 patients affected by degenerative lumbar scoliosis managed by posterior-only surgery were retrospectively evaluated. Fifty-seven patients underwent to a short fusion procedure, while 24 had a long fusion. Clinical and radiographic coronal and sagittal spinopelvic parameters were compared between the two groups.
Results Coronal Cobb angle was 24° preoperatively and passed to 12° in the short fusion group, while changed from 45° to 10° in the long fusion group. Lumbar lordosis was 45° preoperatively and 60° at final follow-up in the short fusion group passed from 24° to 55° in the long fusion group. Sacral slope passed from 25° to 45° in the short fusion group, while from 10° to 40° in the long fusion group. Pelvic tilt passed from 24° to 13° in the short fusion group, and from 28° to 23° in the long fusion group.
Conclusion Surgical treatment of degenerative lumbar scoliosis improved balance and alignment of the spine, and also the coronal plane in terms of Cobb angle. These results were associated to a consistent clinical improvement and an acceptable rate of complications.

Keywords Spine surgery · Adult scoliosis · Spinopelvic alignment

Introduction

Adult scoliosis is a complex spinal disorder affecting a significant number of elderly adults, resulting from a combination of osteoporosis and degenerative disc disease with asymmetric degeneration and subsequent rotatory subluxation of multiple lumbar functional spinal units [1–6].

Peculiar pathoanatomic features distinguish and characterize degenerative lumbar scoliosis patients: it is the result of a progressive, coupled, asymmetrical degeneration of the intervertebral discs and facet joint complexes [2, 7]. In addition, both an asymmetrical collapse of the vertebral bodies and lateral slippage may occur, which further increases the degree of coronal plane deformity [8]. This phenomenon is most commonly observed as a focal deformity, involving only 1 or 2 motion segments, and occurs in the midportion of the lumbar spine [9] with a convex curve that opens the corresponding contralateral neural foramen [10] determining radiculopathy; however, many patients develop multisegmental involvement with long curves associated to sagittal and coronal decompensation, presence of thoracolumbar spondylosis, hypertrophic spondylarthrosis, laminar hypertrophy, and

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marginal osteophytes most prominent at the scoliotic apex [9].

Several surgical strategies have been performed to address the deformity in adult scoliosis. Operative treatment is aimed to the treatment of these typical pathoanatomic features, and characteristically comprehends neural and lumbar nerve roots decompression, and fusion to the instable motion segments, to reestablish both regional and global spinal balance in the frontal and sagittal planes, and to prevent progression of deformity or decompensation of adjacent motion segments [11, 12]. A recent meta-analysis of the surgical treatments for degenerative lumbar scoliosis written by Wang et al. demonstrated that surgery is effective regardless of its high rate of complications and repeat procedures [13]. This is due to the fact that patients with adult degenerative scoliosis are typically quite elderly, and usually have comorbidities, exposing them to a higher risk of complications, above all in the case of extensive procedures. Today, there are no clear guidelines regarding which surgical procedure yields the best results in which patients [14, 15].

The introduction of posterior pedicle screw instrumentation systems allows for proper restoration of lordosis, and may be an option in older patients with small curve deformities [16]. However, to address the pathology of the anterior column still remains of paramount importance since it allows for stability of the construct and correction of the deformity of the coronal and sagittal planes [1].

The clinical presentation in patients with adult degenerative scoliosis includes simple radiculopathy and unilateral leg pain to severe mechanical low back pain with loss of sagittal and coronal balance. The main treatments are: decompression, short fusion limited to 1–3 segments, or long fusion in those who require a full correction of the deformity.

Aim of this study is to compare the clinical and radiological results of patients operated on of short vs. long fusions in a cohort of patients affected by adult scoliosis who underwent posterior surgery at our institution, and followed for 2–5 year follow-up.

