

Guideline update for the performance of fusion procedures for degenerative disease of the lumbar spine. Part 8: Lumbar fusion for disc herniation and radiculopathy

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Patients suffering from a lumbar herniated disc will typically present with signs and symptoms consistent with radiculopathy. They may also have low-back pain, however, and the source of this pain is less certain, as it may be from the degenerative process that led to the herniation. The surgical alternative of choice remains a lumbar discectomy, but fusions have been performed for both primary and recurrent disc herniations. In the original guidelines, the inclusion of a fusion for routine discectomies was not recommended. This recommendation continues to be supported by more recent evidence. Based on low-level evidence, the incorporation of a lumbar fusion may be considered an option when a herniation is associated with evidence of spinal instability, chronic low-back pain, and/or severe degenerative changes, or if the patient participates in heavy manual labor. For recurrent disc herniations, there is low-level evidence to support the inclusion of lumbar fusion for patients with evidence of instability or chronic low-back pain. (<http://thejns.org/doi/abs/10.3171/2014.4.SPINE14271>)

KEY WORDS • fusion • lumbar spine • herniated disc • practice guidelines

Recommendations

There is no evidence that conflicts with the previous recommendations formulated from the first generation of the Lumbar Fusion Guidelines.

Grade C

Lumbar spinal fusion is not recommended as a routine treatment following primary disc excision in patients with isolated herniated lumbar discs causing radiculopathy (Level IV evidence).

Lumbar spinal fusion is a potential option in patients with herniated discs who have evidence of significant

chronic axial back pain, work as manual laborers, have severe degenerative changes, or have instability associated with radiculopathy caused by herniated lumbar discs (Level IV evidence).

Reoperative discectomy and fusion is a treatment option in patients with recurrent disc herniations associated with instability or chronic axial low back pain (Level III and IV evidence).

Rationale

Herniation of a lumbar disc will typically manifest with radicular signs and symptoms consistent with the spinal nerve under compression. Less specific complaints of low-back pain, presumably from the degeneration associated with the disc herniation, may also be present. To address the primary pathology, which is the compression

Abbreviations used in this paper: JOA = Japanese Orthopaedic Association; LHNP = lumbar herniated nucleus pulposus; ODI = Oswestry Disability Index.

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of the spinal nerve, lumbar discectomy has become the established surgical procedure in cases in which conservative management fails to provide relief.

Although spinal fusion is routinely performed for lumbar instability or low-back pain associated with severe disc degeneration, it has been used for patients presenting with either a primary or recurrent lumbar herniated nucleus pulposus (LHNP) and this application has been described in the literature. Incorporating a fusion during a routine discectomy would increase the complexity of the case, prolong the surgical time, and potentially increase complication rates, without proven medical necessity. As indicated in the first generation of the Lumbar Fusion Guidelines, justification for fusion under these circumstances is lacking.¹⁵ The purpose of this update is to examine the more recent literature investigating the role of fusion in the operative management of patients presenting with radiculopathy and/or back pain secondary to a LHNP.

Search Criteria

A computerized search of the database of the National Library of Medicine from July 2003 to December 2011 was conducted using the search terms ((("Lumbosacral Region"[MeSH] OR "Lumbar Vertebrae"[MeSH]) AND "Spinal Fusion"[MeSH]) OR "lumbar fusion"[All Fields] OR ("lumbar"[title] AND "fusion"[title])) AND ("Radiculopathy"[MeSH] OR radiculopathy[title] OR "intervertebral disk displacement"[title] OR "herniated"[title] OR "intervertebral disc displacement"[title] OR "herniation"[title]) AND (("2003"[PDAT]: "3000"[PDAT]) AND "humans"[MeSH] AND English[lang]). The search was restricted to the English language. This yielded a total of 74 references. The titles and abstracts of each of these references were reviewed, and papers not concerned with the use of fusion with lumbar disc herniations were discarded. References were identified that provided either direct or supporting evidence relevant to the use of fusion as a treatment for lumbar disc herniations. These papers were obtained and reviewed, and relevant references from the bibliographies of these papers were identified. Relevant papers providing Level IV or better evidence are summarized in the evidentiary table. Other papers providing supportive data are shown in the reference section.

