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REVIEW ARTICLE

Surgical treatments for degenerative lumbar scoliosis: a meta analysis

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Abstract
Purpose Degenerative lumbar scoliosis (DLS) is a spinal deformity that typically develops in adults over 50 years old. Although its etiology is unclear, asymmetric degeneration of the spine is the main cause. Individuals with DLS may experience no symptoms of the deformity, mild symptoms, or severe disability. Most patients with DLS receive conservative treatment, while a small number of patients receive surgery for severe DLS with back pain and/or progressive neurological symptoms. A variety of surgical procedures have emerged. However, a systemic comparison of these surgical procedures is currently unavailable. This study reviews the main outcomes and complications of surgical treatments.
Methods A meta analysis of main outcomes and complications of surgical treatments of DLS was conducted through searching PubMed and EMbase databases.
Results A total of 45 studies were included in this study, which were classified into four surgical categories. Nine studies utilized isolated decompression, 12 used short interbody fusion, 17 used long interbody fusion, and 11 studies included patients using short or long interbody fusion or surgery other than fusion, respectively. Decompression surgery is used to release the symptoms of neurogenic claudication. Spine fusion is widely utilized to prevent worsening of the curve. Instrumentation has been used together with fusion to straighten the spine, correct sagittal imbalance, and repair rotational defects. Decompression is commonly combined with fusion surgery when treating an individual with DLS.
Conclusion Despite a high rate of complications, this review demonstrates that surgery is an effective and reasonable treatment intervention for severe DLS and ultimately improves spine function and deformity. This review also suggests that large scale, high quality studies with long term follow-up are needed to provide more reliable evidence for future evaluation.

Keywords Degenerative lumbar scoliosis · Decompression · Spinal fusion · Short interbody fusion · Long interbody fusion · Instrumentation · Complication

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Introduction

Degenerative lumbar scoliosis (DLS) is lumbar scoliosis that is secondary to degenerative lumbar disc, bone, and joint changes, which can develop after a person reaches full skeletal maturity [1]. DLS is a common disease among the elderly over the age of 50 [1]. Back pain and nerve compression symptoms are the main clinical complaints. Different from idiopathic scoliosis, congenital scoliosis, and neuromuscular scoliosis, DLS is often accompanied by lateral lumbar displacement and rotatory dislocation, as well as complications of other degenerative lumbar diseases. Nonsurgical treatment is generally recommended and effective for relieving pain and restoring normal activity in DLS patients. However, the treatment of severe

DLS is relatively more complex than that of general degenerative lumbar diseases. Surgery is mainly indicated for severe back pain and/or progressive neurological symptoms refractory to nonsurgical treatment [1, 2].

Decompression surgery is essential for relieving the symptoms of neurogenic claudication [3]. Decompression can be used alone (isolated decompression), but most surgeons recommend decompression at the time of spinal fusion, including short fusion and long fusion [4, 5]. Spinal fusion is the most widely performed surgery for a variety of degenerative spine disorders including scoliosis, spondylolisthesis, spinal instability, deformity, and spinal stenosis [6]. During spinal fusion, bone is grafted to the vertebrae to form a solid bone mass during the healing process, and then the vertebral column becomes rigid. Thus, spinal fusion prevents worsening of the curve, but reduces some spinal movement [7]. The intercorporal implantation of cage devices has been used to avoid the high rate of pseudarthrosis produced during traditional spinal fusion [8]. The cage can be loaded with bone graft materials. Spinal fusion can be performed from the anterior aspect of the spine by entering the thoracic or abdominal cavities, or more commonly, performed from the posterior. A combination of anterior and posterior procedure is used in more severe cases. However, anterior surgery has been associated with complications, such as vascular complications, retrograde ejaculation, postoperative colonic obstruction, and injury to the sympathetic chain [9]. Posterior surgery has been associated with dural tears, paraspinal muscle denervation, and neural complications [10]. The lateral fusion has been described as a minimally invasive procedure [11] and has the advantage of reducing complications associated with anterior and posterior surgery [12].

In 1962, Paul Harrington introduced a metal spinal system of instrumentation to straighten the spine and to hold it rigid during spinal fusion [13]. Modern spinal instrumentations attempt to address sagittal imbalance and rotational defects unresolved by the Harrington rod system. Recently, all-screw systems have become the gold-standard technique for adolescent idiopathic scoliosis. Pedicle screws have achieved better fixation of the vertebral column and exhibit better biomechanical properties [14]. The anterior instrumentation system has been demonstrated to be successful in restoring immediate post-operative stability and correcting post-traumatic deformities [15]. Posterior instrumentation alone indicated 76 % less axial stiffness compared to the intact spine [6]. Combined use of anterior and posterior instrumentations can increase stability and reduce mobility.

There are a variety of available surgical procedures for the treatment of patients with DLS. The aim of this study was to review the surgical procedures for DLS adopted during the last three decades with the main focus on the outcome and complications.

