

Morbidity and mortality in the surgical treatment of 10,242 adults with spondylolisthesis

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Clinical article

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Object. This is a retrospective review of 10,242 adults with degenerative spondylolisthesis (DS) and isthmic spondylolisthesis (IS) from the morbidity and mortality (M&M) index of the Scoliosis Research Society (SRS). This database was reviewed to assess complication incidence, and to identify factors that were associated with increased complication rates.

Methods. The SRS M&M database was queried to identify cases of DS and IS treated between 2004 and 2007. Complications were identified and analyzed based on age, surgical approach, spondylolisthesis type/grade, and history of previous surgery. Age was stratified into 2 categories: > 65 years and ≤ 65 years. Surgical approach was stratified into the following categories: decompression without fusion, anterior, anterior/posterior, posterior without instrumentation, posterior with instrumentation, and interbody fusion. Spondylolisthesis grades were divided into low-grade (Meyerding I and II) versus high-grade (Meyerding III, IV, and V) groups. Both univariate and multivariate analyses were performed.

Results. In the 10,242 cases of DS and IS reported, there were 945 complications (9.2%) in 813 patients (7.9%). The most common complications were dural tears, wound infections, implant complications, and neurological complications (range 0.7%–2.1%). The mortality rate was 0.1%. Diagnosis of DS had a significantly higher complication rate (8.5%) when compared with IS (6.6%; $p = 0.002$). High-grade spondylolisthesis correlated strongly with a higher complication rate (22.9% vs 8.3%, $p < 0.0001$). Age > 65 years was associated with a significantly higher complication rate ($p = 0.02$). History of previous surgery and surgical approach were not significantly associated with higher complication rates. On multivariate analysis, only the grade of spondylolisthesis (low vs high) was in the final best-fit model of factors associated with the occurrence of complications ($p < 0.0001$).

Conclusions. The rate of total complications for treatment of DS and IS in this series was 9.2%. The total percentage of patients with complications was 7.9%. On univariate analysis, the complication rate was significantly higher in patients with high-grade spondylolisthesis, a diagnosis of DS, and in older patients. Surgical approach and history of previous surgery were not significantly correlated with increased complication rates. On multivariate analysis, only the grade of spondylolisthesis was significantly associated with the occurrence of complications. (DOI: 10.3171/2010.5.SPINE09529)

KEY WORDS • complication • adult spondylolisthesis • spondylolisthesis grade

Abbreviations used in this paper: DS = degenerative spondylolisthesis; EMG = electromyography; IRB = Institutional Review Board; IS = isthmic spondylolisthesis; M&M = morbidity and mor-

talidity; MEP = motor evoked potential; SRS = Scoliosis Research Society; SSEP = somatosensory evoked potential; TLIF/PLIF = transforaminal lumbar interbody fusion/posterior lumbar interbody fusion.

THE optimal surgical treatment for symptomatic IS and DS remains unclear. Depending on the extent of deformity and spinal stenosis, IS and DS can result in either minimal or severe clinical complaints. Hence, there is a very broad spectrum of possibilities for the treatment of this disorder, which range from conservative (nonsurgical) treatment to an anterior/posterior instrumented fusion with interbody grafting.

Several studies have compared surgical techniques in cohorts of patients with adult IS and DS; however, these studies have been of limited sample size.^{1,7,9,10} For DS, to help determine whether surgical treatment was superior to nonsurgical treatment, a randomized multiinstitutional clinical trial was performed (Spine Patient Outcomes Research Trial).¹⁶ This trial demonstrated that patients with DS and spinal stenosis who were treated surgically showed substantially greater improvement in pain and function during a period of 2 years than did patients treated nonsurgically. It is important to note, however, that this was the case only when nonrandomized “as-treated” comparisons were applied without the intent-to-treat principle. Further follow-up in the same patients in the Spine Patient Outcomes Research Trial revealed that surgically treated patients had significantly greater pain relief and improvement when compared with the nonsurgical group at 4 years.¹⁷ In a prospective study performed by Herkowitz and Kurz,⁹ patients in the arthrodesis group had significantly better relief of back and radicular pain when compared with the decompression group. In patients with IS, a prospective randomized study comparing instrumented and uninstrumented fusion to conservative management was performed by Möller and Hedlund.¹⁴ They randomly allocated 111 adult patients to an exercise group and a fusion group, and they were able to assess functional outcome and pain reduction. Disability and pain improved significantly in the surgery group. In the exercise group, pain improved but disability did not.

