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# Economic impact of minimally invasive lumbar surgery

# Hofstetter CP *et al.* Economic impact of minimally invasive lumbar surgery

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**Abstract**

Cost effectiveness has been demonstrated for traditional lumbar discectomy, lumbar laminectomy as well as for instrumented and noninstrumented arthrodesis. While emerging evicence suggests that minimally invasive spine surgery reduces morbidity, duration of hospitalization, and accelerates return to activites of daily living, data regarding cost effectiveness of these novel techniques is limited. The current study analyzes all available data on minimally invasive techniques for lumbar discectomy, decompression, short-segment fusion and deformity surgery. In general, minimally invasive spine procedures appear to hold promise in quicker patient recovery times and earlier return to work. Thus, minimally invasive lumbar spine surgery appears to have the potential to be a cost-effective intervention. Moreover, novel less invasive procedures are less destabilizing and may therefore be utilized in certain indications that traditionally required arthrodesis procedures. However, there is a lack of studies analyzing the economic impact of minimally invasive spine surgery. Future studies are necessary to confirm the durability and further define indications for minimally invasive lumbar spine procedures.

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**Key words:** Value-based medicine; Cost efficiency; Minimally invasive spine surgery; Arthrodesis; Outcomes

**Core tip:** Minimally invasive lumbar microdiscectomy, decompression and short segment fixation result in clinical outcomes similar to traditional open surgery while decreasing the amount of blood loss, local tissue trauma, and length of hospitilization. Overall, there are few studies focusing on the economic impact of minimally invasive lumbar spine surgery. There is some evidence that minimally invasive short segment arthrodesis procedures are associated with higher cost effectiveness in acute perioperative period compared to traditional open surgery. Early results of minimally invasive surgical techniques for deformity correction appear promising, however, future studies need to address durability and cost effectiveness of these procedures.

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# INTRODUCTION

National spending on health care varies considerably among OECD countries. In 2012, health care costs in the United States accounted for 16.9% of its GDP, while all OECD countries spent a mean 9.3% of their GDP on healt care[1]. Technological progress has been proposed as the main driving force behind the growth of health care expenditures[2,3]. One of the medical fields that has intensively utilized the most advanced technologies is complex spinal surgery. A multitude of novel types of instrumentation, implants, navigation and biologics have recently become available for the use in complex spine surgery[4]. However, critics point out that technologically advanced treatments may offer little or no clinical benefit compared to traditional treatment strategies[5]. Thus, the use of expensive technology, combined with an increase in the number of complex spine procedures, has attracted public attention to the expenditures associated with spinal surgery.

One of the countervailing issues is that epidemiologically, spinal degenerative disease and particular low back pain are most prevalent amongst musculoskeletal disorders. Nearly 100% of all adults end up with spinal problems at least once during their lifetime, with a point prevalence of 4%–33%[6]. According to the Ontario Health Survey, 40% of all chronic disorders are caused by musculoskeletal conditions. Additionally, 54% of all cases of long-term disability are caused by to musculoskeletal diseases[7]. Based on surveys carried out in Canada, the United States, and Western Europe, physical disabilities caused by musculoskeletal conditions assume a 4%-5% prevalence in the adult population[8]. Symptomatic degenerative spinal disorders are treated with a myriad of treatment strategies ranging from medical management, physical therapy, chiropractic adjustments, injections, to complex spine surgery. In 2005, $85.9 billion was spent on the treatment of low back pain, representing a 65% increase from 1997[9,10]. The majority of those expenditures are related to non-surgical management of spinal pain. Nevertheless, data regarding clinical efficacy of spinal procedures are lacking in general. Indeed, less than 1% of studies on lumbar spine arthrodesis procedures published from 2004 to 2009 include cost effectiveness analysis[10]. There is an even more significant lack of data on the benefits of newer minimally invasive spinal (MIS) surgeries. It has been proposed that MIS procedures may have a lower complication rate and thus use fewer hospital resources compared to traditional open spine surgeries[11-13]. The current review attempts to shed light onto the current scientific evidence for cost effectiveness of MIS procedures compared to traditional open spine surgery.

# VALUE-BASED HEALTH CARE

Recently, strategies in medical economics have changed: attempts have been made to move away from the traditional system of service-oriented payment, toward a value-based health care system[14]. With other words: the value of a health care intervention equals its quality divided by its cost measured over a certain period of time. Quality of care is evaluated by a variety of measures, including process measures, safety measures and outcome measures, with the latter being either disease specific or general health values[10,15]. Using the recent value-based model, each healthcare intervention can be assessed by the following simple formula:

*Value = Quality/Cost*

For value-based calculations, the direct and indirect costs of a particular medical intervention must be determined. Direct costs include the charges accumulated by the medical procedures, hospitalization, medications, imaging services and future direct costs that arise from the same medical condition. Indirect costs include decreased productivity caused by disability associated with the medical condition. The quality of a medical procedure is equivalent to the procedure’s effectiveness to improve the life of affected individuals[10]. For international comparability and reproducibility, it is crucial that outcome measures can be calculated easily in order to have consistent and valid data, which can be compared between different interventions, therapies and patient populations. Furthermore, outcome measures should focus on the patients’ wellbeing. The impact of lumbar disorders on quality of life may be assessed with disease specific measures such as the Oswestry Disability Index (ODI) or general measures such as Medical Outcomes Study 36-item Short-Form General Health Survey (SF-36), or the EuroQol (EQ)-5D. Patient´s functional impairment with activities of daily living caused by pain is assessed by the ODI, which is low-back-specific[16-18]. In contrast, the SF-36 is a general health measure, constisting of 8 scales, including a physical pain and bodily function scale, and two main groups based on physical and mental assessments[16-19]. Similar to the SF-36, the EQ-5D constitutes a general health measure. Utilizing the EQ-50, five health-dimensions of quality-of-life can be evaluated: mobility, self-care, daily activities, pain and discomfort and anxiety or depression. Typically, its fields of application are clinical investigation, cost-effectiveness analysis, and comparison of treatment effects across different disease states. Each of these 5 dimensions is evaluated utilizing a scale of 3 scores. In total, 243 different health states can be assessed using the EQ-5D. The quality-adjusted life year (QALY) is another outcome measure, which is used to assess the value of certain health outcomes, with value being defined as quality per cost over time. QALY measures both quality and duration of treatment. As Prieto and colleagues propose, QALY equals health as a measure of quantity and quality of life. QALY is used to calculate a score based on these two components of health[20]. After calculating the number of QALYs gained, which can be easily done with the formula: utility value of a treatment multiplied by the duration of effect caused by the particular treatment, the cost-effectiveness of different types of treatment can be evaluated[20]. Thus, with optimization of effectiveness and durability of a procedure, the benefits as measured in QALYs increase. To accurately analyze the durability of an intervention, long-term follow-up studies are the most useful[15,20]. QALY is intervention-specific[21].

Cost-effectiveness analysis is a very common application of QALY, which is cost divided by the QALYs gained from the treatment of a specific disease state. With this calculation, the benefit of a given procedure or medical intervention is evaluated, which is comparable with various fields of application. Mathematically, QALYs can be expressed by the formula:

***QALY = 1 \* Q***

Q stands for a value given to a health-related state and ranges from 0 and 1. The maximum Q value of 1.0 represents a state of perfect health. Q decreases when the quality of life (QoL) decreases. Death is assigned a Q value of 0. However, some have suggested that there can be QoL states worse than death, which are assigned a negative value[22-25]. QALY is most often used to assess the effect on QoL following a particular intervention[22]. In some developed countries, policy makers have proposed that the cost per QALY gained should not exceed $50000–$100000 in order to consider an intervention cost effective[14,26,27]. Once an intervention has been linked to a certain amount of QALY, it is possible to compare the cost–utility of two treatment approaches for a given disease. This may be accomplished with the cost-effectiveness ratio (ICER), which is expressed with the equation:

*ICER = (C1 - C2)/(Q1 - Q2)*

C1 and C2 represent the costs of the two different treatments. Q1 and Q2 are the QALY values associated with two different treatments[15]. Interventions that lead to a better clinical outcome or are less expensive will be favored by these types of analyses and are considered “dominant”[24,28,29]. Cost effective interventions are those whose costs per QALY gained are less than or equal to the societal or patient willingness to pay[30]. When this type of analysis is applied to surgical procedures, a reduced rate of postoperative complications enhances the cost-effectiveness as complications can affect both cost and outcome of the procedures.