Methods

Identification of relevant studies

Electronic searching of PubMed and EMbase databases was conducted in February 2014 using the keywords, lumbar degenerative scoliosis and degenerative lumbar scoliosis. Then, the abstracts or full texts, if available, were reviewed one-by-one for the exclusion criteria. Reviews as well as research articles that were not in English, did not involve humans, and non-surgical studies were excluded. We only included studies with surgical treatment for degenerative lumbar scoliosis, number of cases greater than 1, and where surgical procedure can be accurately identified. Surgical studies for other types of degenerative scoliosis were also excluded (Fig. 1).

Data extraction

From each publication, we extracted data on the number of cases, surgical procedure, follow-up, outcomes, and complications. The surgical procedures were classified into isolated decompression, short fusion—if the fusion can be clearly identified in 1–2 segments or if the mean number of segments fused was less than three, long fusion—if the fusion can be clearly identified in more than two segments or if the mean number of segments fused was greater than or equal to three, and mix fusion—if a study contained short and long fusion in one group without providing a mean number of segments fused, or other surgical procedure if neither decompression nor fusion was used. If a study included more than one surgical procedure to compare the differences between two or more surgery procedures, each individual procedure in the study was classified in this review and the number of cases was extracted.

Data analysis

The duration of follow-up, preoperative ODI (Oswestry Disability Index), ODI at final follow-up, change in ODI, Cobb angles, curve reduction, curve reduction as a percentage of the original curve, and the incidence of complications were calculated. A pooled analysis of the data recorded in the individual studies was undertaken. The incidence of complications was calculated as the total number of complications divided by the total number of patients in the reported studies.

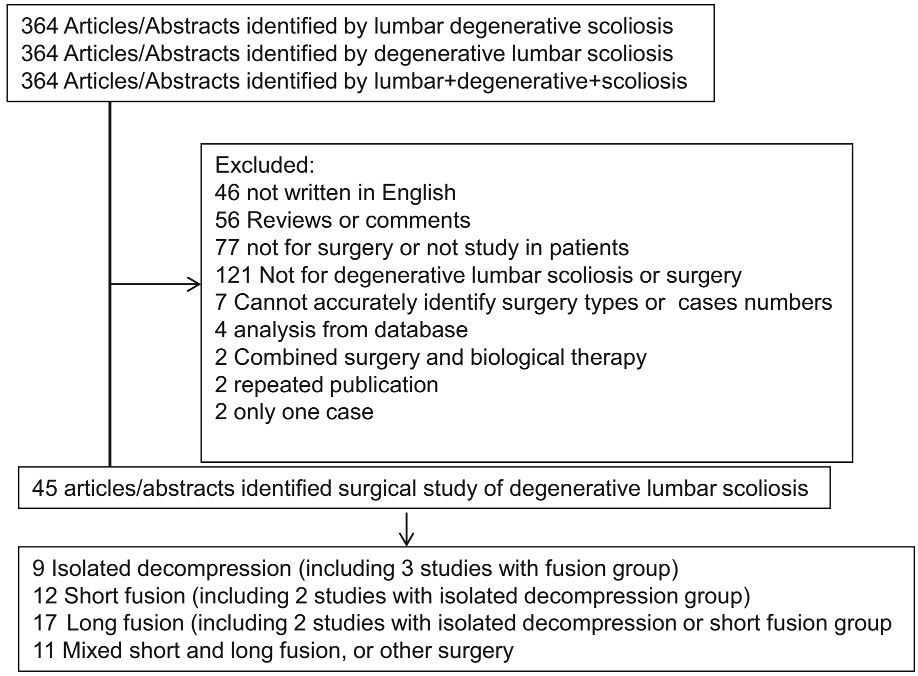

Fig. 1 A flowchart of literature search strategy. A flowchart of the included and excluded studies in the current meta analysis

Results

The literature search identified 365 articles from PubMed and 752 articles from EMbase using the keywords degenerative lumbar scoliosis. A total of 364 articles were identified after removing duplicates. After excluding 46 articles not written in English, 56 reviews or comments, 77 articles of non-surgical studies, 121 articles of non-DLS or non-surgery studies for DLS, and 15 others including two studies reporting previous results, and two studies that reported one case, 45 full texts were included in this study (Fig. 1). The 45 studies were classified into four main surgical categories for analysis: isolated decompression, short fusion, long fusion, and mixed fusion or other surgical procedure. If multiple surgical types were used, the article will be included in each category for analysis. In this review, nine studies utilized isolated decompression with [4, 16, 17] or without [5, 18–22] instrumentation, 12 used short interbody fusion [3, 5, 21, 23–31], 17 used long interbody fusion [4, 5, 30, 32–45], 11 contained samples with mixed short and long interbody fusion [46–56], and one study used neither isolated decompression nor fusion [57] (Table 1). The interbody infusion techniques are composed of anterior lumbar interbody fusion (ALIF) [3, 47], posterior lumbar interbody fusion (PLIF) [33, 48, 49], direct lateral interbody fusion (DLIF) [50], lateral lumbar interbody fusion (LLIF) [24, 25], transforaminal lumbar interbody fusion (TLIF) [26, 27, 34, 35, 51], and extreme lateral interbody fusion (XLIF) [36]. The 12 articles for short fusion included ten articles using instrumentation [3, 5, 21, 23, 26–31] and two articles not using instrumentation [24, 25]. The 17 articles for long fusion included 16 articles using instrumentation and one study where instrumentation usage could not be determined [32]. The ten articles for mixed short and long fusion included nine articles using instrumentation and one study where instrumentation usage could not be determined [47] (Table 1).

