SPINE Volume 35, Number 26S, pp S375–S382
©2010, Lippincott Williams & Wilkins

The Economics of Minimally Invasive Spine Surgery

The Value Perspective

R. Todd Allen, MD, PhD,*† and Steven R. Garfin, MD*

Study Design. Review of the literature.

Objective. To summarize current cost and clinical efficacy data in minimally invasive spine (MIS) surgery.

Summary of Background Data. Cost effectiveness (CE), using cost per quality-adjusted life-years gained, has been shown for lumbar discectomy, decompressive laminectomy, and for instrumented and noninstrumented lumbar fusions in several high-quality studies using conventional, open surgical procedures. Currently, comparisons of costs and clinical outcomes of MIS surgery to open (or nonoperative) approaches are rare and of lesser quality, but suggest that a potential for cost benefits exist using less-invasive surgical approaches.

Methods. A literature review was performed using the database of the National Center for Biotechnology Information (NCBI), PUBMED/Medline.

Results. Reports of clinical results of MIS approaches are far more common than economic evaluations. MIS techniques can be classified as endoscopic or nonendoscopic. Although endoscopic approaches decrease some approach morbidities, the high cost of instrumentation, steep learning curves, and new complication profiles introduced have prevented widespread adoption. Additionally, the high costs have not been shown to be justified by superior clinical benefits. Nonendoscopic MIS approaches, such as percutaneous posterior or lateral, and mini-open lateral and anterior approaches, use direct visualization, standard operative techniques, and report lower complication rates, reduced length of stay, and faster recovery time. For newer MIS and mini-open techniques, significantly lower acute and subacute costs were observed compared with open techniques, mainly due to lower rates of complications, shorter length of stay, and less blood loss, as well as fewer discharges to rehab. Although this suggests that certain MIS procedures produce early cost benefits, the quality of the existing data are low.

Conclusion. Although the CE of MIS surgery is yet to be carefully studied, the few economic studies that do exist suggest that MIS has the potential to be a cost-effective intervention, but only if improved clinical outcomes are maintained (durable). Longer follow-up and better outcome and cost data are needed to determine if incremental CE exists with MIS techniques, *versus* open or nonsurgical interventions.

Key words: cost-effectiveness, indirect costs, socioeconomics, mini-open, endoscopic, economics. **Spine 2010;35:S375–S382**

A shift in health economics is occurring, away from traditional fee-for-service medicine, toward a value-based health care system.[1] The value of a health care intervention is defined as the quality of the intervention divided by the cost of the intervention measured over time.[1] Unlike the current US system in which Medicare reimbursements are typically independent of health-related outcomes or cost considerations, a value-based system emphasizes how much it costs to improve the health-related outcomes and quality of life (QoL) of our patients. The United States embraces some of the most technologically advanced health care available, including several minimally invasive spinal (MIS) procedures.[1–3] Given the increasing demands from an aging population, exponential increases in health care spending, and emerging technologies (including MIS), demonstration of clinical efficacy must be "married" with economic value if resource allocation in the future is to be sustainable.[1,4] Rising US health care costs cannot coexist with limited resources, and future studies in MIS and all spine surgery must focus on both the quality and costs of care.

Currently, high-level cost and clinical efficacy data for newer MIS (including mini-open techniques) surgical procedures are sparse. However, there are several elements of MIS which have the potential to differentiate it from open surgery in certain treatment populations, if favorable improvements in health status and QoL are demonstrated in higher level studies. For example, comorbidities are reported to significantly affect general and disease-specific outcome measures, causing a decrease in average change in outcome scores, particularly noted for lumbar surgeries.[5,6] In an aging population and in patients with multiple comorbidities, who are at higher risk for complications,[7] MIS may result in lower complication rates and less hospital resource utilization, as has been previously reported for open surgeries.[8–11] Measuring these outcomes and the effects of MIS will be essential when determining the future value of MIS spine interventions.