Given the evidence to support surgical intervention in patients with both DS and IS, spine surgeons must now decide which surgical treatment provides the optimal results with the minimum amount of risk. It is therefore necessary to have a comprehensive review of the M&M data for the various surgical options available to treat IS and DS. The purpose of this paper was to review the SRS M&M database to assess overall complication rates in IS and DS, and to determine what clinical factors influence the rate of complications. In particular, age, surgical approach, history of previous surgery, and type and grade of spondylolisthesis were assessed for potential association with the occurrence of complications.

The SRS has been collecting data on short-term surgical complications from its members for more than 40 years. Thus far, this database has only been used to report the M&M rates related to scoliosis surgery.^{3,13} It has not been queried for a formal report of the short-term M&M rates related to surgery for adult spondylolisthesis. Due to the large number of cases reported by various surgeons, an analysis of the SRS database has the potential to be the most comprehensive assessment of the operative and perioperative M&M rate for IS and DS.

Methods

Members of the SRS submit spinal surgery case data, including M&M data, by using a secure internet-based questionnaire, which was developed by the SRS M&M committee in the early 1990s. The questionnaire was modified in 2004 to include more detailed questions about specific aspects of the surgical indications, surgical procedure, and complications. The M&M data in the SRS database is short term, ranging from the day of surgery up to 1 year after surgery, because the data are reported on an annual basis. The process of data submission includes a process in which members formally attest that submitted data are true and complete. Approval was obtained from the IRB to review and report studies based on the SRS M&M database. Patients in the database are de-identified. This project was submitted to the IRB at the Hospital for Special Surgery (New York, New York), and was determined to be exempt from IRB approval based on the use of deidentified data (IRB number 29045).

For the purpose of this study, the SRS M&M database was queried to identify cases of IS and DS treated between 2004 and 2007. All reported complications were tabulated and totaled. Complications were stratified by patient age, surgical approach, and whether revision surgery was performed. Grade of spondylolisthesis was only available in the year 2007. Age was stratified into > 65 years, and ≤ 65 years. The different surgical approaches in the database were as follows: decompression without fusion, anterior fusion only, combined anterior/posterior fusion, posterior fusion without instrumentation, posterior fusion with instrumentation, and TLIF/PLIF with instrumentation. If the surgeon chose to use neurological monitoring, the type of monitoring was recorded as one of the following: SSEPs, MEPs, and/or EMG. Furthermore, if neurological monitoring detected a deficit during the procedure, a note was made regarding whether implants were removed. Based on data collection parameters, acute new neurological deficits were defined as those that developed intraoperatively or within 24 hours of surgery, and delayed new neurological deficits were defined as those that developed > 24 hours after surgery. For the 2007 data, low-grade was classified as Meyerding Grades I and II, and high-grade was classified as Meyerding Grades III, IV, and V.

Statistical Analysis

Univariate and multivariate statistical analyses were performed, and statistical significance was based on a *p* value < 0.05. All *p* values for univariate analyses are 2-sided and from the Fisher exact tests unless otherwise noted. Independent-samples *t*-tests were used for comparison of means.