# LUMBAR MICRODISCECTOMY

Hansson and colleagues compared the cost effectiveness of surgical versus conservative treatment for lumbar disc herniations in a non-randomized 2-year study[31]. Total costs favored surgery over non-operative management due to greater work productivity as well as lower indirect costs in the surgery group. The QALY gained was tenfold higher in the surgery group[31]. A 1-year Dutch study compared early surgery versus prolonged conservative care in patients with symptomatic lumbar disc herniations[32]. The QALY analysis favored early surgery over conservative therapy[32]. The direct costs of the surgery exceed that for conservative care, but significant differences in non-healthcare costs (paid domestic help and monetary loss from decreased work productivity) favored the surgical group. This results in similar total costs between the two interventions[32]. A cost utility analysis demonstrated an 87% probability that surgery is more cost effective than conservative care at a willingness-to-pay of 80000 Euros per QALY gained, suggesting that early surgical intervention for lumbar disc herniation is cost effective[32]. In conclusion, surgery was able to confer additional clinical benefits in contrast to conservative care at reasonable economic prices in part due to greater improvements in patient work productivity. Tosteson *et al*[33] evaluated the cost effectiveness of surgery versus conservative treatment for lumbar disc herniations. They analyzed 2-year follow-up data from the multicenter Spine Patient Outcomes Research Trial (SPORT). Standard open discectomy resulted in greater QALYs gained but, on the other hand, was associated with higher total costs compared to conservative treatment. The ICER for surgery relative to non-operative care was calculated to be $69403 per QALY gained for the general population. It was lower at $34355 per QALY gained in Medicare patients. Because of this, surgical treatment for lumbar disc herniations seemed to be cost effective and to be even more cost effective in Medicare patients[33]. Using 4-year follow-up data of the SPORT patient cohort, both the QALY gained and total costs were higher in surgical patients. The difference in total costs between surgery and conservative treatment groups over 4 years was $7006, which was lower than the difference in total costs at the end of 2 years ($14142). The four-year cost per QUALY gained was estimated to be $20600, leading to the conclusion that surgical intervention for lumbar disc herniations becomes more cost effective with longer follow-up[34]. In conclusion, the current literature provides a solid body of evidence that traditional microdiscectomy constitutes a cost effective treatment for symptomatic lumbar disc herniations.

In an attempt to limit access related tissue disruption, transforaminal endoscopic techniques for patients with symptomatic lumbar disc herniations have gained popularity in recent years. Various papers have been published, describing these new minimal-invasive surgical techniques, which allow the surgeon to approach the pathological site via an endoscopic uniportal access. The endoscope is entered *via* a posterolateral access, passing through the intervertebral foramen between traversing and exiting spinal nerves[35-38]. Hermantin and colleagues[39] conducted a prospective, randomized study on 60 patients to investigate the effectiveness endoscopic discectomy compared to traditional microdiscectomy. The clinical outcome of both procedures was comparable. Based on patient´s self-evaluation, clinical findings and ability to return to work, 93% of patients treated with a traditional microdiscectomy compared to 97% of patients who underwent an endoscopic discectomy had a satisfactory outcome. Postoperatively, patients who underwent the endoscopic procedure had a lower use of narcotics compared to the traditional group. While this study did not carry out a cost effectiveness analysis, they report that patients who underwent a traditional microdiscectomy stayed for an average of 49 d out of the work force compared to 27 d of patients who underwent an endoscopic procedure. Mayer and colleagues conducted a study to investigate the effectiveness of endoscopic discectomy compared to microsurgical discectomy in a total of 40 patients[40]. Two years after the procedure, sciatic pain had disappeared in 80% of patients who underwent an endoscopic procedure compared to 65% in the traditional group. Sensory deficits disappeared in 92.3% in the endoscopic group and in 68.8% in the open group. Motor deficits resolved in all affected patients in both groups. Mean duration of postoperative disability following an endoscopic surgery was 7.7 wk; in the microdiscectomy group 22.9 wk of disability were reported. Return to their previous occupation was achieved in 95% in the percutaneous endoscopic cohort and in 72.2% in the miscodiscectomy cohort. Ruetten and colleagues conducted a prospective study in patients undergoing either full-endoscopic or traditional microsurgical discectomy, with 178 patients completing 2-year follow-up[41]. At two-year follow-up, a similar improvement of leg pain was measured in patients treated with endoscopic (VAS for leg pain: preoperative 7.1; follow-up 0.9) or traditional (VAS for leg pain: preoperative 7.6; at 2-year follow-up 0.8) technique. Recurrent disc herniations occurred at a rate of 6.2% both treatment groups. Ruetten and colleagues report a significantly lower rate of complications in patients who underwent endoscopic discetomy compared to traditional microdiscectomy. Importantly, the average duration of disability was 25 d in patients with endoscopic discectomy compared to 49 d in patients who had undergone traditional microdiscectomy.

In summary, the current literature suggests that endoscopic lumbar discectomy achieves similar clinical outcomes and similar patient satisfaction compared to traditional microdiscectomy. While, there is some data that endoscopic discectomy is associated with less disc space and concomitant foraminal collapse[42] long-term data on long-term sequele, such as degenerative disc disease or segmental instability of Endoscopic *vs* Microsurgical lumbar discectomy is lacking. Shorter operative times, shorter hospital stays and earlier return to work following endoscopic discectomy are consistently reported in the current literature. While, no cost-effectiveness analysis comparing endoscopic with microscopic technique is available to date, shorter hospital stays and earlier return to work may contribute to potential cost-effectiveness of endoscopic discectomies if their good clinical outcomes are maintained.

# DECOMPRESSIVE SURGERY

Degenerative lumbar spinal stenosis typically manifests with lumbar radiculopathy or neurogenic claudication, which is impairment of walking due to pain or discomfort in the lower extremities. Neurogenic claudication typically is relieved by anteflexion of the trunk. Usually, nonoperative therapy does not result in sustained improvement[43]. Thus, patients are commonly offered a surgical intervention, the most traditional procedure being a decompressive laminectomy. The goal of this procedure is decompression of the narrowed spinal canal. Posterior elements, including lamina and interspinous ligaments, are removed, leading to the exposure of the lateral recess and lumbar foramina. Tosteson and colleagues conducted an analysis of the costs of traditional lumbar laminectomy to treat spinal stenosis, utilizing the prospective spine patient outcomes research trial (SPORT) cohort[44]. Among 634 participants, 394 suffered from spinal stenosis without spondylolisthis and of these patients 320 patients underwent traditional decompressive surgery without arthrodesis. At 2 years a QALY gain of 0.17 was reported at a cost of $77600 per QALY gained. Importantly, more recent 4-year follow-up data confirmed cost effectiveness of traditional lumbar laminectomy for spinal stenosis without spondylolisthesis[34]. At 4 years, decompressive surgery resulted in a 0.23 QALY gain at a cost of $42800 per QALY gained. Katz and colleagues[45] reported similar findings. Lumbar laminectomy resulted in a significant relief of leg pain from preoperative values (3.4 out of maximum 5 points) to 0.9 at 2 years follow-up in patients with spinal stenosis. Direct costs for laminectomy were $12615 for lumbar decompressive procedures and similar to $17688 reported by Tosteson and colleagues[44]. However, the report of Katz and colleagues lacked a more complete cost effectiveness analysis due to the lack of primary patient-reported data or a validated EuroQol instrument. Adogwa and colleagues investigated cost effectiveness of revision decompression, performed in 42 patients[46]. The cumulative gain in QALY relative to preoperative baseline was 0.84 over a two-year period. Estimated costs were as high as $49431. Costs per QALY gained were calculated to be around $60000, which makes revision decompressions a cost effective treatment for recurrent lumbar stenosis.