The conversion and contribution of reliable, validated outcome measures, including general health (*i.e.*, EuroQOL [EQ-5D], SF-36) and potentially, spine-specific outcome scores (*i.e.*, oswestry disability index), to quality-adjusted life-years (QALY) is beyond the scope of this discussion, but this utility score (QALY) continues to be used as a measure of health status following several dif-

From the *Department of Orthopedic Surgery, University of California San Diego Medical Center, San Diego, CA; and †San Diego Veterans Affairs Medical Center, La Jolla, CA.
Acknowledgment date: September 2, 2010. First revision date: October 1, 2010. Second revision date: October 16, 2010. Acceptance date: October 16, 2010.
The legal regulatory status of the device(s)/drug(s) that is/are the subject of this manuscript is not applicable in my country.
No funds were received in support of this work. No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.
Address correspondence and reprint requests to R. Todd Allen, MD, PhD, 350 Dickinson St (8894), San Diego, CA, 92103–8894; E-mail: rtallen@ucsd.edu

Table 1. Definitions and Recommendations for Study Design of Cost-Effectiveness and Cost-Utility Analyses

Primary Cost-Effectiveness/Cost-Utility Analysis Study Design Recommendations[19]

Design Feature	Definition	Recommendation
Perspective	Defines which costs are included in the analysis (direct and/or indirect costs)	CEAs/CUAs should be performed with a societal perspective, including both direct and indirect costs
Utility estimates	Validated general health outcome measures and disease specific measures are used to determine health status, QoL, and utility of the intervention	For lumbar spine conditions, use both general QoL measure (EuroQoL-5D or SF-6D) as well as ODI to assess overall status
Sensitivity analysis	A statistical modeling method to account for uncertainties of the CEA in an open, transparent fashion	Run CEA statistical analysis assuming higher costs and decreased benefit
Discounting of costs and benefits	A statistical model for the decreased value of additional costs spend in the future	Assume that money spent now is worth more to a patient than the same amount being spent in the future
Use of appropriate incremental comparisons	The comparison of cost-effectiveness between two procedures	Use an appropriate comparative group for the indication being examined and record similar cost and effectiveness parameters

CEA indicates cost-effectiveness analysis; CUA, cost-utility analysis; QoL, quality of life; EuroQoL-5D, European quality of life 5 question worksheet; SF-6D, short-form 6 questions quality of life worksheet; ODI, Oswestry disability index.

ferent interventions. Measuring outcome as cost per QALY offers conversion of outcome scores into units that are translatable across disciplines. This makes it valuable among healthcare economists and policy makers who may use this to decide on cost-allocation decisions among different surgical interventions. The ability of spine surgery interventions to maintain improvements in HRQoL over a prolonged time period (durability) is crucial to the cost effectiveness (CE) of an intervention (and built into QALY) and profoundly affects the value equation.[4,12–14]Although controversial, the current threshold dollar amount to determine if an intervention is cost effective, in terms of cost per QALY gained (cost/QALY gained), is between $50,000 and $100,000 or less.[15,16]

Spine-related health care expenditures totaled over $86 billion in 2005, a 65% increase from 1997.[17] Despite the majority of these expenditures being related to nonsurgical management of spine disorders, our zeal for emerging technology to surgically treat an ever-increasing aging population must develop in parallel with the drive to demonstrate improved patient outcomes and the CE of these interventions. The remainder of this manuscript focuses on MIS in the context of economic value and clinical effectiveness.