Finally, nine articles for isolated decompression (352 patients), 12 for short fusion (614 patients), 17 for long fusion (517), and 10 for mixed short and long fusion studies, as well as one study for other surgical procedure (356 patients) were included for clinical outcome analysis (Table 2). The mean age varied from 64 to 77 years for isolated decompression, 53 to 70 years for short fusion, 54 to 66 years for long fusion, and 43 to 66 years for mixed short and long fusion or other surgical procedure. The follow-up duration ranged from 1 to 10 years, and the mean follow-up in most studies was 2 years. The data quality of the included studies was relatively low according to their MINORS scores. The study by Ploumis et al. [54] was the one with the highest quality. The ODI was used as a measure of functional improvement in 18 studies. At final follow-up, patients that underwent isolated decompression surgery showed 20–57 % improvement in mean ODI score, those that underwent short fusion showed 0–44 % improvement in mean ODI score, those that underwent long fusion showed 0–55.5 % improvement in mean ODI score, and those that underwent mixed short/long fusion or other surgical procedure showed 0–56.6 % improvement in mean ODI score. Pre- and post-operative Cobb angles were reported in 29 studies. Patients that underwent isolated decompression showed −7.9 % worsening to 79.9 %

Table 1 Surgical treatments of degenerative lumbar scoliosis

Surgery type	Instrument	No. of patients	Study design	Observations
Isolated decompression				
Di Silvestre et al. [16]	Yes	57	Retrospective	Radiograph, complications
Di Silvestre et al. [4]	Yes	32	Retrospective	Radiological/clinical outcomes
Di Silvestre et al. [17]	Yes	29	Retrospective	Clinical outcomes/complications
Transfeldt [5]	No	21	Prospective	Surgical outcomes, radiograph
Papavero et al. [18]	No	22	Prospective	Lumbar spinal nerve
Hosogane et al. [19]	No	50	Retrospective	Lumbar curve progression
Tsutsui et al. [20]	No	75	Retrospective	Low-back pain, radiographic
Daubs et al. [21]	No	16	Retrospective	Symptomatic stenosis
Matsumura et al. [22]	No	50	Retrospective	Low-back pain, Conn, SWA, CT
Short fusion (<3 segment)				
Rothenfluh et al. [3]	Yes	12	Retrospective	Complication
Transfeldt [5]	Yes	43	Prospective	Surgical outcomes, radiograph
Daubs et al. [21]	Yes	39	Retrospective	Symptomatic stenosis
Hwang et al. [23]	Yes	47	Retrospective	Radiographic progression
Castro et al. [24]	No	46	Retrospective	VAS back pain, ODI, Cobb, etc
Lykissas et al. [25]	No	30	Retrospective	Neurological deficit, pain
Burneikiene et al. [26]	Yes	29	Retrospective	Intra- and postoperative complications
Potter et al. [27]	Yes	4	Retrospective	Fusion mass, clinical outcomes
Ha et al. [28]	Yes	98	Retrospective	Risk factors of ASD
Yagi et al. [29]	Yes	57	Retrospective	Radiographic/functional measurement
Cho et al. [30]	Yes	28	Prospective	Radiographic outcome/complication
Liao et al. [31]	Yes	181	Retrospective	Clinical outcomes/complications
Long fusion (≥3 segment)				
Transfeldt [5]	Yes	20	Prospective	Surgical outcomes, radiograph
Di Silvestre et al. [4]	Yes	25	Retrospective	Radiological and clinical outcomes
Cho et al. [30]	Yes	22	Prospective	Radiographic outcome/complication
Kluba et al. [32]	NI	26	Retrospective	Clinical and radiographic outcomes
Hioki et al. [33]	Yes	19	Retrospective	Surgery outcomes and complications
Scheufler et al. [34]	Yes	30	Prospective	Complication rate, clinical outcome
Aoki et al. [35]	Yes	3	Retrospective	Migration of fusion cages
Caputo et al. [36]	Yes	30	Prospective	Radiographic outcome/complications
Yagi et al. [37]	Yes	73	Retrospective	pGTK
Cho et al. [38]	Yes	51	Retrospective	ASD
Takahashi et al. [39]	Yes	2	Retrospective	Neural complications
Yagi et al. [40]	Yes	33	Prospective	Clinical and surgical outcomes
Watanabe et al. [41]	Yes	6	Prospective	Proximal vertebral fractures
Cho et al. [42]	Yes	45	Retrospective	Radiographic outcomes, etc
Crandall et al. [43]	Yes	40	Prospective	ODI, VAS, radiographic
Cho et al. [44]	Yes	47	Retrospective	Clinical outcome, RF of complication
Cho et al. [45]	Yes	45	Retrospective	Sagittal decompensation
Mixed short and long fusion or other surgery				
Keorochana et al. [46]	Yes	31	Retrospective	ODI, VAS pain, curve correction
Quraishi et al. [47]	Yes	18	Retrospective	Complications
Tsai et al. [48]	Yes	58	Retrospective	VAS, ODI, patient satisfaction, etc
Wu et al. [49]	Yes	26	Retrospective	ODI, lumbar scoliosis angle, etc
Acosta et al. [50]	Yes	36	Retrospective	Radiographic progression
Li et al. [51]	Yes	46	Retrospective	Surgery outcomes