Results

A total of 10,242 cases of adult spondylolisthesis was reported to the SRS M&M database from the years 2004 through 2007. There were 945 complications (9.2%) in 813 patients (7.9%). The most common complications were as follows: 211 dural tears (2.1%); 80 superficial wound

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infections (0.8%); 114 deep wound infections (1.1%); 75 implant complications (0.7%); and 118 neurological complications (1.2%). There were 10 deaths (0.1%). Other complications are listed in Table 1. Age > 65 years was significantly associated with a higher complication rate ($p = 0.02$). The association of older age with a higher complication rate did not remain statistically significant after adjusting for the effects of grade ($p = 0.07$) or type ($p = 0.1$) of spondylolisthesis. The mean age of all patients was 59 years, and the mean ages of patients with IS and DS were found to be 47 and 63 years, respectively ($p < 0.001$). As shown in Table 2, the complication rate according to surgical approach was as follows: 7.1% for decompression without fusion, 7.7% for anterior only, 7.2% for combined anterior/posterior, 7.9% for posterior fusion without instrumentation, 8% for posterior fusion with instrumentation, and 8.1% for TLIF/PLIF. There were no significant differences in overall complication rates based on procedure type ($p = 0.8$; Pearson chi-square 2-sided test).

Neurological complications were also stratified by procedure type, and are summarized in Table 2. Of the 118 neurological complications, 86 (73%) were acute postoperative complications, and 32 (27%) were delayed complications. Of the 118 neurological complications, 117 had data on the classification of neurological injury: 91 were classified as nerve root injuries, 16 were spinal cord injuries, and 10 were cauda equina syndromes. There were data on the recovery of patients with 116 of the 118 neurological deficits: 48 patients had complete recovery, 63 had partial recovery, and 5 had no recovery. Neurological monitoring was used in 5061 patients (49%), and consisted of EMG (3855 patients), SSEPs (3721 patients), and MEPs (1744 patients). Of the 118 patients with neurological deficits, monitoring was obtained in 81 cases (69%). For these 81 cases, 57 had EMG, 68 had SSEP, and 40 had MEP monitoring. In 18 (22%) of these 81 cases with neurological monitoring, intraoperative neurological deficits were detected. In 21 (26%) of these 81 patients, implants were removed in association with suspicion of neurological injury. The rate of neurological complications was the highest in the decompression/no fusion group, but this was not significantly different from the remaining groups ($p = 0.10$). Of the 16 patients with spinal cord injury, neurological monitoring was performed in 13, including EMG (6 patients), SSEP (13), and MEP (9) monitoring. In 5 of these patients implants were removed as a result of suspected neurological injury.

Dural tears were also stratified by surgical approach (Table 2). The rate of dural tears was the highest in the posterior fusion without instrumentation group, but this was not significantly different from that in the remaining groups ($p = 0.06$).

Of the 10,242 patients in the database, 1029 were identified as undergoing revision surgery. There was no significant difference in the complication rate between those undergoing revision surgery and those undergoing initial procedures ($p = 0.8$).

Data for the degree of spondylolisthesis was only available in the year 2007. There were 1767 cases of DS and IS for which grading was submitted in 2007. There were 1275 Meyerding Grade I, 425 Grade II, 55 Grade III,

TABLE 1: Complications in 10,242 cases of adult spondylolisthesis from 2004 to 2007, stratified by patient age*

Complication	No. of Patients (%)		
	All	≤65 Yrs	>65 Yrs
dural tear	211 (2.1)	137	74
wound infection			
superficial	80 (0.8)	44	36
deep	114 (1.1)	77	37
implant	75 (0.7)	49	26
acute neuro	86 (0.8)	55	31
delayed neuro	32 (0.3)	21	11
epidural hematoma	19 (0.2)	15	4
wound hematoma	29 (0.3)	11	18
cardiac	22 (0.2)	13	9
PE	18 (0.2)	12	6
pulmonary (not PE)	63 (0.6)	28	35
DVT	14 (0.1)	9	5
death	10 (0.1)	5	5
visual acuity change	5 (0.05)	2	3
SIADH	10 (0.1)	6	4
other	157 (1.5)	92	65
total complications	945 (9.2)	576 (8.7)	369 (10.3)
total no. patients	10,242	6598	3588
total no. patients w/ complications	813 (7.9)	496 (7.5)	317 (8.8)

* Age not available for 56 patients. Percent complications were calculated with the following formula: $100 \times (\text{total number of patients with complications}) / (\text{number of patients})$. Overall complication rate was significantly higher for procedures performed in patients > 65 years old compared with procedures performed in patients ≤ 65 years old ($p = 0.02$). Abbreviations: DVT = deep venous thrombosis; neuro = neurological; PE = pulmonary embolus; SIADH = syndrome of inappropriate antidiuretic hormone.