In traditional open laminectomy, posterior elements of the vertebral column are removed, including spinous processes and ligaments[30]. While the short-term outcome of traditional laminectomy is favorable[47,48]{Fu, 2008 #96}, it has been proposed that 7-10 years after decompression, 33% of patients have severe back pain and 23% required reoperation[49]. Minimally invasive techniques for lumbar decompression aim to decrease the amount of tissue removal to minimize destabilization of the spine. Biomechanical studies propose that minimally invasive lumbar decompressive techniques cause significantly less hypermobility and less stiffness reduction compared to traditional laminectomy[50,51]. Fu *et al*[30] conducted a prospective study comparing two different decompression techniques (“Windows technique” laminoforaminotomy versus decompressive laminectomy) in patients with lumbar spinal stenosis. Results were good or outstanding in nearly 90% and acceptable in 11% 40 mo following less invasive laminoforaminotomy. There was no need for revision or secondary surgery in any case. In contrast, outcome in the open decompressive laminectomy group was good or excellent in 63% of cases, 30% of patients had acceptable outcomes, while outcome was poor in 7%. In this group, 6 cases of postoperative degenerative spinal instability with worsened back pain were found, which lead to secondary surgery in 4 patients due to recurrent stenosis and instability. Based on adequate long-term outcomes, few complications and low costs, the authors proposed the less invasive laminoforaminotomy as a possible standard method to treat degenerative spinal stenosis.

In a prospective, randomized study, Thomé *et al*[52] compared the clinical outcome of less invasive unilateral or bilateral laminotomy and traditional laminectomy. In all 120 patients adequate decompression was achieved and a massive decrease of pain was observed in each treatment group. The authors report that bilateral laminotomy resulted in significantly less pain compared to unilateral laminotomy or traditional laminectomy at the time of last-follow up 15.5 mo after the procedure. Similarly, SF-36 scores demonstrated marked improvement in all groups, but most pronounced in those patients undergoing bilateral laminotomy. Moreover, bilateral laminotomy exhibited a trend towards a lower rate of complications compared to the other groups. Based on these results, Thomé and colleagues propose that bilateral as well as unilateral laminotomy reliable and valid choices for decompressive surgery of lumbar stenosis, with the most crucial outcomes being relief of symptoms and improvement of quality of life. While unilateral laminotomy and laminectomy seemed to be equal regarding clinical outcome, bilateral laminotomy enables more favorable results.

Parker *et al*[53] conducted cost-effectiveness study over a 2-year period, analyzing unilateral laminotomies using either a subperiosteal dissection via midline incision or tubular access *via* a paramedian incision. They especially focused on the utilization of medical resources provocated by back-related conditions, sickness absence rate and outcome measures like quality adjusted life years (QALYs). The type of access did not affect direct, indirect or overall costs and both treatment arms presented with a cumulative gain of 0.72 QALYs at 2 years postoperative. Total costs averaged $23109 for a hemilaminotomy using a paramedian incision and $25420 for a hemilaminotomy using a midline incision. These results suggest that less invasive hemilaminotomies are a highly cost effective for the treatment of lumbar spinal stenosis. However, there is a paucity of literature comparing cost effectiveness of traditional open laminectomy to less invasive laminectomies. Knight and colleagues compared clinical outcome and cost in 104 patients with lumbar spinal stenosis following either traditional laminectomy or tubular decompression[54]. Consistent with previous studies, the authors detected a similar degree of improvement of the Oswestry Disability Index (ODI) and VAS (Visual Analoge Scale) for back and leg pain following either open or tubular procedure. There was a trend towards more complications in patients treated with open laminectomy. While this study did no perform a complete cost effectiveness analysis it provides information regarding the direct cost of these procedures. Thus, the median cost for traditional laminectomy was $7305 compared to $4518 for tubular decompression.

In conclusion, several studies have demonstrated that traditional laminectomy is a highly cost efficient treatment for spinal stenosis. However, several controversies remain: While short-term outcome of laminectomy (without fusion) is satisfactory, concerns have been voiced regarding the long-term durability of clinical outcomes. Katz *et al*[49] reported that 7-10 years after decompression, 33% of patients have severe back pain and 23% already underwent reoperation. Moreover, it is not known if the use of less invasive decompression techniques with sparing of the posterior elements will decrease the occurrence of late symptomatic instability. The topic of increased instability is further complicated by co-existing spondylolisthesis. While spinal stenosis with concomitant spondylolisthesis is typically treated with decompression and arthrodesis, there is some emerging evidence that less invasive decompression techniques may be suitable even in the presence of mild spondylolisthesis. If less invasive decompression techniques achieve durable alleviation for spinal stenosis even in the setting of mild spondylolistesis, abandoning the need for arthrodesis (in patients with only neurological symptoms) would certainly greatly enhance the cost effectiveness of less invasive decompression techniques. Further studies on the durability of clinical outcome and possible inclusion of spinal stenosis with mild spondylolisthesis as indication may dramatically increase the cost effectiveness of less invasive decompression techniques.

# SHORT SEGMENT FIXATION

Chronic low back pain, defined as pain lasting for more than three months[55], is a common health issue causing a significant healthcare burden. The cost from back pain is mainly due to indirect cost from loss of work productivity. Direct costs associated with the disability were estimated to be around £1.6 billion in the United Kingdom in 1998[56], and the condition is estimated to be responsible for close to 120 million United Kingdom work days lost per year[57]. Back pain may be caused by spondylolisthesis and/or degenerative disc disease, both of which may surgically be treated with arthrodesis. Tosteson *et al*[44] analyzed the cost-effectiveness of traditional fusion utilizing the prospective spine patient outcomes research trial (SPORT) cohort. Among 634 participants, 368 suffered from degenerative spondylosis. Of these patients 344 underwent surgical decompression with spinal fusion. At 2 years a QALY gain of 0.19 was reported at a cost of $120000 per QALY gained. Importantly, the cost effectiveness for spinal arthrodesis for degenerative spondylolisthesis improved markedly 4 years after the procedure. At 4 years, decompressive surgery resulted in a 0.29 QALY gain at a cost of $66300 per QALY gained spondylolisthesis[34]. Fritzell and colleagues performed a prospective randomized controlled study evaluating the cost-effectiveness of lumbar fusion compared to nonsurgical treatment for chronic low back pain[58]. A total of 284 patients were randomized to either fusion surgery (*n* = 217) or best medical management (*n* = 67). At 2 years, clinical outcome was improved in 60% of patients who underwent lumbar fusion compared to 34% who received non-surgical treatment. During 2 years, the societal costs per patient, consisting of direct and indirect costs were higher in the surgical group (704000 Swedish kroner [SEK]) compared to the control group (636000 SEK). With a difference of 60200 SEK, average hospital care costs were significantly higher in the surgical group. The most probable explanation for this finding is the higher cost associated with the fusion procedure itself, as well as the postoperative hospitalization. When using the noninstrumented posterolateral fusion as a reference, there was a 66% increase in costs when instrumentation was performed and a 103% increase if an interbody procedure was performed as well. In contrast to hospital costs, primary and private care seemed to be more expensive in the non-surgical group, with a difference of 1000 SEK, as were drug-associated costs with a difference of 1400 SEK. Another important finding was the significant difference in return-to-work-incidence: patients who had undergone surgery were able to return to work in 33%, while the only 16% of nonsurgical treated patients returned to work. Costs for production losses per patient on sick leave in the control group were: 460200 SEK. To conclude, health care costs and societal costs were higher with surgical treatment. Nevertheless, treatment efficacy clearly favored surgical treatment.