Materials and methods

The study is a retrospective analysis of collected data of 93 patients affected by adult scoliosis who underwent surgery at our institution between 2006 and 2012. Inclusion criteria were: (1) presence of adult scoliosis, defined by a coronal Cobb angle above 10° [1]; (2) posterior-only procedure for adult scoliosis correction; (3) minimum 2-year follow-up; (4) no history of previous spinal surgery; (5) availability of radiographic examinations. Twelve patients not corresponding to inclusion criteria were excluded by the study due to: (1) unwillingness to complete study questionnaires (2 patients); (2) non-adherence to clinical and radiographic follow-up protocols (4 patients); (3) six because had undergone previous surgery: 4 patients had 1 previous operation for lumbar disc herniation, and the remaining two patients had been treated for relapsed lumbar disc herniation and had previous reoperations comprehending hemilaminectomy without instrumentation.

A total of 81 patients were then included in the study (Fig. 1). The study population consisted of 62 females (76.5 %) and 19 males (23.5 %), and was aged on average 61 years (range 44–73).

Fifty-seven patients underwent to a short fusion procedure, while 24 had a long fusion. Short fusion was defined as fusion within the deformity, not exceeding the end vertebra and limited to 1–3 segments. Conversely, if fused segments were equal or greater than four, the surgical procedure was defined as long fusion.

Patients were evaluated clinically by the Roland–Morris Disability Questionnaire (RMDQ) in the validated translated version of local language [17]. Routine radiological studies in the preoperative setting consisted of plain radiographs of the standing spine, antero-posterior and lateral views, flexion/extension views, and side bending views. Postoperatively, patients were followed by radiographs that were postoperatively and at 3, 6 months, 1 year after surgery, and at the final follow-up. Radiographic assessment included measurements of the coronal plane deformity according to Cobb method (using the maximally angled end-vertebrae of the coronal curve), and the evaluation of spinopelvic parameters such as: pelvic tilt (PT), lumbar lordosis (LL), pelvic incidence (PI), and sacral slope (SS). Patients were further divided according to spinal alignment according to Lafage et al., and classified as properly aligned when PT $<20°$ and SVA <50 mm, or improperly aligned otherwise [18].

Computed tomographic scan or magnetic resonance imaging were also done, as routinely performed in the preoperative evaluation of all the patients, to assess the degree and main cause of spinal stenosis and the cause of radiculopathy, if present.

In all patients, surgery consisted of posterior-only instrumented correction of the degenerative scoliosis by the means of posterior screw-bar construct, and when required by selective placement of a unilateral cage on the side of the concavity. Intervertebral cage positioning was performed in the segments which met one or more of the following criteria: (1) asymmetric disc degeneration or lumbar disc herniation, (2) presence of vertebral translation in any orientation (>3 mm), (3) segmental instability and (4) evident degeneration at the concave side of the curve.

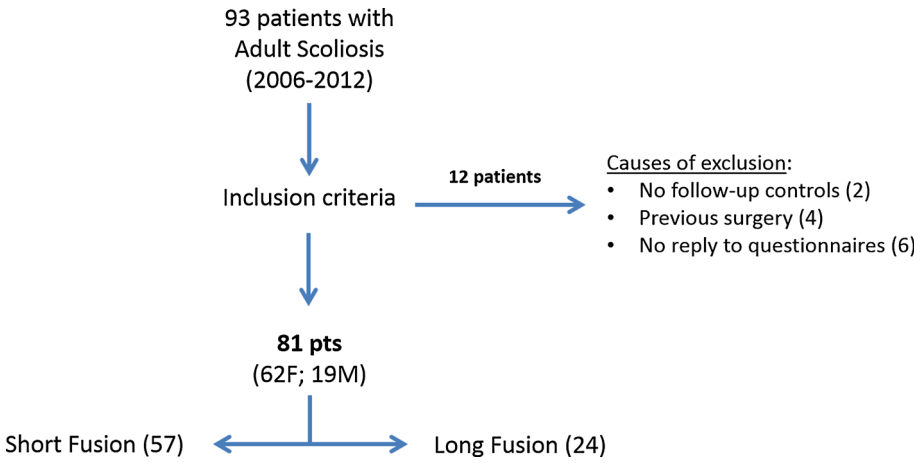

Fig. 1 Diagram showing the process of patients selection

Accessory surgical procedures consisted in decompression by hemi/laminectomy, foraminotomy and facetectomy at multiple levels according to the unique pathoanatomic characteristics of each patient's disease. Instrumentation was performed according to curve type and levels of upper and lower end-vertebrae.