Scientific Foundation

Primary Herniated Disc With Radiculopathy

In the first generation of the Lumbar Fusion Guidelines, Resnick et al. examined the role of fusion for patients with radiculopathy and an LHNP.¹⁵ The authors performed a literature review of studies of Level IV or better quality and determined that the routine use of fusion in conjunction with a disc excision for primary LHNP is not recommended. The outcome following decompressive surgery for a patient presenting with an LHNP and radiculopathy, whether primary or recurrent, has been demonstrated in numerous publications.^{10,11} There are a plethora of studies reporting excellent results

and outcomes for patients with primary disc herniations having decompressive surgeries without fusion, and many of these studies are Level I and II studies.^{1-4,14,17,20-23}

This current review will examine the studies investigating fusion as compared with discectomy alone to determine if evidence exists for the addition of fusion in patients with primary disc herniation. Advocates for fusion during the index discectomy claim that stabilizing the segment may prevent late-onset instability and the development of chronic low-back pain. Although several studies have demonstrated that the occurrence of instability following discectomy is associated with less-favorable outcomes, the incidence is relatively low, and therefore routine fusion is not recommended.^{15,16}

Some of the studies used to support this recommendation in the past review were examined once again. Takeshima et al. performed a retrospective review of cases involving patients undergoing surgery for primary disc herniations.¹⁹ Of 95 patients, 44 underwent discectomy alone (after 1990) and 51 underwent discectomy and fusion (between 1986 and 1989), with follow-up averaging 7 years and assessments using the Japanese Orthopaedic Association (JOA) rating scale. There was no statistically significant difference between the 2 groups ($p = 0.31$). This study provides Level III evidence that the routine use of a noninstrumented posterolateral fusion does not improve functional outcome in patients treated with lumbar discectomy. In another study, Donceel and DuBois reviewed a series of 3956 cases involving patients with disc herniations treated with either discectomy ($n = 3670$) or discectomy and fusion ($n = 286$).⁶ They found that 70% of the discectomy-alone group were able to resume their preoperative work level at 1 year after surgery, compared with 45% of the fusion group. The authors noted that the fusion group tended to have more significant symptoms and more complex preoperative histories. This retrospective review provides Level IV evidence suggesting that the addition of fusion does not improve patient outcomes. There were no further studies found that compared discectomy alone to discectomy and fusion. This is likely due to the large number of studies demonstrating excellent outcomes without fusion in this patient population with an isolated LHNP.

Primary Herniated Lumbar Disc Associated With Low-Back Pain/Instability

Fusion has also been recommended for patients presenting with new-onset LHNP and radiculopathy in the presence of axial low-back pain or radiographic instability. The previous review concluded that there was Level III evidence to support the use of posterior fusion at the time of initial discectomy surgery in manual laborers or those with significant preoperative axial low-back pain.¹⁵ Matsunaga et al. reported the results of a retrospective study of 80 cases involving manual laborers treated via either open or percutaneous discectomy ($n = 51$) or an open discectomy and fusion ($n = 29$).¹² They found that at the 1-year point 53% of the patients in the discectomy group and 89% of those in the fusion group were able to resume and maintain preoperative manual labor work activities. Although the discectomy patients did return to

work earlier (12 weeks after surgery) than those in the fusion group (25 weeks after surgery), 22% of the discectomy group could not maintain their work activities due to “lumbar fatigue.” These authors concluded that the addition of fusion should be considered in manual laborers, as it seems to provide a better chance of returning to and staying at their preoperative level of function. The paper is judged to provide Level IV evidence supporting the use of posterolateral fusion at the time of discectomy to improve return to work rates in patients involved in heavy manual labor work activities (see Table 1).

Eie reported on 259 patients with disc herniations who were treated either by discectomy alone ($n = 119$) or by discectomy and noninstrumented posterolateral fusion ($n = 68$).⁷ At 6 years postsurgery, 76% of the discectomy-alone group reported satisfaction compared with 85% of the fusion group. The discectomy-alone patients reported a significantly higher incidence of pain recurrence (27% of patients) compared with the discectomy plus fusion group (15% of patients, $p < 0.01$). This is another Level IV paper supporting the use of fusion at the time of discectomy, especially in patients with significant low-back pain, as they have a higher chance of having pain in later years without a concomitant fusion (see Table 1).