Fritzell *et al*[59] performed a cost-effectiveness analysis based on data from a 2-year randomized controlled trial. They compared lumbar arthrodesis with arthroplasty in patients with discogenic low back pain. Both cohorts experienced similar improvements in quality of life 2 years following the procedure (0.45 QALY). This study found that lumbar fusion was associated with significant greater hospital and total healthcare costs. This was due to a higher rate of reoperations following lumbar arthrodesis (36%) compared to arthroplasty (10%). However, the gross majority of re-operations (77%) in the arthrodesis group were performed for implant removal as the implant was determined by the surgeon to act as pain generator. The authors also included an analysis with costs for re-operation removed from both groups, which eliminated the cost difference form the perspective of both the hospital and healthcare sector. After 2- years there was a nonsignificant cost difference of combined indirect and direct costs of lumbar arthroplasty compared to lumbar arthrodesis surgery. Thus, the authors concluded that both procedures were equally cost effective for society within a 2-year time frame

Adogwa *et al*[60] performed a cost-effectiveness analysis on open tranforaminal lumbar interbody fusion (TLIF) surgery for the treatment of degenerative spondylolisthesis. The mean length of hospital stay was 4 d. There were no surgical site infections, CSF leaks or hardware failures, but 4 cases of incidental durotomy. One patient suffered from perioperative hematoma and thus had to be returned to the operating room. A significant improvement in back pain VAS score, leg pain VAS score and Oswestry Disability Index was observed 2 years after TLIF. There was a cumulative health utility value of 0.86 QALY gained over 2-years. The mean total 2-year cost of TLIF was $36836. Surgery costs were $21311. Outpatient resource utilization costs were $3940. Mean direct medical costs were $25251. Indirect costs were $11584, and the mean 2-year cost per QALY gained associated with TLIF was $42854. There was a median amount of 60 d (IQR 30–120 d) missed workdays. TLIF improved pain, disability, and quality of life in patients with degenerative spondylolisthesis–associated back and leg pain.

In summary, traditional open spinal arthrodesis procedures are associated with high direct procedural costs and hospital fees. However, the current literature suggests that lumbar spinal arthrodesis procedures produce stable clinical improvements, which leads to an accumulation of QALYs while only few additional medical costs incur. Therefore, surgical interventions become more cost effective with time[61]. In the SPORT cohort cost effectiveness for spinal fusion surgery for spondylolistesis was achieved 4 years following the procedure.

MIS arthrodesis procedures have been developed in order to achieve the same surgical goals compared to traditional surgery utilizing a smaller access corridor. The goal is to decrease intraoperative tissue trauma and disruption and hereby decrease perioperative morbidity and promote postoperative rehabilitation. In contrast to traditional transforaminal lumbar interbody fusion (TLIF) which is performed via an open midline approach involving extensive soft tissue stripping and retraction of the paraspinous muscles[15], minimally invasive (MIS) TLIF utilizes a paramedian approach with muscle spreading (Figures 1 and 2). Parker *et al*[62] compared the clinical outcomes and conducted a cost–utility analysis of single-level MIS versus open TLIF procedures. While MIS TLIF’s required longer operative times, they were associated with reduced blood loss and decreased length of hospitalization. Return to work was quicker with the MIS group, but postoperative complications were similar between both techniques. No significant differences in outcomes were noted between the two groups in this study. This study also included a cost-utility analysis to compare the MIS and open procedures 2 years following the intervention. They found a significant difference in total costs: Whereas MIS TLIF resulted in total average cost of $38563, open TLIF was $47858 (*P* = 0.03). On the other hand, there were no statistically significant differences in the calculated QALYs (MIS = QALY gain of 0.77; open = QALY gain of 0.70). As the mean cost savings per MIS-TLIF procedure were $9295 with similar gain in QALYs, the MIS approach produced a higher value with a total cost per QALY of $122303[62].

Wang *et al*[63] conducted a retrospective analysis comparing acute hospitalization charges for 1- and 2-level MIS-TLIF versus open PLIF procedures. Patients having bilateral neurological symptoms were treated with open surgery; those with unilateral symptoms were treated with MIS. Blood loss was significantly reduced in MIS-TLIF procedures. Clinical outcomes did not differ significantly in single-level cases, but in two-level MIS-TLIF patients displayed a significant clinical improvement compared to 2-level open cases. Mean length of hospital stay was significantly lower in single-level MIS cases compared to open procedures. Those differences in length of hospital stay correlated with hospital charges: Single-level MIS-TLIF caused an average cost of $70159 compared to $78444 caused by the open approach. This results in average cost savings of $8285 per MIS-TLIF. For 2-level surgery, mean charges totaled $87454 for MIS versus $108843 for open surgery. Costs for implants and rhBMP-2 were nearly identical. The crucial factor for a cost-difference was the number of levels operated on[63].

Adogwa *et al*[64] conducted a study to compare narcotic use, return to work, disability, and quality of life between MIS and open TLIF’s. The duration of narcotic use was significantly less in the MIS TLIF patients and return to work was shorter for the MIS TLIF cohort. However, significant improvements were observed in all clinical measures in both groups, without a significant difference between both groups at 2 years. Wu *et al*[65] conducted a quantitative meta-analysis on studies reporting fusion rates after single- or multi-level open or minimally invasive/mini-open transforaminal lumbar interbody fusion (TLIF) procedures[65]. Recombinant bone morphogenetic protein was used in 50% of MIS TLIFs and in 12.18% of open procedures. Mean fusion rate for open TLIF (16 studies, 716 patients) was 90.9%, compared to a mean fusion rate of MIS TLIF was 94.8% (8 studies, 312 patients). Complication rates differed between both treatment groups as well, with 12.6% for open TLIF versus 7.5% for minimally invasive TLIF. To conclude, fusion rates for both procedures are in similar. Complication rates are also similar, but there is a trend of a lower complication rate in minimally invasive TLIF procedures.

Overall, MIS fusion procedures are associated with a reduction in utilization of inpatient resources as well as increased cost-savings in the acute perioperative period, predominantly due to reduced complication rates[63]. Long-term cost-utility analysis of MIS versus open procedures is necessary to confirm the long-term clinical effectiveness of MIS procedures.

# ADULT SPINAL DEFORMITY CORRECTION

Complex spine surgery is associated with high costs and performed with increasing frequency. It has therefore become a subject of intense economic scrutiny[66-68]. One of the fastest growing and most expensive areas of spine surgery is surgical correction of degenerative scoliosis and adult spinal deformity. Within 10 years (2000-2010) the total number of spine surgeries for the diagnosis of ‘‘curvature of the spine’’ (ICD-9), increased from 9400 to more than 20600[69]. In comparison, the number of all other ICD-9 spine primary diagnosis codes increased by 20% (from 675500 in 2000 to 813800 in 2010)[69]. Several publications have focused on this substantial topic, suggesting up to 32% of all adults being affected by scoliosis and a prevalence of up to 60% in the elderly[70-73]. Nationwide data from the Healthcare Cost and Utilization Project (HCUP) report that hospital costs for a principal diagnosis of curvature of the spine averaged $54000 in 2010, compared with $17000 for more common spine procedures (ICD-9 720-724)[69]. Costs for more complex multilevel fusions are estimated to be as high as $70000 (excluding overhead)[68]. Costs of readmissions subsequent to the initial surgery are estimated to range between $65000 and $80000 per readmission[74].