Complications were defined as any event for which the patient required specific treatment. Intraoperative and postoperative complications were recorded: the complications were categorized as early (<3 months after surgery) or late postoperative complications [19].

Accordingly to our internal protocols, postoperatively patients were bed ridden for the first 24–48 h after surgery, according to hemoglobin levels and general health status. After surgery, patients wear a soft LSO brace and are physical therapist trained and allowed to ambulate. Discharge typically occurred after 5 days.

The RMDQ scores and angles of scoliosis, pelvic tilt, lumbar lordosis, pelvic incidence, and sacral slope were compared preoperatively and at final follow-up. Data before and after surgery were processed with paired-sample *t* test. A $p < 0.05$ was considered significant.

Results

Patients' population characteristics

Preoperatively, all 81 patients complained of severe back pain with or without neurologic symptoms, such as radiculopathy and claudication, and did not respond to conservative treatment for at least 6 months. Before surgery, the symptoms and neurologic examinations were recorded: 66 out of 81 patients (81.5 %) had an associated radiculopathy, while claudication spinalis was a common finding since it was reported by 51 out of 81 patients (63 %).

Short fusion procedure was performed in patients affected by radiculopathy, with a small Cobb angle, minor rotatory subluxation and in elderly patients who had severe comorbidities. Patients with high Cobb angle, sagittal imbalance and instability mostly underwent long fusion instrumentation.

The average number of level fused in the short fusion group was 2 (range 1–3 segments), while in the long fusion group it was 6 (range 4–9 segments). In the short fusion group, the upper-instrumented vertebra was L1 in 11 patients, L2 in 21 patients, L3 in 17 patients, L4 in 8 patients. In the long fusion group the upper-instrumented vertebra was T9 in 3 patients, T10 in 11 patients, T11 in 4 patients, T12 in 4 patients, L1 in 2 patients. The lower instrumented vertebra was L3 in 13 patients, L4 in 21 patients, L5 in 19 patients, and the sacrum in 28 patients. 56 out of 81 patients had insertion of a PEEK interbody fusion cage filled with local bone harvested from laminectomy at single or multiple levels.

According to the RMDQ, the average score in the preoperative period was 15 points (range 12–19) in the short fusion group and 16 points (range 13–21) in the long fusion group. At 6 months postoperatively, the score significantly improved in both groups averaging 7 points (range 6–10 in the short fusion group, and range 6–11 in the long fusion) ($p < 0.01$). One year after surgery, patients presented an average score of 4 (range 3–5) in the short fusion group and 5 points (range 4–6) in the long fusion group. Data from the last follow-up (average 4 years, range 2–5 years postoperatively) showed an average score of 4 (range 2–5) in both groups.

Radiological evaluation

Routine preoperative radiological evaluation showed 49 out 81 patients (60.5 %) with a stable lumbar scoliosis, while 32 patients (39.5 %) had an unstable curve [20].

Nineteen patients with improper alignment and 5 with proper alignment were treated by long fusion, while 34 out of 57 patients of the short fusion group had a degenerative lumbar scoliosis with proper alignment ($p < 0.0001$). Spinal stenosis was observed in 68 out of 81 patients, mainly sustained by hypertrophy of facet joints, flavum ligament hypertrophy and disc prolapse.

Pre- and postoperative assessment of radiographic parameters showed marked correction of the Cobb angle on the coronal plane that passed from an average of 24° preoperatively (range 15–32) in the short fusion group to 12° postoperatively (range 0°–18°), and from 45° preoperatively (range 19–54) to 10° postoperatively (range 3°–17°) in the long fusion group (Table 1). Twenty-eight out of 42 patients passed from improperly aligned to properly aligned after surgery ($p < 0.001$). The lumbar lordosis angle passed from 45° (range 32°–54°) before surgery to 60° postoperatively° (range 44°–66°) in the short fusion group, while from 24° (range −5° to 35°) before surgery to 55° (range 35°–60°) after surgery in the long fusion group (Table 1). Sacral slope passed from 25° (range 18°–40°) preoperatively to 45° (range 34°–55°) postoperatively in the short fusion group, while in the long fusion group changed from 10° (range 5°–25°) to 40° (range 30°–54°). Pelvic tilt passed from 24° (range 10°–27°) preoperatively to 13° (range 8°–25°) postoperatively in the short fusion group, while in the long fusion group changed from 28° (range 25°–36°) to 23° (range 18°–27°). These values did not modify significantly at the final follow-up.