Cost-Effectiveness Analysis

Although the need for economic data in the current healthcare climate is increasingly important, less than 1% of articles published on lumbar spine fusion in the last 5 years (2004–2009) include a CE analysis (CEA).[1] Before discussing available cost studies for open and MIS surgeries, it is important to clarify what should be considered in cost-utility analyses (CUAs). In 1996, the *Journal of the American Medical Association* published recommendations for how to perform CEAs, as concluded by the US Panel on Cost-Effectiveness in Health Medicine.[18–20] Their recommendations for CEAs (or CUAs) discuss several key areas of study design, including perspective, utility estimates, sensitivity analysis, discounting of costs and benefits, and use of appropriate incremental comparisons. A more detailed description of each is included in Table 1. One feature of high-quality cost-analysis studies that has been poorly represented in several prior CEAs is the "perspective" of the study, which simply defines which costs are included in the study. Currently, a "societal perspective" is recommended, meaning that CEAs should include not only direct costs, but indirect costs as well, particularly productivity losses, time lost from work, and potentially other costs (*i.e.*, caregiver expenses). Several currently published CEAs or CUAs lack this comparison group, which does not allow them to determine the incremental CE ratios (*e.g.*, incremental costs per QALY) of one intervention *versus* another. This may have special relevance (see below) to future spine CEAs using either open or MIS techniques.

A consistent method of exactly which costs to include, and how to accurately measure such direct and indirect costs, is yet to be defined in spine care, and existing cost analyses of spine care vary widely in their methods of measurement.[4,11–14,21–26] This variability in methods of determining spine care costs has severely limited the data for spine surgery before 2008.[4,12–14,22,23,25–29] Several primary CUAs and reviews of prior CEAs have attempted to determine whether certain types of open spine surgery interventions were cost effective.[25–27] Unfortunately, the lack of consistent cost measurement tools, costing methods, and lack of high-level (I and II) corollary data markedly limited their ability to appropriately determine whether spine interventions were cost effective. Many studies used average or estimated costs or charge information which does not reflect the true cost of an intervention. These estimates were rarely spine-specific, and can lead to over- or underestimation of costs for different resources used (altering incremental CE ratios).[21] This can introduce significant bias when calculating total spine care costs, a drawback of several prior spine CEAs or CUAs.[23] In some cases, charge data are used to determine CE, and significant overestimations of cost are often introduced, as charges are reimbursed at a mere fraction of face value.

Current Evidence: The Cost Effectiveness of Open Spine Procedures

Several high-level studies have shown that open lumbar discectomies, simple decompressions, and noninstrumented and instrumented spinal fusions for the treatment of lumbar disc herniation, and spinal stenosis without and with spondylolisthesis, respectively, provides significant clinical and cost benefit over nonsurgical care, maintained out to 4 and 5 years.[4,14] Comparing lumbar discectomy to nonoperative treatment at 2 years, total costs were $69,403 per QALY gained for surgery, or $34,355 per QALY gained when using Medicare costs.[12] Surgery for spinal stenosis (decompressive laminectomy) at 2 years showed a QALY gain of 0.17 and a cost of $77,600 per QALY gained.[12] Surgery for degenerative spondylolisthesis (fusion, 93%) improved QALY (0.23 QALYs gained) more than nonoperative care, and costs $115,600 per QALY gained.[13] More recent 4-year data found continued CE for stenosis patients treated with decompressive laminectomy, improving from $77,600 to $64,400 per QALY. The CE for those with degenerative spondylolisthesis treated with instrumented fusion also improved from $115,600 (at 2 years) to $54,500 per QALY gained (at 4 years).[14] A more recent study supports these findings, showing that the total (direct and indirect) costs per QALY gained for instrumented fusions was $50,949 to $53,914 at 5 years out from surgery, supporting it as a cost-effective intervention.[4] When incremental improvements in health- and spine-related outcomes are maintained (durability), the CE of several open spine surgeries is readily seen and compares favorably not only with nonsurgical treatment, but also across many currently funded medical and surgical treatments.