McCarthy *et al*[75] conducted a retrospective study to analyze the total per-patient hospital and operating room costs of adult spinal deformity surgery with minimum three levels fused through extended follow-up. Total hospital costs of surgical treatment averaged $120394. Primary surgery averaged $103143 and total readmission costs averaged $67262 per patient with a readmission (*n* = 130, 27% of all patients). Total costs in patients readmitted averaged $174629 compared to $100477 for patients without readmission. Average operating room costs were $70514 per patient, constituting 59% of total hospital costs. Due to prevalent readmissions, the average cost of spinal deformity surgery in adults rose by at least 70%, which illustrates the financial burden of revisions/reoperations. In another study, McCarthy and colleagues compared observed postoperative QALYs with predicted QALYs using observed preoperative health-related theoretical QALYs lacking operative treatment[75]. One cohort consisted of surgical patients who completed 3-year follow-up and the other group of crossover patients with two preoperatively completed HRQOL (health related quality of life) assessments. Average total hospital costs, with discounting and including readmissions, were $125407. At the 3-year follow-up assessment, there was an average QALY of 1.93. Average nonsurgical QALYs were supposed to be 1.6 at this same point of time. Three-years postoperative, the ICER was estimated to be $375000 and 5-year follow-up it was $198000. At the 10-year follow-up, the ICER was $80000. Based upon these calculations, McCarthy and colleagues proposed a cost-effectiveness of surgical spinal deformity treatment in adults after 10-years. This emphasizes the need for the durability of surgical treatment to assess the value of surgery[75].

Surgery for ASD definitely remains challenging. While marked clinical improvement may be seen following successful surgical correction of ASD, intra- and postoperative complications and morbidity remain probable. In a recently published report using data of the Spinal Deformity Study Group, the rate of minor complications was estimated to be 26.2% and the rate of major complications 15.5% in a cohort of 206 patients[76]. This has led spine surgeons all over the world to develop minimally invasive surgical techniques to address spinal deformities. During the last decade a multitude of minimally invasive techniques has evolved to correct coronal spinal deformities. Wang and colleagues presented their early experience with minimally invasive thoracolumbar surgery in 2010[77]. They achieved internal fixation with an extreme lateral interbody fusion. RhBMP-2 was routinely used in all fusion sites and levels. Radiographic fusion was recorded in 84 of 86 operated levels. There was no pseudarthrosis. The patient cohort experienced significant improvement in leg and axial back pain (*P* < 0.01). Only 3 patients had minimal or no improvement of symptoms. Two patients had to be returned to the OR. One patient required extension of the construct and the other patient had a CSF leak. The majority of complications were associated with the transpsoas access. Thus, 30.4% of all patients experienced new postoperative neurological complications like thigh numbness or painful sensations, which lateralized to the side of the approach. Two of these patients had to be admitted to inpatient rehabilitation. In one patient neurological complications were severe, making the permanent use of assistive ambulatory devices mandatory.

Uribe *et al*[78] analyzed complications associated with 3 types of surgery: minimally invasive, hybrid and open. Blood loss was the least in the MIS group, while the open group had the shortest operating time. Length of hospital stay was similar among the groups. Oswestry disability index and visual analog scale scores improved significantly in all groups, except for leg pain, which was not significantly improved in the MIS group. Open surgery achieved significantly better correction of the pelvic incidence-lumbar lordosis (PI-LL) mismatch compared to the MIS group postoperatively (*P* < 0.03). Complication rates were as follows: 30% in the MIS group, 47% in the hybrid group and 63% in the open group.

Wang *et al*[79] surveyed 3 different surgical methods to treat adult spinal deformity: stand-alone, 360° MIS and hybrid. The stand-alone procedure was least invasive; the hybrid group underwent the most substantial procedure. The circumferential MIS group was intermediate. Surgical time was lowest in the stand-alone group and highest in the hybrid group. Clinical improvement was seen in all 3 groups, without significant differences. The hybrid construct allowed for the highest degree of coronal curve correction (Figure 3), and was the only procedure that led to substantial correction of lumbar lordosis (16.6°). Major complications occurred in 29% of stand-alone procedures, 14% of circumferential procedures and in 40% of hybrid group patients. Wang and colleagues concluded that less invasive approaches are associated with specific limitations to coronal and sagittal plane deformity. More invasive procedures have the potential to result in comparable outcomes as open surgery, but are also associated with a higher morbidity.

In conclusion, MIS ASD surgery constitutes a rapidly evolving field which shows promise for certain types of deformities. Several studies have demonstrated that MIS deformity surgery leads to improvement of clinical outcomes and may reduce the rate of perioperative morbidity[80]. Current research is determining particular limitations for scoliotic curve correction utilizing specific less invasive surgical techniques. To date there is no data on the impact of minimally invasive surrey on the cost effectiveness of deformity surgery.

# CONCLUSION

In the lumbar spine, MIS techniques are available for treating a variety of clinical indications. In general, clinicial outcomes following MIS procedures compare favorably to traditional open surgery. MIS procedures appear to improve the cost effectiveness of lumbar spine procedures by decreasing hospital stay and rehabilitation time. Less invasive decompressive techniques such as endoscopic foraminal decompression and tubular spinal decompression also hold great promise to greatly reduce cost by replacing arthrodesis procedures in strictly selected indications. MIS ASD surgery is currently evolving and will potentially play an important role to make adult deformity surgery economically feasible in our aging society. Our current study identifies a great need for high quality cost-effectiveness studies comparing standard open lumbar spine surgeries with MIS techniques.

**REFERENCES**

1 **OECD**. Oecd health data 2014 how does the United States compare. 2014. Available from: http: //www.oecd.org/unitedstates/Briefing-Note-UNITED-STATES-2014.pdf

2 **Newhouse JP**. Medical care costs: how much welfare loss? *J Econ Perspect* 1992; **6**: 3-21 [PMID: 10128078 DOI: 10.1257/jep.6.3.3]

3 **Barros PP**. The black box of health care expenditure growth determinants. *Health Econ* 1998; **7**: 533-544 [PMID: 9809710]

4 **Orr RD**, Postak PD, Rosca M, Greenwald AS. The current state of cervical and lumbar spinal disc arthroplasty. *J Bone Joint Surg Am* 2007; **89 Suppl 3**: 70-75 [PMID: 17908872 DOI: 10.2106/JBJS.G.00396]

5 **Enthoven AC**. Shattuck Lecture--cutting cost without cutting the quality of care. *N Engl J Med* 1978; **298**: 1229-1238 [PMID: 418336 DOI: 10.1056/NEJM197806012982204]

6 **Woolf AD**, Pfleger B. Burden of major musculoskeletal conditions. *Bull World Health Organ* 2003; **81**: 646-656 [PMID: 14710506 DOI: 10.1590/S0042-96862003000900007]

7 **Badley EM**, Rasooly I, Webster GK. Relative importance of musculoskeletal disorders as a cause of chronic health problems, disability, and health care utilization: findings from the 1990 Ontario Health Survey. *J Rheumatol* 1994; **21**: 505-514 [PMID: 8006895]

8 **Reynolds DL**, Chambers LW, Badley EM, Bennett KJ, Goldsmith CH, Jamieson E, Torrance GW, Tugwell P. Physical disability among Canadians reporting musculoskeletal diseases. *J Rheumatol* 1992; **19**: 1020-1030 [PMID: 1387418]

9 **Martin BI**, Deyo RA, Mirza SK, Turner JA, Comstock BA, Hollingworth W, Sullivan SD. Expenditures and health status among adults with back and neck problems. *JAMA* 2008; **299**: 656-664 [PMID: 18270354 DOI: 10.1001/jama.299.6.656]