Complications

There were 15 patients showing intraoperative or postoperative complications. Five patients had intraoperative tears of the dura requiring suture and fibrin glue application. Postoperatively, the patients were bedridden for one week and then let ambulate with a soft lumbar brace. No patients required additional treatment such as lumbar drains or re-surgery. One patient presented with transient foot-drop and sciatica: the patient underwent revision surgery and repositioning of a screw. Complete neurological recovery was observed in 6 months. Seven patients developed early soft tissue infection managed by surgical debridement leaving the implants in place, and prolonged intravenous antibiotics for 12 weeks, as agreed with our infective disease consultant. Screw loosening was observed in two patients who required revision surgery.

Four late complications were observed on patients who presented after 2 (3 patients) to 3 year (1 patient), respectively, from surgery with broken bars for non-union: the patients underwent revision surgery, bar removal and application of local bone graft and autologous platelet-rich fibrin with eventual healing.

Discussion

The surgical goals with adult scoliosis surgery are decompression of stenosis, restoring spinal balance, and improving clinical deformity, pain and disability. Achievement of these goals can be difficult. Also, adult deformity surgery is accompanied by high rates of major complications [20, 21].

Surgery of ASD was based upon coronal plane radiographical analysis using Cobb angle measurements. Recent research has shown that sagittal spinopelvic alignment among patients with ASD plays a critical role in pain and disability and is a primary determinant of health-related quality of life (HRQOL) measures [22].

Sagittal imbalance is an independent predictor of outcomes in adult degenerative spine and deformity and it has been confirmed in studies on different clinical settings. Restoration of sagittal balance correlates with better postoperative outcomes. Sagittal imbalance is a more significant cause of pain than coronal imbalance and restoring it has a more positive influence on patient's outcomes than coronal restoration [23].

This shift in emphasis on the sagittal plane gained substantial interest following several reports that correlated the sagittal alignment with the quality of life in patients with ASD.

In our study, patients who were subjected to short fusions were more likely to be properly aligned and to be affected by radiculopathy compared to patients operated on by long fusions, who were more likely to be improperly aligned and to suffer from symptoms of spinal deformity.

Table 1 SPPs in short vs. long fusion patients

	LL			SS			PT			Cobb		
	Pre	Post	*p*	Pre	Post	*p*	Pre	Post	*p*	Pre	Post	*p*
Short fusion ($n = 57$)	45°	60°	**0.05**	25°	45°	**0.01**	24°	13°	**0.001**	24°	12°	**0.01**
Long fusion ($n = 24$)	24°	55°	**0.001**	10°	40°	**0.001**	28°	23°	0.06	45°	10°	**0.001**
p	**0.02**	0.1	–	**<0.0001**	**0.01**	–	**0.01**	**0.001**	–	**0.01**	0.8	–

Bold values are statistically significant

Surgery in those patients has been able to improve the clinical and radiological parameters closer to physiology.

In the study by Cho et al. [24], who performed both long and short posterior fusions and instrumentations for degenerative lumbar scoliosis, long segment fusions provided better correction of the scoliotic curvature and coronal imbalance than did the short fusions; conversely, they observed a lesser effect on sagittal alignment and lumbar lordosis with long fixations. They also supported the use of cage insertion to improve the lumbar lordosis, even though they found it ineffective at restoring sagittal imbalance.

There is growing evidence that a posterior-only approach to surgical correction of degenerative lumbar scoliosis may be as effective as combined anterior/posterior surgery for most cases [25, 26].