10 Grade IV, and 2 Grade V cases of DS and IS. High-grade spondylolisthesis (Meyerding Grades III, IV, and V) correlated strongly with a higher complication rate (22.9%) when compared with low-grade spondylolisthesis (8.3%, $p < 0.0001$). This association remained statistically significant after adjusting for the effects of patient age, type of spondylolisthesis, whether the surgery was primary or revision, and surgical approach ($p < 0.0001$).

Of the 10,242 patients, 7368 had DS, 2608 had IS, and 266 did not have classifications for type of spondylolisthesis. There was a significantly higher complication rate (8.5%) in the patients with DS when compared with those with IS (6.6%, $p = 0.002$). This association remained statistically significant after adjusting for the effects of patient age ($p = 0.01$), but not after adjusting for the effects of grade of spondylolisthesis ($p = 0.7$).

Multivariate forward stepwise analysis was performed using the variables that had a statistically significant association with the occurrence of complications on univariate analysis, specifically patient age (> 65 years), grade of spondylolisthesis (low-grade vs high-grade), and

type of spondylolisthesis (degenerative vs isthmic). Of these variables, only the grade of spondylolisthesis was included in the final best-fit model ($p < 0.0001$).

Discussion

In this paper we review the short-term complication rates in the largest known series of adult patients with spondylolisthesis. The large number of patients treated and the broad range of experience from multiple medical centers makes the SRS database a valuable resource for spine research. However, just as there are strengths to the SRS database, one must also consider its limitations. Limitations include the following: the lack of reporting of long-term follow-up, lack of pain and functional outcome data, and the potential for underreporting of events. This database also lacks factors that typically influence the surgeon's choice of approach, including presence of medical comorbidities, body habitus, and available resources, and hence these are further limitations that must be acknowledged. Nevertheless, since the complication rates reported in this paper are based on the largest series of spine patients in the literature, these rates may serve as benchmarks for the future.

Because there is great heterogeneity in treatment recommendations for adult spondylolisthesis, it is useful for spine surgeons to be able to compare the complication rates of the various surgical approaches. We did not find the overall complication rates to differ significantly from other smaller series.^{5,6,8,10} Similarly, as demonstrated in our series, there have been no definitive studies demonstrating a significant difference in complication rates among different surgical approaches.^{5,6,8,10} The choice of surgical approach seems to depend on the surgeon, and the individual circumstances of each patient impact the decision-making process regarding which approach to perform.

The rate of neurological complications was the highest in the decompression/no fusion group, but this was not significantly different from the remaining groups. Neurological monitoring was obtained in the majority of cases in which neurological deficits were present (81 of 118), which may reflect a tendency to use neuromonitoring in more complex cases. Within these 81 cases, abnormalities were detected intraoperatively in 18. Hence, monitoring influenced the surgeon intraoperatively in only 22% of the times in which a deficit occurred. The utility of neurological monitoring remains a debatable issue.