Newer studies reviewed since the prior recommendations were published support the use of fusion for patients with significant preoperative low-back pain and those with existing instability. Satoh et al. published a retrospective review of 174 cases involving patients with disc herniations treated with fusion and 177 involving patients treated with discectomy alone.¹⁸ All patients had at least 5 years of follow-up. Fusion criteria included either a massive disc herniation, as defined by a complete myelographic block on a CT myelogram, or segmental instability, as defined by an anterolisthesis of greater than 3 mm with or without local kyphosis of more than 5° on a flexion lateral radiograph. Patients were assessed on a clinical outcomes questionnaire with a scale consisting of excellent, good, fair, and poor, which appeared to be a modification of Odom’s criteria. Patients undergoing a fusion demonstrated significantly better outcomes with respect to low-back pain. The frequency of revision surgery was significantly higher in patients who did not receive a fusion, but met the criteria for fusion. Interestingly, those patients who did not fulfill the criteria for fusion but had a fusion surgery also had significantly better results in terms of low-back pain scores compared with those without fusions. The authors concluded with this Level IV study that patients with disc herniations and instability or massive herniations can be successfully treated with fusion at the time of primary discectomy.

Recurrent Disc Herniation

The previous Lumbar Fusion Guidelines concluded that reoperative discectomy is recommended as a treatment option in patients with recurrent disc herniations and radiculopathy.¹⁵ For a first-time recurrence, this recommendation continues to be supported by more recent publications. Fu et al., in a retrospective Level III review, investigated the outcome in 41 cases of recurrent lumbar

disc herniation.⁸ In this study, 23 patients underwent a revision discectomy and 18 underwent a revision discectomy with posterolateral instrumentation and fusion.⁸ The minimum follow-up for both cohorts was 60 months, and patients were evaluated using the JOA scores for low-back pain. The clinical outcome was excellent or good in 78.3% of the discectomy cohort and 83.3% of the fusion group. There was no significant difference in clinical outcome parameters between the 2 groups including low-back pain scores, but intraoperative blood loss, length of surgery, and length of hospitalization were significantly less in the nonfusion group. This study provides Level III evidence that in patients presenting with an isolated recurrent herniation with sciatica, disc excision alone without fusion is recommended. This study had very few patients lost to follow-up and was from a single-center with excellent longer-term follow-up.

Fusion at the time of revision discectomy has been more consistently recommended as a treatment option for patients with associated lumbar instability, radiographic degenerative changes, and/or chronic axial low-back pain.¹⁵ This recommendation in the previous guidelines was based on several studies. Huang and Chen reported on 28 patients undergoing posterior interbody fusion (8 with recurrent disc herniations and 10 with low-grade spondylolisthesis).⁹ These patients all had significant degenerative changes and some had spondylolisthesis. The average follow-up was 14 months, and all patients had pedicle screw fixation. Overall, 93% of the patients were satisfied with their condition, and 82% were considered to have achieved radiographic fusion. Of the 8 patients with recurrent disc herniations, 6 had excellent or good outcomes, and 2 had fair outcomes. In another study, Chitnavis and colleagues reported on a group of patients with recurrent disc herniations with symptoms of back pain or signs of instability, who were treated with posterior decompression and interbody fusion.⁵ Of a total of 50 patients with 6 months to 5 years of follow-up, 92% improved after surgery and 90% were very satisfied with their results. This study provides Level IV evidence demonstrating good results with fusion in these patients with recurrent disc herniations with instability and/or axial low-back pain. There is a paucity of more recent evidence to support or refute the previous conclusions from the initial publication of the Lumbar Fusion Guidelines. The majority of these studies were case series and not comparative studies looking at discectomy alone versus discectomy and fusion.¹³

Summary

Based on the recent literature reviewed, there does not appear to be evidence to support the routine use of fusion at the time of an index discectomy operation. There remains conflicting Level III and IV evidence regarding the potential benefit of the addition of fusion in certain situations; however, the increase in morbidity, cost, and potential complications associated with the use of fusion are not justified in routine situations. Patients with demonstrated preoperative instability and significant chronic low-back pain in addition to radicular symptoms may be

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TABLE 1: Lumbar fusion for disc herniation and radiculopathy: summary of evidence*