As witnessed by Wang et al. [27], while commenting on the manuscript by Tsai et al. [28], the main drawbacks of multi-level posterior-only adult scoliosis correction by the use of interbody cages are the limited deformity correction at any single level, and consequently the need to treat multiple levels to achieve the required correction. On the opposite, the main advantages are the chance to better correct lordosis by the concomitant use of the posterior instrumentation [29], and the relative ease of the technique as witnessed by the diffusion of posterior-only technique in these patients. This might not be true for more complex cases that cannot be treated by this technique and would require sagittal osteotomies to achieve a more effective correction of the deformity and sagittal balance [30]: however, spinal osteotomies are the ultimate chance for deformity correction, and are fortunately unnecessary in most patients. In this study, we treated the pathology of the anterior column by the use of a peek cage inserted asymmetrically in the disc space on the concave side of the scoliosis curve in 56 out of 81 patients [31]. Heary reported the use of this technique on female patients affected by lumbar scoliotic deformities and complaining of axial low back pain and intractable unilateral radicular pain. Radiculopathy was considered as the main reason to implant the cage on the affected site, and encouraging results were reported.

The strengths of the present study include the use of validated clinical and radiological measures, the relatively large patient population and the middle term follow-up. The report of a prolonged follow-up is not a minor issue. In the study by Bridwell et al. [32], the authors studied a cohort of 113 patients affected by adult spinal deformity and treated surgically. They observed how in most studies the ultimate follow-up was 2 years. However, differently from common sense, they showed how the increase of follow-up to at least the 3- to 5-year point was associated to an increased observation of late complications, while clinical and radiological results usually remain constant. In our study, the increase of follow-up allowed for the observation of one non-union that occurred after 3 years (the other three occurred at 2 years from surgery). Conversely, the main limitation of this study remains the retrospective design, which is our major objective for further studies.

The surgical procedure investigated in this study, meaning the posterior-only approach with eventual cage insertion on the concave side of the curve, has been associated with an acceptable rate of intra- and postoperative complications. As demonstrated by Smith et al. [33], patients aged 46 or older are usually associated to a greater severity of deformity and are more prone to complications compared with patients in the younger age group. This was the age of our study group, and when possible we strongly suggest a less invasive surgery consisting of a posterior-only approach, to reduce the potential exposure to general complications. Revision surgery in this patient population is also a major issue. In the manuscript by Pichelmann et al. [34], on a cohort of 643 patients followed up to 22 years, the rate of re-intervention approximated the 9 %. Authors reported that the most common reasons for revision surgery were pseudarthrosis, curve progression and infection. The revision surgeries were more frequent in the first 2 years (26 out of 58 patients), but were still performed after 10 years from surgery. In our study population, re-interventions were performed in 14 out of 81 patients; in particular, one patient was re-operated 3 days after first surgery for a foot-drop due to screw malpositioning, seven had surgical revision for an early infection, two had a repositioned screw, and four had a late revision at 2 and 3 years, respectively, from surgery because of non-union. However, the study by Pichelmann [34] only reports outcome of long fixations of at least 5 fused levels, and this difference may justify the increased rate of complications in this cohort. Similar findings are in fact reported by Cho et al. [24], that compared patients operated with long and short instrumentations. They observed how long fusion patients had more of a tendency to increase the early complication rate than did short fusion group. Moreover, in the long fusion group, four patients received reoperation for distal adjacent segment disease in two patients, non-union in one patient, and loosening of screws in one patient. In the short fusion group, three patients had a reoperation for proximal adjacent segment disease.

In conclusion, surgery was associated to an improved balance and alignment of the spine, together with an improvement at either the coronal plane in terms of Cobb angle. These results were associated to a consistent clinical improvement and an acceptable rate of complications. Moreover, we observed that patients who were operated on by short or long fixations showed different characteristics. We acknowledge that our results represent a level of evidence of 3; however, on the base of this positive report, a long-term follow-up prospective comparative study has been designed to validate these outcomes and improving the level of evidence.

Compliance with ethical standards

Conflict of interest None.