Table 1 continued

Surgery type	Instrument	No. of patients	Study design	Observations
Mcphee et al. [52]	Yes	21	Retrospective	Fusion rate, correction of deformity
Xie et al. [53]	Yes	31	Retrospective	ODI, Cobb, clinical outcomes
Ploumis et al. [54]	Yes	28	Retrospective	VAS, ODI, Cobb, fusion status
Heary et al. [55]	Yes	4	Prospective	Clinical outcomes
Khan et al. [56]	Yes	14	Retrospective	Clinical outcome
Kanayama et al. [57]	No fusion	43	Retrospective	Pain, clinical outcomes

NI not identified

Table 2 Clinical outcome of surgical treatment of degenerative lumbar scoliosis

Surgical techniques	No. of patients	Mean age (years)	Follow-up (years)	ODI (%)	Cobb changes (%)	Major complications (%)
Isolated decompression	352	64–77	1–6.4	−20 to −57	7.9 to −79.9	10–18
Short fusion (<3 segment)	614	53–70	1.75–5.1	NC to −44	NC to −52.1	6.5–40
Long fusion (≥3 segment)	517	54–66	1–4.8	NC to −55.5	NC to −72.3	18–58.3
Mixed short and long fusion	356	43–66	2–10	NC to −56.6	NC to −67.5	20–32.6

improvement in mean Cobb angle, those that underwent short fusion showed 0–52 % improvement in mean Cobb angle, those that underwent long fusion showed 0–72.3 % improvement in mean Cobb angle, and those that underwent short or long fusion showed 0–67.5 % improvement in mean Cobb angle. Surgical complication was reported alone or together with other outcomes in 26 studies with a range of 10–18 % in isolated decompression, 6.5–40 % in short fusion, 18–58.3 % in long fusion, and 20–32.6 % in mixed samples with short or long fusion. Pain release was evaluated as an outcome in ten studies with a range of 38.4–77.1 % decrease in VAS score in nine studies and 65.1 % increase in one study [49].

Discussion

Although nonsurgical treatment is effective for relieving symptoms of DLS, surgery is commonly thought of as a crucial treatment option for severe DLS. A wide spectrum of surgical procedures has been developed with varying treatment efficacy and rate of complications. This meta analysis demonstrated that surgery is effective in treating DLS regardless of its high rate of complications and repeat procedures. Surgical treatment significantly improved the function of the spine (based on ODI), corrected deformities (based on Cobb angle), and released pain.

This review demonstrated that isolated decompression, short interbody fusion, and long interbody fusion are the three main surgical procedures for DLS treatment. Instrumentation is used to increase stability and reduce mobility of spine. In this review, the instrumentation is commonly used together with both short and long fusion (35 in 39 studies for fusion). Instrumentation was also used, but less commonly, for isolated decompression (3 in 9 studies). Isolated decompression (9 in 45 studies) is less common than interbody fusion (39 in 45 studies). This review demonstrated that isolated decompression without instrumentation was not a common choice of surgery for DLS (6 in 45 studies). In contrast, decompression is a basic procedure for fusion surgery [5].

The ODI is a valid and rigorous functional index for assessing spinal disorders [58] and 18 of the included 45 studies used ODI as an outcome of surgical treatment. However, the mean percentage decrease in ODI varied between studies, and no obvious differences was observed between studies with isolated decompression, short fusion, long fusion, and mixed fusion. Although the length of follow-up may be a critical factor that affects readout of the final ODI value, all surgical procedures significantly improved spine function. This suggests that surgery is an effective and reasonable treatment option for recovering the spine function of DLS patients. Deformity correction, as measured by the Cobb angle, is another critical index to evaluate the efficacy of surgery for DLS. Patients treated with long interbody fusion gained up to 72 % curve correction after surgery and patients treated with short fusion can gain up to 52 % curve correction. In contrast, there is a very large range in the percent improvement in curve correction in patients who received isolated decompression treatment with a range from 79.9 % correction to 7.9 %

worsening. However, most studies utilizing these three surgical procedures reported effective correction of deformities. Moreover, pain release was evaluated as a single outcome or one of the outcomes in ten studies. Surgery decreased VAS score in nine studies with a range of 38.4–77.1 % release, although one study showed that pain is a complication of surgery. Decompression was not as effective in restoring spine function and correcting the Cobb angle compared to interbody fusion. Other than the one study that showed a 79.9 % reduction in Cobb angle [19], the three remaining studies showed an increase in Cobb angle [20–22]. The ODI data were only available in two studies with isolated decompression and showed a 20 % and 32 % increase, respectively.