10 **Rihn JA**, Berven S, Allen T, Phillips FM, Currier BL, Glassman SD, Nash DB, Mick C, Crockard A, Albert TJ. Defining value in spine care. *Am J Med Qual* 2009; **24**: 4S-14S [PMID: 19890180 DOI: 10.1177/1062860609349214]

11 **Cummock MD**, Vanni S, Levi AD, Yu Y, Wang MY. An analysis of postoperative thigh symptoms after minimally invasive transpsoas lumbar interbody fusion. *J Neurosurg Spine* 2011; **15**: 11-18 [PMID: 21476801 DOI: 10.3171/2011.2.SPINE10374]

12 **O'Toole JE**, Eichholz KM, Fessler RG. Surgical site infection rates after minimally invasive spinal surgery. *J Neurosurg Spine* 2009; **11**: 471-476 [PMID: 19929344 DOI: 10.3171/2009.5.SPINE08633]

13 **Villavicencio AT**, Burneikiene S, Roeca CM, Nelson EL, Mason A. Minimally invasive versus open transforaminal lumbar interbody fusion. *Surg Neurol Int* 2010; **1**: 12 [PMID: 20657693 DOI: 10.4103/2152-7806.63905]

14 **Allen RT**, Garfin SR. The economics of minimally invasive spine surgery: the value perspective. *Spine (Phila Pa 1976)* 2010; **35**: S375-S382 [PMID: 21160403 DOI: 10.1097/BRS.0b013e31820238d9]

15 **Anderson DG,** Wang P. Value analysis of minimally invasive spine surgery. *Seminars in Spine Surgery* 2014; **26**: 52-55 [DOI: 10.1053/j.semss.2013.07.011]

16 **Weinstein JN**, Lurie JD, Tosteson TD, Skinner JS, Hanscom B, Tosteson AN, Herkowitz H, Fischgrund J, Cammisa FP, Albert T, Deyo RA. Surgical vs nonoperative treatment for lumbar disk herniation: the Spine Patient Outcomes Research Trial (SPORT) observational cohort. *JAMA* 2006; **296**: 2451-2459 [PMID: 17119141 DOI: 10.1001/jama.296.20.2451]

17 **Weinstein JN**, Tosteson TD, Lurie JD, Tosteson AN, Blood E, Hanscom B, Herkowitz H, Cammisa F, Albert T, Boden SD, Hilibrand A, Goldberg H, Berven S, An H. Surgical versus nonsurgical therapy for lumbar spinal stenosis. *N Engl J Med* 2008; **358**: 794-810 [PMID: 18287602 DOI: 10.1056/NEJMoa0707136]

18 **Weinstein JN**, Tosteson TD, Lurie JD, Tosteson AN, Hanscom B, Skinner JS, Abdu WA, Hilibrand AS, Boden SD, Deyo RA. Surgical vs nonoperative treatment for lumbar disk herniation: the Spine Patient Outcomes Research Trial (SPORT): a randomized trial. *JAMA* 2006; **296**: 2441-2450 [PMID: 17119140 DOI: 10.1001/jama.296.20.2441]

19 **McHorney CA**, Ware JE, Lu JF, Sherbourne CD. The MOS 36-item Short-Form Health Survey (SF-36): III. Tests of data quality, scaling assumptions, and reliability across diverse patient groups. *Med Care* 1994; **32**: 40-66 [PMID: 8277801]

20 **Prieto L**, Sacristán JA. Problems and solutions in calculating quality-adjusted life years (QALYs). *Health Qual Life Outcomes* 2003; **1**: 80 [PMID: 14687421 DOI: 10.1186/1477-7525-1-80]

21 **Barnett DB**. Assessment of quality of life. *Am J Cardiol* 1991; **67**: 41C-44C [PMID: 2021119]

22 **Sassi F**. Calculating QALYs, comparing QALY and DALY calculations. *Health Policy Plan* 2006; **21**: 402-408 [PMID: 16877455 DOI: 10.1093/heapol/czl018]

23 **Ernst R**. Indirect costs and cost-effectiveness analysis. *Value Health* 2006; **9**: 253-261 [PMID: 16903995 DOI: 10.1111/j.1524-4733.2006.00114.x]

24 **Fenwick E**, Marshall DA, Levy AR, Nichol G. Using and interpreting cost-effectiveness acceptability curves: an example using data from a trial of management strategies for atrial fibrillation. *BMC Health Serv Res* 2006; **6**: 52 [PMID: 16623946 DOI: 10.1186/1472-6963-6-52]

25 **Furlong WJ**, Feeny DH, Torrance GW, Barr RD. The Health Utilities Index (HUI) system for assessing health-related quality of life in clinical studies. *Ann Med* 2001; **33**: 375-384 [PMID: 11491197 DOI: 10.3109/07853890109002092]

26 **Laupacis A**, Feeny D, Detsky AS, Tugwell PX. Tentative guidelines for using clinical and economic evaluations revisited. *CMAJ* 1993; **148**: 927-929 [PMID: 8448707]

27 **Laupacis A**, Feeny D, Detsky AS, Tugwell PX. How attractive does a new technology have to be to warrant adoption and utilization? Tentative guidelines for using clinical and economic evaluations. *CMAJ* 1992; **146**: 473-481 [PMID: 1306034]

28 **Bambha K**, Kim WR. Cost-effectiveness analysis and incremental cost-effectiveness ratios: uses and pitfalls. *Eur J Gastroenterol Hepatol* 2004; **16**: 519-526 [PMID: 15167152 DOI: 10.1097/00042737-200406000-00003]

29 **Detsky AS**, Naglie IG. A clinician's guide to cost-effectiveness analysis. *Ann Intern Med* 1990; **113**: 147-154 [PMID: 2113784 DOI: 10.7326/0003-4819-113-2-147]

30 **Fu YS**, Zeng BF, Xu JG. Long-term outcomes of two different decompressive techniques for lumbar spinal stenosis. *Spine (Phila Pa 1976)* 2008; **33**: 514-518 [PMID: 18317196 DOI: 10.1097/BRS.0b013e3181657dde]

31 **Hansson E**, Hansson T. The cost-utility of lumbar disc herniation surgery. *Eur Spine J* 2007; **16**: 329-337 [PMID: 16683121 DOI: 10.1007/s00586-006-0131-y]

32 **van den Hout WB**, Peul WC, Koes BW, Brand R, Kievit J, Thomeer RT. Prolonged conservative care versus early surgery in patients with sciatica from lumbar disc herniation: cost utility analysis alongside a randomised controlled trial. *BMJ* 2008; **336**: 1351-1354 [PMID: 18502912 DOI: 10.1136/bmj.39583.709074.BE]

33 **Tosteson AN**, Skinner JS, Tosteson TD, Lurie JD, Andersson GB, Berven S, Grove MR, Hanscom B, Blood EA, Weinstein JN. 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)* 2008; **33**: 2108-2115 [PMID: 18777603 DOI: 10.1097/BRS.0b013e318182e390]

34 **Tosteson AN**, Tosteson TD, Lurie JD, Abdu W, Herkowitz H, Andersson G, Albert T, Bridwell K, Zhao W, Grove MR, Weinstein MC, Weinstein JN. Comparative effectiveness evidence from the spine patient outcomes research trial: surgical versus nonoperative care for spinal stenosis, degenerative spondylolisthesis, and intervertebral disc herniation. *Spine (Phila Pa 1976)* 2011; **36**: 2061-2068 [PMID: 22048651 DOI: 10.1097/BRS.0b013e318235457b]

35 **Kambin P**, O'Brien E, Zhou L, Schaffer JL. Arthroscopic microdiscectomy and selective fragmentectomy. *Clin Orthop Relat Res* 1998: 150-167 [PMID: 9520885]