On the basis of a cost registry analysis (available at: www.tuftsmedicalcenter.org/cearegistry) of CE and cost-utility studies, the analyses performed by Tosteson *et al* on the SPORT (spine patient outcomes and research trial) data appear to be the strongest CEA or CUA study available, comparing surgical with nonsurgical spine care.[12–14] Several features of these studies have been highlighted in Table 2, including their comprehensive collection or inclusion of direct and indirect costs, allowing appropriate conclusions to be drawn about the CE of surgery interventions for several common spinal pathologies. In addition to the SPORT CE results, several systematic reviews examining indirect costs found that from an economic, "societal perspective" for lumbar spinal fusion, the costs of production loss from work absenteeism and disability constitute an economic effect, greatly exceeding those of the diagnostic, therapeutic, and treatment regimens.[22,30] These data strongly suggested that the CE of an in-hospital treatment could not be determined without considering extra-hospital service utilization, including direct (*e.g.*, physical therapy) and indirect costs.

Costs of MIS *Versus* Open Spine Procedures

Data from open spine surgery CEAs can be used to ask 3 important questions—how these data relate specifically to MIS surgery, what cost parameters of MIS surgery *versus* open surgery (or nonsurgical treatment) differentiate them, and how those similarities and differences will determine CE and economic evaluations in the future. Several surgical subspecialties have shown CE for a variety of minimally invasive approaches despite initially higher costs of technology, equipment, increased OR times, and relatively high learning curves. In one report, a review of laparoscopic and abdominal hysterectomy costs and effects were examined in 2226 patients.[31] Although total procedural costs were 6.1% higher for laparoscopically treated patients, decreased hospital stay, fewer complications, and lower indirect costs compensated for the higher initial cost.[31] However, this trend has not been seen in the few examples available in spinal endoscopic fusions *versus* open cases.[32,33] In spine thus far, relatively few prospective, randomized level I studies have been performed comparing MIS techniques with open surgery or nonsurgical treatment, and they deal almost exclusively with lumbar decompressions ± discectomies.[34,35]

To our knowledge, only 2 studies have been published comparing the costs of nonendoscopic MIS with traditional open techniques. One study, examining open *versus* minimally invasive posterior lumbar interbody fusion (PLIF), showed decreases in OR time, blood loss (EBL), length of stay (LOS), complications, discharge to inpatient rehabilitation, and overall charges when using a minimally invasive approach.[11] For example, mean LOS for single-level MIS *versus* open surgeries were 3.9 *versus* 4.8 days (P = 0.017), whereas 2-level MIS surgery patients LOS was 5.1 day, *versus* 7.1 for open surgeries. In addition, 5% of patients undergoing single-level MIS PLIF were discharged to rehab, compared with 13% who underwent open PLIF. Comparing the costs of single-level MIS *versus* open PLIF, mean hospital charges were $70,159 (MIS; complication rate: 4.3%) *versus* $78,444 (open; complication rate, 13.4%), respectively; while 2-level MIS *versus* open PLIFs charges were $87,454 *versus* $108,843, with complication rates of 25% *versus* 71.2%, respectively.[11]The complication rates of the 2-level PLIF cohorts are exceedingly high compared with other findings in the literature, though this is likely a result of the small sample size (8 MIS, 7 open). For instance, Okuda *et al* reported an overall complication rate of 24.7%, with a reoperation rate of 8% using open PLIFs in 251 patients.[36] Although several variables likely account for some of the cost differences in this study, such as patient selection, study population, surgeon expectations, and hospital setting, the authors did not include rehab charges in their analysis. On the basis of their

Table 2. Cost-Effectiveness Parameters and Basic Results of Direct and Indirect Cost Comparisons Between Surgically and Conservatively Treated Patients From the Spine Outcomes and Research Trial (SPORT)[12]

Spine Outcomes and Research Trial (SPORT) CUA Direct and Indirect Cost Parameters[12]