Complications are an important concern in surgical treatment of DLS and a high incidence of surgical complications has been reported. The observed complications were classified into major complications and minor complications, such as repeated surgery, back pain, sensory deficit, vascular complications, global thoracic kyphosis, and stenosis. The percentage of major complications was 10–18 % in patients treated with isolated decompression, 6.5–40 % in those treated with short fusion, 18–58.3 % in those treated with long fusion, and 20–32.6 % in studies containing patients treated with mixed short and long fusion. However, the data quality assay yielded low MINORS scores [59] for these studies and complications were not fully observed and recorded. Therefore, comparison between surgical procedures becomes unreliable. Overall, the rate of complications was generally high. There is an urgent need to establish a standard to systemically observe and record the complications related to different surgical procedures. Most importantly, the complications related to surgery must be taken into account when deciding whether or not to proceed with surgery.

In general, most patients with LDS only needed conservative treatment. Surgery was only used for sacral nerve roots and cauda equina nerve decompression, restoring or rebuilding the mechanical balance of the lumbar spine, preventing the progression of the deformity, and in particular restoring physiological lumbar lordosis [60]. The surgical indications in the clinic include: (1) severe lower back pain and/or sciatica associated with lumbar scoliosis, which increases gradually and impacts daily life, and was not relieved with non-surgical treatment; (2) lumbar spinal stenosis and nerve dysfunction with progressive intermittent claudication; (3) progression of scoliosis with complication of acute and chronic cauda equina syndrome loss, as well as sagittal and coronal imbalance [60]. Among spinal fusion procedures, ALIF is a minimally invasive surgical approach with advantages of direct visualization of the intervertebral space, small incision size, and reduced tissue invasiveness [61], but with disadvantages of increased risk of intra-abdominal vascular and visceral injury [62]. In contrast, PLIF has advantages in avoiding intra-abdominal vascular and visceral injury, but is associated with an increased risk of damage to neural structures and epidural vein injury [63]. LLIF reduces the risk of surgical collateral damage associated with ALIF and PLIF approaches and brings increased post-operative vertebral column stability and improved alignment, but LLIF has a risk of neurological adverse sequelae [64]. TLIF is another minimally invasive approach to achieve circumferential fusion, which could reduce the extent of nerve root retraction associated with the PLIF procedure [65, 66]. DLIF is a minimally invasive lateral approach for placement of an interbody fusion device with advantages of not requiring nerve root retraction, reducing damage to the midline back muscles, and improving alignment of the spinal bones, but its use is limited to the lumbosacral (L5–S1) junction [11]. XLIF is a minimally invasive lateral transpsoas approach similar to DLIF, but cannot be used for the lumbosacral (L5–S1) junction [36]. In this review, TLIF was found to be the most commonly used interbody fusion and most effective in restoring spine function, and induced a 53–68 % improvement in correction of Cobb angle, although the complication rates were up to 49–60 %.

This meta-analysis made no recommendation for which specific type of surgery is the best and which surgical technique should be selected for different patients because the circumstances surrounding each patient are highly complex. This meta analysis included a study that found no significant differences in Roland–Morris score, Oswestry score, and patients' satisfaction between patients who underwent isolated decompression, short fusion, and long fusion surgery [5]. One study compared the clinical outcome, recurrent leg pain, and complications between isolated decompression and decompression plus limited fusion, and revealed that recurrent leg pain occurred significantly more often in patients within 6 months post isolated decompression [21]. One study compared the clinical outcome, radiologic data, and complications between patients who underwent decompression with dynamic stabilization and patients who underwent long instrumented fusion [4]. Although decompression plus dynamic stabilization was less invasive than long instrumented fusion, no difference was found between the two techniques in terms of functional clinical outcomes [4]. It would be misleading to conclude that there were no significant differences between surgical techniques based on only 3 studies. Also, it is meaningless to make a simplistic conclusion on which surgical technique is best for DLS by using studies from different centers. This review demonstrated that the indications for surgery, surgical procedures, and outcome measures varied among the studies. In addition, the data quality of the included studies was not high.

However, despite a high rate of complications, this systematic review demonstrates that surgery is an effective and reasonable treatment intervention for DLS, providing improvements in spine function indicated by ODI and deformity correction as measured using the Cobb angle. A detailed evaluation of indications for surgery, standardization of surgical procedures, systemic evaluation of spinal function and deformity correction, and detailed records on complications should enhance the comparability and validity of future studies on this subject. Large scale, high quality studies with long term follow-up are needed to provide more reliable evidence for future evaluation.

Conflict of interest The authors declared no conflict of interest.