36 **Yeung AT**, Tsou PM. Posterolateral endoscopic excision for lumbar disc herniation: Surgical technique, outcome, and complications in 307 consecutive cases. *Spine (Phila Pa 1976)* 2002; **27**: 722-731 [PMID: 11923665]

37 **Tsou PM**, Yeung AT. Transforaminal endoscopic decompression for radiculopathy secondary to intracanal noncontained lumbar disc herniations: outcome and technique. *Spine J* 2002; **2**: 41-48 [PMID: 14588287 DOI: 10.1016/S1529-9430(01)00153-X]

38 **Savitz MH**. Same-day microsurgical arthroscopic lateral-approach laser-assisted (SMALL) fluoroscopic discectomy. *J Neurosurg* 1994; **80**: 1039-1045 [PMID: 8189259 DOI: 10.3171/jns.1994.80.6.1039]

39 **Hermantin FU**, Peters T, Quartararo L, Kambin P. A prospective, randomized study comparing the results of open discectomy with those of video-assisted arthroscopic microdiscectomy. *J Bone Joint Surg Am* 1999; **81**: 958-965 [PMID: 10428127]

40 **Mayer HM**, Brock M. Percutaneous endoscopic discectomy: surgical technique and preliminary results compared to microsurgical discectomy. *J Neurosurg* 1993; **78**: 216-225 [PMID: 8267686 DOI: 10.3171/jns.1993.78.2.0216]

41 **Ruetten S**, Komp M, Merk H, Godolias G. Full-endoscopic interlaminar and transforaminal lumbar discectomy versus conventional microsurgical technique: a prospective, randomized, controlled study. *Spine (Phila Pa 1976)* 2008; **33**: 931-939 [PMID: 18427312 DOI: 10.1097/BRS.0b013e31816c8af7]

42 **Lee SH**, Chung SE, Ahn Y, Kim TH, Park JY, Shin SW. Comparative radiologic evaluation of percutaneous endoscopic lumbar discectomy and open microdiscectomy: a matched cohort analysis. *Mt Sinai J Med* 2006; **73**: 795-801 [PMID: 17008941]

43 **Johnsson KE**, Rosén I, Udén A. The natural course of lumbar spinal stenosis. *Clin Orthop Relat Res* 1992: 82-86 [PMID: 1534726 DOI: 10.3109/17453679309160122]

44 **Tosteson AN**, Lurie JD, Tosteson TD, Skinner JS, Herkowitz H, Albert T, Boden SD, Bridwell K, Longley M, Andersson GB, Blood EA, Grove MR, Weinstein JN. Surgical treatment of spinal stenosis with and without degenerative spondylolisthesis: cost-effectiveness after 2 years. *Ann Intern Med* 2008; **149**: 845-853 [PMID: 19075203]

45 **Katz JN**, Lipson SJ, Lew RA, Grobler LJ, Weinstein JN, Brick GW, Fossel AH, Liang MH. Lumbar laminectomy alone or with instrumented or noninstrumented arthrodesis in degenerative lumbar spinal stenosis. Patient selection, costs, and surgical outcomes. *Spine (Phila Pa 1976)* 1997; **22**: 1123-1131 [PMID: 9160471]

46 **Adogwa O**, Parker SL, Shau DN, Mendenhall SK, Aaronson O, Cheng JS, Devin CJ, McGirt MJ. Cost per quality-adjusted life year gained of revision neural decompression and instrumented fusion for same-level recurrent lumbar stenosis: defining the value of surgical intervention. *J Neurosurg Spine* 2012; **16**: 135-140 [PMID: 22054639 DOI: 10.3171/2011.9.SPINE11308]

47 **Hall S**, Bartleson JD, Onofrio BM, Baker HL, Okazaki H, O'Duffy JD. Lumbar spinal stenosis. Clinical features, diagnostic procedures, and results of surgical treatment in 68 patients. *Ann Intern Med* 1985; **103**: 271-275 [PMID: 3160275]

48 **Sanderson PL**, Wood PL. Surgery for lumbar spinal stenosis in old people. *J Bone Joint Surg Br* 1993; **75**: 393-397 [PMID: 8496206]

49 **Katz JN**, Lipson SJ, Chang LC, Levine SA, Fossel AH, Liang MH. Seven- to 10-year outcome of decompressive surgery for degenerative lumbar spinal stenosis. *Spine (Phila Pa 1976)* 1996; **21**: 92-98 [PMID: 9122770]

50 **Lee MJ**, Bransford RJ, Bellabarba C, Chapman JR, Cohen AM, Harrington RM, Ching RP. The effect of bilateral laminotomy versus laminectomy on the motion and stiffness of the human lumbar spine: a biomechanical comparison. *Spine (Phila Pa 1976)* 2010; **35**: 1789-1793 [PMID: 20562732 DOI: 10.1097/BRS.0b013e3181c9b8d6]

51 **Smith ZA**, Vastardis GA, Carandang G, Havey RM, Hannon S, Dahdaleh N, Voronov LI, Fessler RG, Patwardhan AG. Biomechanical effects of a unilateral approach to minimally invasive lumbar decompression. *PLoS One* 2014; **9**: e92611 [PMID: 24658010 DOI: 10.1371/journal.pone.0092611]

52 **Thomé C**, Zevgaridis D, Leheta O, Bäzner H, Pöckler-Schöniger C, Wöhrle J, Schmiedek P. Outcome after less-invasive decompression of lumbar spinal stenosis: a randomized comparison of unilateral laminotomy, bilateral laminotomy, and laminectomy. *J Neurosurg Spine* 2005; **3**: 129-141 [PMID: 16370302 DOI: 10.3171/spi.2005.3.2.0129]

53 **Parker SL**, Adogwa O, Davis BJ, Fulchiero E, Aaronson O, Cheng J, Devin CJ, McGirt MJ. Cost-utility analysis of minimally invasive versus open multilevel hemilaminectomy for lumbar stenosis. *J Spinal Disord Tech* 2013; **26**: 42-47 [PMID: 21959840 DOI: 10.1097/BSD.0b013e318232313d]

54 **Knight RQ,** Scribani M, Krupa N, Grainger S, Goldberg C, Spivak C, Jenkins P. Lumbar decompressive laminectomy or laminotomy for degenerative conditions: “Outcome comparison of traditional open versus less invasive techniques”. *Spine J* 2013 [DOI: 10.4172/2165-7030.S2-006]

55 **Rivero-Arias O**, Campbell H, Gray A, Fairbank J, Frost H, Wilson-MacDonald J. Surgical stabilisation of the spine compared with a programme of intensive rehabilitation for the management of patients with chronic low back pain: cost utility analysis based on a randomised controlled trial. *BMJ* 2005; **330**: 1239 [PMID: 15911536 DOI: 10.1136/bmj.38441.429618.8F]

56 **Maniadakis N**, Gray A. The economic burden of back pain in the UK. *Pain* 2000; **84**: 95-103 [PMID: 10601677]

57 **Bupa**. Bupa's health information, back pain. 2014. Available from: http: //www.bupa.co.uk/individuals/health-information/directory/b/backpain

58 **Fritzell P**, Hägg O, Jonsson D, Nordwall A. Cost-effectiveness of lumbar fusion and nonsurgical treatment for chronic low back pain in the Swedish Lumbar Spine Study: a multicenter, randomized, controlled trial from the Swedish Lumbar Spine Study Group. *Spine (Phila Pa 1976)* 2004; **29**: 421-34; discussion Z3 [PMID: 15094539]

59 **Fritzell P**, Berg S, Borgström F, Tullberg T, Tropp H. Cost effectiveness of disc prosthesis versus lumbar fusion in patients with chronic low back pain: randomized controlled trial with 2-year follow-up. *Eur Spine J* 2011; **20**: 1001-1011 [PMID: 21053028 DOI: 10.1007/s00586-010-1607-3]