Cost	Measurements	How Measured
Direct costs	Surgery	Costs of surgery depended on procedure and complication occurrence based on 2004. Medicare mean total diagnosis-related group payments reflected hospital-related surgery costs. Reflected hospital-related surgery costs
	Hospital stay	Estimates based on Medicare national allowable payment amounts. Estimated by unit costing to each visit, test and procedure
	Emergency department visits	
	Outpatient visits	
	Surgeon	Surgeon costs were based on Medicare allowable amounts in 2004 and used "resource-based relative value scale"
	Anesthesia	Anesthesia costs were estimated by OR time
	Hospital supplies and materials	Estimated by unit costing to each visit, test and procedure
	Physical therapy	
	Acupuncture	
	Diagnostics	
	MRI	
	Radiographs	
	CT	
	Injections	
	Medical devices	
	Braces, canes, walkers	Medication estimates based on wholesale prices
	Medications	
	Rehabilitation	
	Nursing days	
Indirect costs	Spine-related productivity loss	Based on total expected production losses for an individual worked for duration of impairment
	Missed days from work or homemaking	Multiplying the change in hours worked by the gross tax wage rate
	Also incorporated unpaid caregiver days missed	On the basis of self-reported wages at study entry
Results		
Direct costs	Diagnostic test utilization	Performed more frequently among those having surgery
	Injection use	Higher among nonoperative group
	Narcotic use	More common in surgical group
	Assist-device use	Similar between groups
Indirect costs	Unpaid caregiver costs	Similar between groups
	Missed homemaking costs	Substantial for both groups

CUA indicates cost-utility analysis; OR, operating room; MRI, magnetic resonance imaging; CT, computed tomography.

data, including rehab costs would further favor MIS, and the trends for quicker discharge suggest that early or intermediate cost benefits may exist for these MIS procedures in some patients. However, long-term CE should not be implied, because no durable maintenance of outcomes, with the same or less postoperative resource utilization, has yet been shown.

Deluzio *et al* compared open PLIF with a minimally invasive lateral (retroperitoneal), transpsoas approach for discectomy and instrumented lumbar interbody fusion and found significantly fewer complications, transfusions, shorter LOS, and a ~10% decrease in in-hospital costs when using a minimally invasive approach. In that study, the open technique cost $26,770.54 per patient, while the MIS technique cost $24,208.07 per patient.[8] Although this early lower cost data are encouraging, and is supported clinically in several case series, it is premature to assume that these early data will translate into increased value (cost/QALY gained) for MIS interventions. Again, this will be true only if one assumes that MIS surgery offers (or embodies the promise of) at least equal outcomes and improvements in QoL compared with traditional, open procedures. The lack of high-level data in support of these outcome improvements and their durability will need to be addressed in future investigations. However, there are several clues as to how data from current MIS spine studies may affect the cost equation in the short and long term.

The most important features differentiating several MIS procedures include fewer infections, fewer approach and possibly surgery-related complications, less blood loss, shorter LOS, less early narcotic pain medicine requirements, and a more rapid return to work (RTW) and productivity (shorter recovery period). The obvious implications are that less EBL, shorter LOS, and lower rates of infection and complications means lower in-hospital and postdischarge costs. Faster RTW and productivity means lower indirect costs to the patient and society. If these reported benefits become widespread and reproducible across a variety of treatment groups, these elements may further contribute to the incremental CE of MIS surgery over time, despite potentially higher instrumentation or implant fees, biologics, equipment, and the like.