References

1. Aebi M (2005) The adult scoliosis. Eur Spine J 14:925–948. doi:10.1007/s00586-005-1053-9
2. Daffner SD, Vaccaro AR (2003) Adult degenerative lumbar scoliosis. Am J Orthop (Belle Mead NJ) 32:77–82 **(discussion 82)**
3. Ploumis A, Transfeldt EE, Gilbert TJ et al (2006) Degenerative lumbar scoliosis: radiographic correlation of lateral rotatory olisthesis with neural canal dimensions. Spine (Phila Pa 1976) 31:2353–2358. doi:10.1097/01.brs.0000240206.00747.cb
4. Freedman BA, Horton WC, Rhee JM et al (2009) Reliability analysis for manual radiographic measures of rotatory subluxation or lateral listhesis in adult scoliosis. Spine (Phila Pa 1976) 34:603–608. doi:10.1097/BRS.0b013e31819a841e
5. Urrutia J, Espinosa J, Diaz-Ledezma C, Cabello C (2011) The impact of lumbar scoliosis on pain, function and health-related quality of life in postmenopausal women. Eur Spine J 20:2223–2227. doi:10.1007/s00586-011-1829-z
6. Kilshaw M, Baker RP, Gardner R et al (2011) Abnormalities of the lumbar spine in the coronal plane on plain abdominal radiographs. Eur Spine J 20:429–433. doi:10.1007/s00586-010-1610-8
7. Ploumis A, Transfledt EE, Denis F (2007) Degenerative lumbar scoliosis associated with spinal stenosis. Spine J 7:428–436. doi:10.1016/j.spinee.2006.07.015
8. Tribus CB (2003) Degenerative lumbar scoliosis: evaluation and management. J Am Acad Orthop Surg 11:174–183
9. Pritchett JW, Bortel DT (1993) Degenerative symptomatic lumbar scoliosis. Spine (Phila Pa 1976) 18:700–703. doi:10.1097/00007632-199305000-00004
10. Wang Y, Zhang XS, Zhang YG et al (2005) Characteristics of nerve root compression caused by degenerative lumbar stenosis with scoliosis. Zhongguo Yi Xue Ke Xue Yuan Xue Bao 27:170–173. doi:10.1016/j.spinee.2003.07.006
11. Wu C-H, Wong C-B, Chen L-H et al (2008) Instrumented posterior lumbar interbody fusion for patients with degenerative lumbar scoliosis. J Spinal Disord Tech 21:310–315. doi:10.1097/BSD.0b013e318148b256
12. Glassman SD, Carreon LY, Djurasovic M et al (2009) Lumbar fusion outcomes stratified by specific diagnostic indication. Spine J 9:13–21. doi:10.1016/j.spinee.2008.08.011
13. Wang G, Hu J, Liu X, Cao Y (2015) Surgical treatments for degenerative lumbar scoliosis: a meta analysis. Eur Spine J 24:1792–1799. doi:10.1007/s00586-015-3942-x
14. Bridwell KH, Berven S, Edwards C et al (2007) The problems and limitations of applying evidence-based medicine to primary surgical treatment of adult spinal deformity. Spine (Phila Pa 1976) 32:S135–S139. doi:10.1097/BRS.0b013e3181453e22
15. Kleinstueck FS, Fekete TF, Jeszenszky D et al (2014) Adult degenerative scoliosis: comparison of patient-rated outcome after three different surgical treatments. Eur Spine J. doi:10.1007/s00586-014-3484-7
16. Birknes JK, Harrop JS, White AP et al (2008) Adult degenerative scoliosis: A review. Neurosurgery. doi:10.1227/01.NEU.0000325485.49323.B2
17. Padua R, Padua L, Ceccarelli E et al (2002) Italian version of the Roland Disability Questionnaire, specific for low back pain: cross-cultural adaptation and validation. Eur Spine J 11:126–129. doi:10.1007/s005860100262
18. Lafage V, Schwab F, Vira S et al (2011) Spino-pelvic parameters after surgery can be predicted: a preliminary formula and validation of standing alignment. Spine (Phila Pa 1976) 36:1037–1045. doi:10.1097/BRS.0b013e3181eb9469