60 **Adogwa O**, Parker SL, Davis BJ, Aaronson O, Devin C, Cheng JS, McGirt MJ. Cost-effectiveness of transforaminal lumbar interbody fusion for Grade I degenerative spondylolisthesis. *J Neurosurg Spine* 2011; **15**: 138-143 [PMID: 21529203 DOI: 10.3171/2011.3.SPINE10562]

61 **Glassman SD**, Polly DW, Dimar JR, Carreon LY. The cost effectiveness of single-level instrumented posterolateral lumbar fusion at 5 years after surgery. *Spine (Phila Pa 1976)* 2012; **37**: 769-774 [PMID: 20489676 DOI: 10.1097/BRS.0b013e3181e03099]

62 **Parker SL**, Mendenhall SK, Shau DN, Zuckerman SL, Godil SS, Cheng JS, McGirt MJ. Minimally Invasive versus Open Transforaminal Lumbar Interbody Fusion for Degenerative Spondylolisthesis: Comparative Effectiveness and Cost-Utility Analysis. *World Neurosurg* 2013; **82**: 230-238 [PMID: 23321379 DOI: 10.1016/j.wneu.2013.01.041]

63 **Wang MY**, Cummock MD, Yu Y, Trivedi RA. An analysis of the differences in the acute hospitalization charges following minimally invasive versus open posterior lumbar interbody fusion. *J Neurosurg Spine* 2010; **12**: 694-699 [PMID: 20515357 DOI: 10.3171/2009.12.SPINE09621]

64 **Adogwa O**, Parker SL, Bydon A, Cheng J, McGirt MJ. Comparative effectiveness of minimally invasive versus open transforaminal lumbar interbody fusion: 2-year assessment of narcotic use, return to work, disability, and quality of life. *J Spinal Disord Tech* 2011; **24**: 479-484 [PMID: 21336176 DOI: 10.1097/BSD.0b013e3182055cac]

65 **Wu RH**, Fraser JF, Härtl R. Minimal access versus open transforaminal lumbar interbody fusion: meta-analysis of fusion rates. *Spine (Phila Pa 1976)* 2010; **35**: 2273-2281 [PMID: 20581757 DOI: 10.1097/BRS.0b013e3181cd42cc]

66 **Deyo RA**, Mirza SK. The case for restraint in spinal surgery: does quality management have a role to play? *Eur Spine J* 2009; **18** Suppl 3: 331-337 [PMID: 19266220 DOI: 10.1007/s00586-009-0908-x]

67 **Deyo RA**, Nachemson A, Mirza SK. Spinal-fusion surgery - the case for restraint. *N Engl J Med* 2004; **350**: 722-726 [PMID: 14960750 DOI: 10.1056/NEJMsb031771]

68 **McCarthy IM**, Hostin RA, O'Brien MF, Fleming NS, Ogola G, Kudyakov R, Richter KM, Saigal R, Berven SH, Ames CP. Analysis of the direct cost of surgery for four diagnostic categories of adult spinal deformity. *Spine J* 2013; **13**: 1843-1848 [PMID: 24315558 DOI: 10.1016/j.spinee.2013.06.048]

69 **Healthcare cost and utilization project (hcup)**. national inpatient sample. 2012. Available from: http://hcupnet.ahrq.gov

70 **Robin GC**, Span Y, Steinberg R, Makin M, Menczel J. Scoliosis in the elderly: a follow-up study. *Spine (Phila Pa 1976)* 1982; **7**: 355-359 [PMID: 6215719]

71 **Schwab F**, Dubey A, Gamez L, El Fegoun AB, Hwang K, Pagala M, Farcy JP. Adult scoliosis: prevalence, SF-36, and nutritional parameters in an elderly volunteer population. *Spine (Phila Pa 1976)* 2005; **30**: 1082-1085 [PMID: 15864163 DOI: 10.1097/01.brs.0000160842.43482.cd]

72 **Schwab F**, Dubey A, Pagala M, Gamez L, Farcy JP. Adult scoliosis: a health assessment analysis by SF-36. *Spine (Phila Pa 1976)* 2003; **28**: 602-606 [PMID: 12642769 DOI: 10.1097/01.BRS.0000049924.94414.BB]

73 **Schwab FJ**, Lafage V, Farcy JP, Bridwell KH, Glassman S, Shainline MR. Predicting outcome and complications in the surgical treatment of adult scoliosis. *Spine (Phila Pa 1976)* 2008; **33**: 2243-2247 [PMID: 18794768 DOI: 10.1097/BRS.0b013e31817d1d4e]

74 **Hart RA**, Prendergast MA, Roberts WG, Nesbit GM, Barnwell SL. Proximal junctional acute collapse cranial to multi-level lumbar fusion: a cost analysis of prophylactic vertebral augmentation. *Spine J* 2008; **8**: 875-881 [PMID: 18375188 DOI: 10.1016/j.spinee.2008.01.015]

75 **McCarthy IM**, Hostin RA, Ames CP, Kim HJ, Smith JS, Boachie-Adjei O, Schwab FJ, Klineberg EO, Shaffrey CI, Gupta MC, Polly DW. Total hospital costs of surgical treatment for adult spinal deformity: an extended follow-up study. *Spine J* 2014; **14**: 2326-2333 [PMID: 24469004 DOI: 10.1016/j.spinee.2014.01.032]

76 **Smith JS**, Shaffrey CI, Glassman SD, Berven SH, Schwab FJ, Hamill CL, Horton WC, Ondra SL, Sansur CA, Bridwell KH. Risk-benefit assessment of surgery for adult scoliosis: an analysis based on patient age. *Spine (Phila Pa 1976)* 2011; **36**: 817-824 [PMID: 20683385 DOI: 10.1097/BRS.0b013e3181e21783]

77 **Wang MY**, Mummaneni PV. Minimally invasive surgery for thoracolumbar spinal deformity: initial clinical experience with clinical and radiographic outcomes. *Neurosurg Focus* 2010; **28**: E9 [PMID: 20192721 DOI: 10.3171/2010.1.FOCUS09286]

78 **Uribe JS**, Deukmedjian AR, Mummaneni PV, Fu KM, Mundis GM, Okonkwo DO, Kanter AS, Eastlack R, Wang MY, Anand N, Fessler RG, La Marca F, Park P, Lafage V, Deviren V, Bess S, Shaffrey CI. Complications in adult spinal deformity surgery: an analysis of minimally invasive, hybrid, and open surgical techniques. *Neurosurg Focus* 2014; **36**: E15 [PMID: 24785480 DOI: 10.3171/2014.3.FOCUS13534]

79 **Wang MY**, Mummaneni PV, Fu KM, Anand N, Okonkwo DO, Kanter AS, La Marca F, Fessler R, Uribe J, Shaffrey CI, Lafage V, Haque RM, Deviren V, Mundis GM. Less invasive surgery for treating adult spinal deformities: ceiling effects for deformity correction with 3 different techniques. *Neurosurg Focus* 2014; **36**: E12 [PMID: 24785477 DOI: 10.3171/2014.3.FOCUS1423]

80 **Bach K**, Ahmadian A, Deukmedjian A, Uribe JS. Minimally invasive surgical techniques in adult degenerative spinal deformity: a systematic review. *Clin Orthop Relat Res* 2014; **472**: 1749-1761 [PMID: 24488750 DOI: 10.1007/s11999-013-3441-5]

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**Figure 1 Minimally invasive transforaminal interbody fusion.** An expandable tubular retractor is positioned via a paramedian approach. Note that the contralateral perdicle screws are in place.

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**Figure 2 Intraoperative view of a pedicle-rod construct during the final stages of a minimally invasive tranforaminal lumbar interbody fusion.**

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**Figure 3 Scatterplot depicting scoliotic curve correction achieved at last follow-up as a function of peroperative curve severity.**