For a series on spondylolisthesis, it was unexpected to encounter 16 spinal cord injuries. This amounts to a spinal cord injury rate of 0.16% (16 of 10,242). Although the database simply does not permit determination of the operative spinal levels or the lengths of constructs in patients with spinal cord injury, it is possible that these spinal cord injuries could have occurred in the less common cases of L-1, L-2, or thoracic spondylolisthesis, or in cases in which long constructs extended to levels above the spondylolisthesis. It is interesting to note that, for the 13 patients with spinal cord injury in whom monitoring was performed, 13 had SSEP and 9 had MEP monitoring, which could suggest an operation involving a spinal cord

TABLE 2: Complications by type of surgery

Type of Op*	No. of Cases	No. of Complications (%)		
		Total	Neuro	Dural Tears
decompression/no fusion	532	38 (7.1)	10 (1.9)†	9 (1.7)
combined anterior/posterior	893	64 (7.2)	10 (1.1)	17 (1.9)
anterior only	286	22 (7.7)	3 (1.0)	5 (1.7)
posterior fusion w/o instrumentation	491	39 (7.9)	4 (0.8)	16 (3.3)‡
posterior fusion w/ instrumentation	4117	328 (8.0)	42 (1.0)	85 (2.1)
TLIF/PLIF	3860	314 (8.1)	47 (1.2)	79 (2.0)

* In 63 cases (0.6%) the surgical approach was not specified.

† The rate of neurological complications was the highest in the decompression/no fusion group, but this was not significantly different from the remaining groups ($p = 0.10$).

‡ The rate of dural tears was the highest in the posterior fusion without instrumentation group, but this was not significantly different from the remaining groups ($p = 0.06$).

level. However, none of these speculations can be either supported or refuted with the data available.

The rate of dural tears was the highest in the posterior fusion without instrumentation group, but this was not significantly different from that in the remaining groups. We were expecting the rate of nerve injuries and/or dural tears to be higher in the interbody fusion group due to the manipulation of the thecal sac performed during these procedures. Because surgical approach did not influence the rate of perioperative complications, one may say that the results of this study support greater future use of anterior column support in patients in whom it might not have been considered previously due to fear of increased complication risk.

Traditionally, older age has been well documented to be associated with higher complication rates in spine surgery.¹² Other studies, however, have shown that age is not predictive of outcome, or that if age is predictive of outcome, it is due to the confounding presence of other variables.^{2,15} In our study, whereas age was significantly associated with the complication rate on univariate analysis, it did not remain significant after adjusting for the effects of grade or type of spondylolisthesis.

It makes intuitive sense that high-grade spondylolisthesis is significantly associated with the complication rate, because these cases are challenging even for the most experienced spine surgeon. In the present series, a higher grade of spondylolisthesis was strongly associated with the occurrence of complications, and was the only significant factor incorporated into a best-fit multivariate model. Because of the known risk of complications in this patient population, some authors advocate in situ fusion without reduction in adult patients who have not had previous surgery and who demonstrate stability on dynamic radiographic studies.^{4,11}

Regarding the type of spondylolisthesis, DS was significantly associated with a higher rate of complications,

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even after adjusting for the effects of patient age. This may reflect a greater presence of comorbid factors among patients with DS, which may predispose them to a higher risk of developing complications. Alternatively, the increased risk of complications among surgically treated cases of DS, compared with IS, may be a reflection of a greater severity of underlying pathological conditions in DS.

Despite the limitations mentioned, this report provides spine surgeons with perioperative complication rates based on the largest known repertoire of information on patients undergoing spine surgery. It is hoped that this information will be useful when spine surgeons consider their surgical options in the treatment of their patients.

Conclusions

The overall rate of complications for this series of surgically treated adult patients with spondylolisthesis is 9.2%. On univariate analysis, the complication rate was significantly higher in patients with high-grade spondylolisthesis, a diagnosis of DS, and in older patients. Surgical approach and history of previous surgery were not significantly correlated with increased complication rates. On multivariate analysis, only the grade of spondylolisthesis was significantly associated with the occurrence of complications.

Disclosure

This study was performed without any financial support from industry or other organizations. The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Reviewed final version of the manuscript and approved it for submission: all authors.