19. Cho K-J, Suk S-I, Park S-R et al (2007) Complications in posterior fusion and instrumentation for degenerative lumbar scoliosis. Spine (Phila Pa 1976) 32:2232–2237. doi:10.1097/BRS.0b013e31814b2d3c
20. Faldini C, Di Martino A, De Fine M et al (2013) Current classification systems for adult degenerative scoliosis. Musculoskelet Surg 97:1–8. doi:10.1007/s12306-013-0245-4
21. Koller H, Pfanz C, Meier O et al (2015) Factors influencing radiographic and clinical outcomes in adult scoliosis surgery: a study of 448 European patients. Eur Spine J. doi:10.1007/s00586-015-3898-x
22. Schwab FJ, Blondel B, Bess S et al (2013) Radiographical spinopelvic parameters and disability in the setting of adult spinal deformity: a prospective multicenter analysis. Spine (Phila Pa 1976) 38:E803–E812. doi:10.1097/BRS.0b013e318292b7b9
23. Berjano P, Langella F, Ismael M-F et al (2014) Successful correction of sagittal imbalance can be calculated on the basis of pelvic incidence and age. Eur Spine J 23(Suppl 6):587–596. doi:10.1007/s00586-014-3556-8
24. Cho KJ, Il Suk S, Park SR et al (2008) Short fusion versus long fusion for degenerative lumbar scoliosis. Eur Spine J 17:650–656. doi:10.1007/s00586-008-0615-z
25. Crandall DG, Revella J (2009) Transforaminal lumbar interbody fusion versus anterior lumbar interbody fusion as an adjunct to posterior instrumented correction of degenerative lumbar scoliosis: three year clinical and radiographic outcomes. Spine (Phila Pa 1976) 34:2126–2133. doi:10.1097/BRS.0b013e3181b612db
26. Zimmerman RM, Mohamed AS, Skolasky RL et al (2010) Functional outcomes and complications after primary spinal surgery for scoliosis in adults aged forty years or older: a prospective study with minimum two-year follow-up. Spine (Phila Pa 1976) 35:1861–1866. doi:10.1097/BRS.0b013e3181e57827
27. Wang MY (2011) PLIF for the treatment of adult spinal deformity. Acta Neurochir (Wien) 153:557. doi:10.1007/s00701-010-0910-4
28. Tsai T-H, Huang T-Y, Lieu A-S et al (2011) Functional outcome analysis: instrumented posterior lumbar interbody fusion for degenerative lumbar scoliosis. Acta Neurochir (Wien) 153:547–555. doi:10.1007/s00701-010-0909-x
29. La Grone MO (1988) Loss of lumbar lordosis. A complication of spinal fusion for scoliosis. Orthop Clin North Am 19:383–393
30. Hassanzadeh H, Jain A, El Dafrawy MH et al (2013) Three-column osteotomies in the treatment of spinal deformity in adult patients 60 years old and older: outcome and complications. Spine (Phila Pa 1976) 38:726–731. doi:10.1097/BRS.0b013e31827c2415
31. Heary RF, Karimi RJ (2010) Correction of lumbar coronal plane deformity using unilateral cage placement. Neurosurg Focus 28:E10. doi:10.3171/2009.12.FOCUS09281
32. Bridwell KH, Baldus C, Berven S et al (2010) Changes in radiographic and clinical outcomes with primary treatment adult spinal deformity surgeries from two years to three- to five-years follow-up. Spine (Phila Pa 1976) 35:1849–1854. doi:10.1097/BRS.0b013e3181efa06a
33. Smith JS, Shaffrey CI, Glassman SD et al (2013) Clinical and radiographic parameters that distinguish between the best and worst outcomes of scoliosis surgery for adults. Eur Spine J 22:402–410. doi:10.1007/s00586-012-2547-x
34. Pichelmann MA, Lenke LG, Bridwell KH et al (2010) Revision rates following primary adult spinal deformity surgery: six hundred forty-three consecutive patients followed-up to twenty-two years postoperative. Spine (Phila Pa 1976) 35:219–226. doi:10.1097/BRS.0b013e3181c91180