Authors & Year	Level of Evidence	Brief Description	Comment
Eie, 1978	IV	A retrospective study of 259 pts: 119 discectomy only & 88 discectomy w/ in situ noninstrumented PLF. At the 6-mo follow-up, 89% of the discectomy-only pts & 88% of the fusion pts were satisfied. At the 6-yr follow-up, satisfaction rates were 76% vs 85% (NS). The rate of pain recurrence was much higher in the discectomy group (27% vs 15%, $p < 0.01$). Ability to maintain work at the preop status was 79% in the discectomy group & 86% in the fusion group at 6 yrs.	Results were similar at 6 mos, but fusion provided more stable relief of pain & maintenance of work function over prolonged follow-up.
Matsunaga et al., 1993	IV	A retrospective review of 82 pts (defined as laborers) who engaged daily in work that repeatedly put large amounts of stress on their lumbar spine & 28 athletes. 81 pts had discectomy alone (microdiscectomy in 30 & percutaneous discectomy in 51); 29 pts had discectomy & fusion. The groups had similar demographics w/ a slightly shorter duration of Sx in the percutaneous discectomy group. Follow-up range: 2–7 yrs. Return to work at 1 yr: 75% in discectomy group, but 22% could not sustain work, leaving 53% in end; 89% in spinal fusion group; 58% in percutaneous discectomy group. Time to return to work: 9 wks for percutaneous discectomy, 15 wks for microdiscectomy, 25 wks for fusion. "Lumbar fatigue" given as reason pts w/ discectomy alone had to stop their work or change their jobs from manual labor.	Manual laborers do better after spinal fusion. The selection criteria for defining which pts are appropriate for fusion is unclear & validated outcome assessment was not used.
Donceel & Du Bois, 1998	IV	A retrospective series of 3956 cases (percutaneous nucleotomy in 126, microdiscectomy in 3544, discectomy & fusion in 286) taken from a Belgian sickness fund database. Follow-up averaged 1–3 yrs & fitness to resume work w/in 12 mos was seen in 70% of the discectomy group but only 45% of the fusion group ($p < 0.0001$). The poorest overall outcomes were seen in the fusion group: unemployment, a longer work capacity prior to surgery, longer hospital stay, older age, blue collar job, & lower compensation. The authors found no differences btwn the 2 discectomy techniques.	Large cohort w/ clearly poorer outcomes w/ fusion, but no validated outcome measures were used. In addition, there were no clear surgical indications described.
Takeshima et al., 2000	III	A retrospective study evaluating clinical & radiographic results in 95 pts w/ lumbar disc herniation. The purpose was to evaluate the results of disc excision, w/ & w/o posterolateral fusion. 44 pts underwent disc excision (after 1990), & 51 pts underwent disc excision & fusion (between 1986 & 1989). Clinical Sx were evaluated using the JOA back scores. Clinical outcome was excellent or good in 73% of the nonfusion group & in 82% of the fusion group ($p = 0.31$). The fusion group had greater postop reduction in LBP & lower rate of recurrence.	Retrospective study looking at discectomy vs discectomy & fusion for primary disc herniation. The authors concluded that there is seldom an indication for primary fusion for an isolated lumbar disc herniation.
Chitnavis et al., 2001	IV	A retrospective study of 50 cases of recurrent lumbar disc herniation w/ both leg pain & LBP treated w/ posterior interbody spinal fusion & cage placement; follow-up 6 mos–5 yrs. Pts in whom MRI demonstrated "simple" recurrent herniation w/ no back pain & those w/ only LBP were all excluded from the study. Surgery was performed in pts w/ Sx of neural root compression, tension signs, & back pain w/ focal disc degeneration & nerve root distortion on MRI compatible w/ clinical signs & Sx. In 40 pts (80%) pedicle screws were not used. Clinical outcome was assessed using the Prolo scale. 46 pts (92%) had Sx improvement at 6-mo follow-up, & at the latest follow-up, 45 (90%) would have undergone the same surgery again. Two-thirds of pts experienced good or excellent outcomes (Prolo score ≥ 8) at early & late follow-up. The fusion rate at 2 yrs after surgery was 95%. Only 36 of the 50 pts had more than 2 yrs of follow-up.	Pts w/ recurrent herniated discs w/ degenerative changes & LBP were treated successfully w/ posterior fusion. The authors felt that fusion was a good treatment option for pts w/ recurrent disc herniation w/ both leg pain & LBP w/ focal degenerative changes.
Fu et al., 2005	III	Retrospective study of 41 pts w/ repeat surgery for recurrent lumbar disc herniation w/ & w/o lumbar fusion. The mean follow-up was 88.7 mos (range 60–134). Clinical outcomes were excellent or good in 80.5% of pts (78.3% w/ discectomy alone & 83.3% w/ fusion, NS). No differences in LBP scores (2.2 in nonfusion group & 2.2 in fusion group at final follow-up) & no preop differences in scores or demographics/Sx.	The authors concluded that the results of fusion vs repeat discectomy alone were not significantly different, although there were slightly better results in the fusion group. Discectomy w/o fusion is recommended.