References

1. Ploumis A, Transfledt EE, Denis F (2007) Degenerative lumbar scoliosis associated with spinal stenosis. Spine J 7:428–436
2. Oskouian RJ Jr, Shaffrey CI (2006) Degenerative lumbar scoliosis. Neurosurg Clin N Am 17:299–315
3. Rothenfluh DA, Koenig M, Stokes OM, Behrbalk E, Boszczyk BM (2014) Access-related complications in anterior lumbar surgery in patients over 60 years of age. Eur Spine J 23(Suppl 1):S86–S92
4. Di Silvestre M, Lolli F, Bakaloudis G (2014) Degenerative lumbar scoliosis in elderly patients: dynamic stabilization without fusion versus posterior instrumented fusion. Spine J 14:1–10
5. Transfeldt EE, Topp R, Mehbod AA, Winter RB (2010) Surgical outcomes of decompression, decompression with limited fusion, and decompression with full curve fusion for degenerative scoliosis with radiculopathy. Spine (Phila Pa 1976) 35:1872–1875
6. Lykissas MG, Aichmair A (2013) Current concepts on spinal arthrodesis in degenerative disorders of the lumbar spine. World J Clin Cases 1:4–12
7. Phillips FM, Slosar PJ, Youssef JA, Andersson G, Papatheofanis F (2013) Lumbar spine fusion for chronic low back pain due to degenerative disc disease: a systematic review. Spine (Phila Pa 1976) 38:E409–E422
8. Zdeblick TA, Phillips FM (2003) Interbody cage devices. Spine (Phila Pa 1976) 28:S2–S7
9. Than KD, Wang AC, Rahman SU, Wilson TJ, Valdivia JM, Park P, La Marca F (2011) Complication avoidance and management in anterior lumbar interbody fusion. Neurosurg Focus 31(4):E6
10. Mehta VA, McGirt MJ, Garcés Ambrossi GL, Parker SL, Sciubba DM, Bydon A, Wolinsky JP, Gokaslan ZL, Witham TF (2011) Trans-foraminal versus posterior lumbar interbody fusion: comparison of surgical morbidity. Neurol Res 33:38–42
11. Shirzadi A, Birch K, Drazin D, Liu JC, Acosta F Jr (2012) Direct lateral interbody fusion (DLIF) at the lumbosacral junction L5-S1. J Clin Neurosci 19:1022–1025
12. Ozgur BM, Aryan HE, Pimenta L, Taylor WR (2006) Extreme lateral interbody fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. Spine J 6:435–443
13. Harrington PR (2002) Treatment of scoliosis: correction and internal fixation by spine instrumentation. June 1962. J Bone Joint Surg Am 84-A(2):316
14. Stenning M, Nelson I (2011) Recent advances in the treatment of scoliosis in children. British Editorial Society of Bone and Joint Surgery. Retrieved 1 Jan 2014
15. Gurr KR, McAfee PC, Shih CM (1988) Biomechanical analysis of anterior and posterior instrumentation systems after corpectomy. A calf-spine model. J Bone Joint Surg Am 70:1182–1191
16. Di Silvestre M, Lolli F, Greggi T, Vommaro F, Baioni A (2013) Adult's degenerative scoliosis: midterm results of dynamic stabilization without fusion in elderly patients—is it effective? Adv Orthop 2013:365059
17. Di Silvestre M, Lolli F, Bakaloudis G, Parisini P (2010) Dynamic stabilization for degenerative lumbar scoliosis in elderly patients. Spine (Phila Pa 1976) 35:227–234
18. Papavero L, Kothe R (2013) Microsurgical extraforaminal decompression of lumbar root canal stenosis. Oper Orthop Traumatol 25:16–30
19. Hosogane N, Watanabe K, Kono H, Saito M, Toyama Y, Matsumoto M (2013) Curve progression after decompression surgery in patients with mild degenerative scoliosis. J Neurosurg Spine 18:321–326
20. Tsutsui S, Kagotani R, Yamada H, Hashizume H, Minamide A, Nakagawa Y, Iwasaki H, Yoshida M (2013) Can decompression surgery relieve low back pain in patients with lumbar spinal stenosis combined with degenerative lumbar scoliosis? Eur Spine J 22:2010–2014
21. Daubs MD, Lenke LG, Bridwell KH, Cheh G, Kim YJ, Stobbs G (2012) Decompression alone versus decompression with limited fusion for treatment of degenerative lumbar scoliosis in the elderly patient. Evid Based Spine Care J 3:27–32
22. Matsumura A, Namikawa T, Terai H, Tsujio T, Suzuki A, Dozono S, Yasuda H, Nakamura H (2010) The influence of approach side on facet preservation in microscopic bilateral decompression via a unilateral approach for degenerative lumbar scoliosis. Clinical article. J Neurosurg Spine 13:758–765
23. Hwang DW, Jeon SH, Kim JW, Kim EH, Lee JH, Park KJ (2009) Radiographic progression of degenerative lumbar scoliosis after short segment decompression and fusion. Asian Spine J 3:58–65
24. Castro C, Oliveira L, Amaral R, Marchi L, Pimenta L (2014) Is the lateral transpsoas approach feasible for the treatment of adult degenerative scoliosis? Clin Orthop Relat Res 472(6):1776–1783
25. Lykissas MG, Cho W, Aichmair A, Sama AA, Hughes AP, Lebl DR, Du JY, Cammisa FP, Girardi FP (2013) Is there any relation between the amount of curve correction and postoperative neurological deficit or pain in patients undergoing standalone lateral lumbar interbody fusion? Spine (Phila Pa 1976) 38:1656–1662
26. Burneikiene S, Nelson EL, Mason A, Rajpal S, Serxner B, Villavicencio AT (2012) Complications in patients undergoing combined transforaminal lumbar interbody fusion and posterior instrumentation with deformity correction for degenerative scoliosis and spinal stenosis. Surg Neurol Int 3:25
27. Potter BK, Freedman BA, Verwiebe EG, Hall JM, Polly DW Jr, Kuklo TR (2005) Transforaminal lumbar interbody fusion: clinical and radiographic results and complications in 100 consecutive patients. J Spinal Disord Tech 18:337–346
28. Ha KY, Son JM, Im JH, Oh IS (2013) Risk factors for adjacent segment degeneration after surgical correction of degenerative lumbar scoliosis. Indian J Orthop 47:346–351
29. Yagi M, Patel R, Lawhorne TW, Cunningham ME, Boachie-Adjei O (2014) Adult thoracolumbar and lumbar scoliosis treated with long vertebral fusion to the sacropelvis: a comparison between new hybrid selective spinal fusion versus anterior-posterior spinal instrumentation. Spine J 14(4):637–645
30. Cho KJ, Suk SI, Park SR, Kim JH, Kim SS, Lee TJ, Lee JJ, Lee JM (2008) Short fusion versus long fusion for degenerative lumbar scoliosis. Eur Spine J 17:650–656
31. Liao JC, Chen WJ, Chen LH, Niu CC (2009) Outcome of the L5-S1 segment after posterior instrumented spinal surgery in degenerative lumbar diseases. Chang Gung Med J 32:81–88