References

1. Bridwell KH, Sedgewick TA, O'Brien MF, Lenke LG, Baldus C: The role of fusion and instrumentation in the treatment of degenerative spondylolisthesis with spinal stenosis. **J Spinal Disord** 6:461–472, 1993
2. Cassinelli EH, Eubanks J, Vogt M, Furey C, Yoo J, Bohlman HH: Risk factors for the development of perioperative complications in elderly patients undergoing lumbar decompression and arthrodesis for spinal stenosis: an analysis of 166 patients. **Spine** 32:230–235, 2007
3. Coe JD, Arlet V, Donaldson W, Berven S, Hanson DS, Mudiyam R, et al: Complications in spinal fusion for adolescent idiopathic scoliosis in the new millennium. A report of the Scoliosis Research Society Morbidity and Mortality Committee. **Spine** 31:345–349, 2006
4. DeWald CJ, Vartabedian JE, Rodts MF, Hammerberg KW: Evaluation and management of high-grade spondylolisthesis in adults. **Spine** 30 (6 Suppl):S49–S59, 2005
5. DiPaola CP, Molinari RW: Posterior lumbar interbody fusion. **J Am Acad Orthop Surg** 16:130–139, 2008
6. Ekman P, Möller H, Tullberg T, Neumann P, Hedlund R: Posterior lumbar interbody fusion versus posterolateral fusion in adult isthmic spondylolisthesis. **Spine** 32:2178–2183, 2007
7. Fischgrund JS, Mackay M, Herkowitz HN, Brower R, Montgomery DM, Kurz LT: 1997 Volvo Award winner in clinical studies. Degenerative lumbar spondylolisthesis with spinal stenosis: a prospective, randomized study comparing decompressive laminectomy and arthrodesis with and without spinal instrumentation. **Spine** 22:2807–2812, 1997
8. Glassman SD, Carreon LY, Djurasovic M, Dimar JR, Johnson JR, Puno RM, et al: Lumbar fusion outcomes stratified by specific diagnostic indication. **Spine** J 9:13–21, 2009
9. Herkowitz HN, Kurz LT: Degenerative lumbar spondylolisthesis with spinal stenosis. A prospective study comparing decompression with decompression and intertransverse process arthrodesis. **J Bone Joint Surg Am** 73:802–808, 1991
10. Jacobs WC, Vreeling A, De Kleuver M: Fusion for low-grade adult isthmic spondylolisthesis: a systematic review of the literature. **Eur Spine J** 15:391–402, 2006
11. Johnson JR, Kirwan EO: The long-term results of fusion in situ for severe spondylolisthesis. **J Bone Joint Surg Br** 65:43–46, 1983
12. Li G, Patil CG, Lad SP, Ho C, Tian W, Boakye M: Effects of age and comorbidities on complication rates and adverse outcomes after lumbar laminectomy in elderly patients. **Spine** 33:1250–1255, 2008
13. MacEwen GD, Bunnell WP, Sriram K: Acute neurological complications in the treatment of scoliosis. A report of the Scoliosis Research Society. **J Bone Joint Surg Am** 57:404–408, 1975
14. Möller H, Hedlund R: Surgery versus conservative management in adult isthmic spondylolisthesis—a prospective randomized study: part 1. **Spine** 25:1711–1715, 2000
15. Raffo CS, Lauerma WC: Predicting morbidity and mortality of lumbar spine arthrodesis in patients in their ninth decade. **Spine** 31:99–103, 2006
16. Weinstein JN, Lurie JD, Tosteson TD, Hanscom B, Tosteson AN, Blood EA, et al: Surgical versus nonsurgical treatment for lumbar degenerative spondylolisthesis. **N Engl J Med** 356:2257–2270, 2007
17. Weinstein JN, Lurie JD, Tosteson TD, Zhao W, Blood EA, Tosteson AN, et al: Surgical compared with nonoperative treatment for lumbar degenerative spondylolisthesis. four-year results in the Spine Patient Outcomes Research Trial (SPORT) randomized and observational cohorts. **J Bone Joint Surg Am** 91:1295–1304, 2009

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