(continued)

TABLE 1: Lumbar fusion for disc herniation and radiculopathy: summary of evidence* (continued)

Authors & Year	Level of Evidence	Brief Description	Comment
Satoh et al., 2006	IV	Retrospective review of 174 pts w/ disc herniation treated w/ fusion & 177 treated w/ discectomy alone. All pts had at least 5 yrs of follow-up. Criteria for fusion were either massive disc herniation (complete myelographic block on CT/myelogram) or segmental instability (defined as an anterior slip of 3 mm &/or local kyphosis of >5° on a lateral flexion radiograph). These pts were divided into 4 groups (Group 1, fusion indicated & performed; Group 2, fusion not indicated but performed; Group 3, fusion indicated but not performed; & Group 4, fusion not indicated & not performed). The pts who had lumbar fusion had statistically superior results compared to the pts undergoing discectomy alone in terms of Sx of LBP, regardless of whether there was an indication for fusion ($p < 0.05$). The worst outcome in terms of LBP & leg pain scores was in the group in which fusion was indicated but only discectomy was performed (w/o fusion). In this group, the frequency of additional surgery was significantly higher. No validated outcomes scores were used to evaluate these cases.	Pts treated w/ fusion compared to those w/ discectomy alone have higher success rates in terms of Sx of LBP. Lumbar disc herniation w/ massive herniations or segmental instability can be well treated w/ posterior interbody fusion.
Huang & Chen, 2003	IV	28 pts (8 w/ recurrent disc herniations & 20 w/ low-grade degenerative spondylolisthesis) were treated w/ posterior decompression & interbody fusion w/ placement of a single threaded titanium cage w/ pedicle screw supplementation. The mean follow-up was 14.4 mos (range 8–39). Clinical outcomes were assessed using the Prolo scale. Dynamic radiography for fusion mass was interpreted by an independent radiologist. Overall, 92.86% of the pts were satisfied w/ their condition after surgery. Radiography showed the rate of bony fusion as 82.14%. All pts had significant degenerative disc disease w/ some having spondylolisthesis.	The authors concluded that recurrent disc herniations w/ LBP & degenerative changes can be managed w/ spinal fusion.

* LBP = low-back pain; NS = not significant; PLF = posterolateral lumbar fusion; Prolo scale = Prolo Functional Economic Outcome Rating Scale; pts = patients; Sx = symptoms.

candidates for fusion at the time of primary disc excision. Patients with recurrent disc herniations have been treated successfully with repeated excision as well as with excision and fusion. In patients with significant spinal deformity, instability, or associated chronic low-back pain, consideration of fusion is reasonable.

Key Issues for Future Investigation

The fact that fusion surgery is not required following a routine, index discectomy is well established, but further investigation to define various radiographic findings predicative of progressive disease would be very valuable. The utility of fusion for recurrent disc herniation remains controversial, and further investigation incorporating improved study design will be required to address this issue.

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References

- Anderson PA, McCormick PC, Angevine PD: Randomized controlled trials of the treatment of lumbar disk herniation: 1983-2007. *J Am Acad Orthop Surg* 16:566–573, 2008