32. Kluba T, Dikmenli G, Dietz K, Giehl JP, Niemeyer T (2009) Comparison of surgical and conservative treatment for degenerative lumbar scoliosis. Arch Orthop Trauma Surg 129:1–5
33. Hioki A, Miyamoto K, Kodama H, Hosoe H, Nishimoto H, Sakaeda H, Shimizu K (2005) Two-level posterior lumbar interbody fusion for degenerative disc disease: improved clinical outcome with restoration of lumbar lordosis. Spine J 5:600–607
34. Scheufler KM, Cyron D, Dohmen H, Eckardt A (2010) Less invasive surgical correction of adult degenerative scoliosis. Part II: complications and clinical outcome. Neurosurgery 67:1609–1621
35. Aoki Y, Yamagata M, Nakajima F, Ikeda Y, Takahashi K (2009) Posterior migration of fusion cages in degenerative lumbar disease treated with transforaminal lumbar interbody fusion: a report of three patients. Spine (Phila Pa 1976) 34:E54–E58
36. Caputo AM, Michael KW, Chapman TM, Jennings JM, Hubbard EW, Isaacs RE, Brown CR (2013) Extreme lateral interbody fusion for the treatment of adult degenerative scoliosis. J Clin Neurosci 20:1558–1563
37. Yagi M, Hosogane N, Okada E, Watanabe K, Machida M, Tezuka M, Matsumoto M, Asazuma T (2014) Factors affecting the post operative progression of thoracic kyphosis in surgically treated adult patient with lumbar degenerative scoliosis. Spine (Phila Pa 1976) 39(8):E521–E528
38. Cho KJ, Suk SI, Park SR, Kim JH, Jung JH (2013) Selection of proximal fusion level for adult degenerative lumbar scoliosis. Eur Spine J 22:394–401
39. Takahashi S, Delécrin J, Passuti N (2001) Intraspinal metallosis causing delayed neurologic symptoms after spinal instrumentation surgery. Spine (Phila Pa 1976) 26:1495–1498
40. Yagi M, Patel R, Boachie-Adjei O (2013) Complications and unfavorable clinical outcomes in obese and overweight patients treated for adult lumbar or thoracolumbar scoliosis with combined anterior/posterior surgery. J Spinal Disord Tech (Epub ahead of print)
41. Watanabe K, Lenke LG, Bridwell KH, Kim YJ, Koester L, Hensley M (2010) Proximal junctional vertebral fracture in adults after spinal deformity surgery using pedicle screw constructs: analysis of morphological features. Spine (Phila Pa 1976) 35:138–145
42. Cho KJ, Suk SI, Park SR, Kim JH, Choi SW, Yoon YH, Won MH (2009) Arthrodesis to L5 versus S1 in long instrumentation and fusion for degenerative lumbar scoliosis. Eur Spine J 18:531–537
43. 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
44. Cho KJ, Suk SI, Park SR, Kim JH, Kim SS, Choi WK, Lee KY, Lee SR (2007) Complications in posterior fusion and instrumentation for degenerative lumbar scoliosis. Spine (Phila Pa 1976) 32:2232–2237
45. Cho KJ, Suk SI, Park SR, Kim JH, Kang SB, Kim HS, Oh SJ (2010) Risk factors of sagittal decompensation after long posterior instrumentation and fusion for degenerative lumbar scoliosis. Spine (Phila Pa 1976) 35:1595–1601
46. Keorochana G, Tawonsawatruk T, Laohachareonsombat W, Wajanavisit W, Jaovisidha S (2010) The results of decompression and instrumented fusion with pedicular screw plate system in degenerative lumbar scoliosis patients with spinal stenosis: a prospective observational study. J Med Assoc Thai 93:457–461
47. Quraishi NA, Konig M, Booker SJ, Shafafy M, Boszczyk BM, Grevitt MP, Mehdian H, Webb JK (2013) Access related complications in anterior lumbar surgery performed by spinal surgeons. Eur Spine J 22(Suppl 1):S16–S20