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- Arts MP, Brand R, van den Akker ME, Koes BW, Bartels RH, Tan WF, et al: Tubular discectomy vs conventional microdiscectomy for the treatment of lumbar disk herniation: 2-year results of a double-blind randomized controlled trial. **Neurosurgery** **69**:135–144, 2011
- Atlas SJ, Keller RB, Wu YA, Deyo RA, Singer DE: Long-term outcomes of surgical and nonsurgical management of sciatica secondary to a lumbar disc herniation: 10 year results from the Maine Lumbar Spine Study. **Spine (Phila Pa 1976)** **30**:927–935, 2005
- Bruggeman AJ, Decker RC: Surgical treatment and outcomes of lumbar radiculopathy. **Phys Med Rehabil Clin N Am** **22**:161–177, 2011
- Chitnavis B, Barbagallo G, Selway R, Dardis R, Hussain A, Gullan R: Posterior lumbar interbody fusion for revision disc surgery: review of 50 cases in which carbon fiber cages were implanted. **J Neurosurg** **95 (2 Suppl)**:190–195, 2001
- Donceel P, Du Bois M: Fitness for work after surgery for lumbar disc herniation: a retrospective study. **Eur Spine J** **7**:29–35, 1998
- Eie N: Comparison of the results in patients operated upon for ruptured lumbar discs with and without spinal fusion. **Acta Neurochir (Wien)** **41**:107–113, 1978
- Fu TS, Lai PL, Tsai TT, Niu CC, Chen LH, Chen WJ: Long-term results of disc excision for recurrent lumbar disc herniation with or without posterolateral fusion. **Spine (Phila Pa 1976)** **30**:2830–2834, 2005
- Huang KF, Chen TY: Clinical results of a single central interbody fusion cage and transpedicle screws fixation for recurrent herniated lumbar disc and low-grade spondylolisthesis. **Chang Gung Med J** **26**:170–177, 2003
- Kast E, Oberle J, Richter HP, Börm W: Success of simple sequestrectomy in lumbar spine surgery depends on the competence of the fibrous ring: a prospective controlled study of 168 patients. **Spine (Phila Pa 1976)** **33**:1567–1571, 2008
- Kim JS, Lee SH, Moon KH, Lee HY: Surgical results of the oblique paraspinous approach in upper lumbar disc herniation and thoracolumbar junction. **Neurosurgery** **65**:95–99, 2009
- Matsunaga S, Sakou T, Taketomi E, Ijiri K: Comparison of operative results of lumbar disc herniation in manual laborers and athletes. **Spine (Phila Pa 1976)** **18**:2222–2226, 1993
- Niemeyer T, Halm H, Hackenberg L, Liljenqvist U, Bövingloh AS: Post-discectomy syndrome treated with lumbar interbody fusion. **Int Orthop** **30**:163–166, 2006
- Pearson AM, Blood EA, Frymoyer JW, Herkowitz H, Abdu WA, Woodward R, et al: SPORT lumbar intervertebral disk herniation and back pain: does treatment, location, or morphology matter? **Spine (Phila Pa 1976)** **33**:428–435, 2008
- Resnick DK, Choudhri TF, Dailey AT, Groff MW, Khoo L, Matz PG, et al: Guidelines for the performance of fusion procedures for degenerative disease of the lumbar spine. Part 8: lumbar fusion for disc herniation and radiculopathy. **J Neurosurg Spine** **2**:673–678, 2005
- Resnick DK, Groff MC: Evidence-based guidelines in lumbar spine surgery. **Prog Neurol Surg** **19**:123–134, 2006
- Rihn JA, Hilibrand AS, Radcliff K, Kurd M, Lurie J, Blood E, et al: Duration of symptoms resulting from lumbar disc herniation: effect on treatment outcomes: analysis of the Spine Patient Outcomes Research Trial (SPORT). **J Bone Joint Surg Am** **93**:1906–1914, 2011
- Satoh I, Yonenobu K, Hosono N, Ohwada T, Fuji T, Yoshikawa H: Indication of posterior lumbar interbody fusion for lumbar disc herniation. **J Spinal Disord Tech** **19**:104–108, 2006
- Takehima T, Kambara K, Miyata S, Ueda Y, Tamai S: Clinical and radiographic evaluation of disc excision for lumbar disc herniation with and without posterolateral fusion. **Spine (Phila Pa 1976)** **25**:450–456, 2000
- Tosteson AN, Skinner JS, Tosteson TD, Lurie JD, Andersson GB, Berven S, et al: The cost effectiveness of surgical versus nonoperative treatment for lumbar disc herniation over two years: evidence from the Spine Patient Outcomes Research Trial (SPORT). **Spine (Phila Pa 1976)** **33**:2108–2115, 2008
- Weinstein JN, Lurie JD, Tosteson TD, Skinner JS, Hanscom B, Tosteson AN, et al: Surgical vs nonoperative treatment for lumbar disk herniation: the Spine Patient Outcomes Research Trial (SPORT) observational cohort. **JAMA** **296**:2451–2459, 2006
- Weinstein JN, Lurie JD, Tosteson TD, Tosteson AN, Blood EA, Abdu WA, et al: Surgical versus nonoperative treatment for lumbar disc herniation: four-year results for the Spine Patient Outcomes Research Trial (SPORT). **Spine (Phila Pa 1976)** **33**:2789–2800, 2008
- Weinstein JN, Tosteson TD, Lurie JD, Tosteson AN, Hanscom B, Skinner JS, et al: Surgical vs nonoperative treatment for lumbar disk herniation. The Spine Patient Outcomes Research Trial (SPORT): a randomized trial. **JAMA** **296**:2441–2450, 2006

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