48. Tsai TH, Huang TY, Lieu AS, Lee KS, Kung SS, Chu CW, Hwang SL (2011) Functional outcome analysis: instrumented posterior lumbar interbody fusion for degenerative lumbar scoliosis. Acta Neurochir (Wien) 153:547–555
49. Wu CH, Wong CB, Chen LH, Niu CC, Tsai TT, Chen WJ (2008) Instrumented posterior lumbar interbody fusion for patients with degenerative lumbar scoliosis. J Spinal Disord Tech 21:310–315
50. Acosta FL, Liu J, Slimack N, Moller D, Fessler R, Koski T (2011) Changes in coronal and sagittal plane alignment following minimally invasive direct lateral interbody fusion for the treatment of degenerative lumbar disease in adults: a radiographic study. J Neurosurg Spine 15:92–96
51. Li F, Chen Q, Chen W, Xu K, Wu Q (2011) Posterior-only approach with selective segmental TLIF for degenerative lumbar scoliosis. J Spinal Disord Tech 24:308–312
52. McPhee IB, Swanson CE (1998) The surgical management of degenerative lumbar scoliosis. Posterior instrumentation alone versus two stage surgery. Bull Hosp Jt Dis 57:16–22
53. Xie Y, Fu Q, Chen ZQ, Shi ZC, Zhu XD, Wang CF, Li M (2011) Comparison between two pedicle screw augmentation instrumentations in adult degenerative scoliosis with osteoporosis. BMC Musculoskelet Disord 12:286
54. Ploumis A, Albert TJ, Brown Z, Mehbod AA, Transfeldt EE (2010) Healos graft carrier with bone marrow aspirate instead of allograft as adjunct to local autograft for posterolateral fusion in degenerative lumbar scoliosis: a minimum 2-year follow-up study. J Neurosurg Spine 13:211–215
55. Heary RF, Karimi RJ (2010) Correction of lumbar coronal plane deformity using unilateral cage placement. Neurosurg Focus 28:E10
56. Khan SN, Hofer MA, Gupta MC (2009) Lumbar degenerative scoliosis: outcomes of combined anterior and posterior pelvis surgery with minimum 2-year follow-up. Orthopedics 32(4) [pii:orthosupersite.com/view.asp?rID=8060]
57. Kanayama M, Hashimoto T, Shigenobu K, Togawa D, Oha F (2007) A minimum 10-year follow-up of posterior dynamic stabilization using Graf artificial ligament. Spine (Phila Pa 1976) 32:1992–1996
58. Fairbank JC, Pynsent PB (2000) The Oswestry disability index. Spine (Phila Pa 1976) 25:2940–2952
59. Prommahachai A, Wittayapirot K, Jirarattanaphochai K, Sae-Jung S (2010) Correction with instrumented fusion versus noncorrective surgery for degenerative lumbar scoliosis: a systematic review. J Med Assoc Thai 93:920–929
60. Polly DW Jr, Hamill CL, Bridwell KH (2006) Debate: to fuse or not to fuse to the sacrum, the fate of the L5 ~ S1 disc. Spine 31(19 Suppl):179–184
61. Shen FH, Samartzis D, Khanna AJ, Anderson DG (2007) Minimally invasive techniques for lumbar interbody fusions. Orthop Clin North Am 38:373–386
62. Fantini GA, Pappou IP, Girardi FP, Sandhu HS, Cammisa FP (2007) Major vascular injury during anterior lumbar spinal surgery: incidence, risk factors, and management. Spine (Phila Pa 1976) 32:2751–2758
63. Chrastil J, Patel AA (2012) Complications associated with posterior and transforaminal lumbar interbody fusion. J Am Acad Orthop Surg 20:283–291
64. Pumberger M, Hughes AP, Huang RR, Sama AA, Cammisa FP, Girardi FP (2012) Neurologic deficit following lateral lumbar interbody fusion. Eur Spine J 21:1192–1199
65. Hee HT, Castro FP, Majd ME, Holt RT, Myers L (2001) Anterior/posterior lumbar fusion versus transforaminal lumbar interbody fusion: analysis of complications and predictive factors. J Spinal Disord 14:533–540
66. Rosenberg WS, Mummaneni PV (2001) Transforaminal lumbar interbody fusion: technique, complications, and early results. Neurosurgery 48:569–574