Complications

Recent national data in over 66,000 patients found an overall complication rate of 13.07% after "open" posterior lumbar fusion for spondylolisthesis.[7] An even more recent review of more than 505,000 patients suggests that this rate may be slightly higher (14.0%), with the authors also reporting mean reoperation rates of 9.5% to 19%.[37] In national databases, the most common method of determining a complication is by the occurrence of a billable event during the index hospitalization. This almost assuredly results in underreporting the true incidence of complications, as readmissions, complications occurring after discharge, and events that do not result in a bill would go unnoticed unless tracked during the study. In this respect, prospective and retrospective studies conducted at the local or multicenter level may better be able to determine the true complication rate throughout the perioperative period and beyond. Although endoscopic interbody fusion techniques have steep learning curves, endoscopic discectomies and other MIS transforaminal lumbar interbody fusions, MIS discectomies, *etc*., and mini-open approaches (*e.g*., lateral, mini-open, retroperitoneal interbody lumbar fusions) do not appear to exhibit the same level of technical difficulty that has negatively affected the widespread adoption of endoscopic fusion techniques.[8,10,11,34,35,38–44] Whether this is due to newer instrumentation, techniques, surgeon training or expertise, or familiarity, is unclear, but is likely a combination thereof. Much can be learned from published reports on the learning curve, where complication rates are expected to be higher, as are OR times. For example, during the first 50 cases of direct lateral interbody fusions for degenerative conditions, major adverse events occurred in 8.6%, with nerve irritation (meralgia paresthetica) being the major approach-related complaint (3.4%).[43] In a recent report by Rodgers *et al* of 600 patients treated with a minimally invasive, lateral, transpsoas approach (extreme lateral interbody fusion [XLIF], NuVasive, Inc, San Diego, CA), relatively low complication and reoperation rates of 6.2% and 1.8%, respectively, were observed.[44] Similarly, in mini-open anterior lumbar interbody fusions, overall complication rates of 4.3% to 5.1% have been reported.[38,41,45,46] However, these low rates of complications have not been seen in all nonendoscopic, minimally invasive techniques when compared with open approaches, as in some minimally invasive transforaminal lumbar interbody fusion techniques.[10,40] Additionally, in discectomies for herniated discs, high-quality trials have shown fewer complications using a full-endoscopic approach compared with the standard microsurgical approach.[35]

Factors that significantly increase the likelihood of an infection in open procedures include increased blood loss (and transfusion rates), extended OR time, the use of a posterior approach to the spine, and several patient risk factors, such as increased age, diabetes mellitus, smoking, and high BMI.[7,47] The costs surrounding a unit of blood transfused is estimated at over $1000 now, and often is associated with increased resource utilization and LOS. Practically speaking, the occurrence of any one of these complications or risk factors may directly increase in-hospital and, potentially, extrahospital costs and resource utilization. Because hospitals spend most of the money on a patient in the first 3 days,[48] decreasing LOS with MIS techniques may decrease these costs substantially. In fact, discharge before 3 days will have the most effect on hospital costs not related to the surgical procedure, as was recently reported, where LOS for 2-level "XLIF" (lateral transpsoas interbody fusion) was 1.2 days compared with 3.2 days for open PLIF patients.[8] Data from MIS studies have also suggested that shorter LOS translates into faster recovery and potentially, a faster RTW.[46,49] This may profoundly affect the cost equation, and is highly beneficial from a societal perspective. Infection rates in MIS and open spine procedures, as reported in the literature,[7,9,38,44,50–56] are included in Table 3, and is discussed further in detail within this journal special edition by McAfee and others.

Data regarding the costs of complications vary, ranging from approximately $10,000[7] per in-hospital complication for a spine patient to potentially 3 × that of the original surgery costs, if readmission and surgery must be performed. One study found that a single complication may increase hospital costs for a patient in general surgery (except cardiac) by 79%,[57] and when broken down further, median costs for each complication was $4278 (range, $2511–$25,168), which increased LOS by 131% to 297%. When complications occur, significant increases in LOS, mean total charges, and in-hospital mortality are subsequently observed.[7] Complications are more likely in the elderly and in patients with multiple comorbidities, and one complication increases the likelihood for a second and third.[7] This is relevant, particularly as we treat an aging population and more complex spine disorders, where open techniques for complex adult deformity, for example, may have complication rates as high as 50%.[58] Importantly, however, although complications can be costly, certain complications may not always affect long-term surgical success or patient outcomes.[58] Therefore, the intuitive goal of these newer MIS spine procedures is to achieve similar (or improved) outcomes as traditional open procedures in basic, and especially in the most complex spinal pathologies, using less-invasive techniques, in the hope that this will result in lower complication rates, thereby lowering costs and increasing CE while optimizing patient outcomes and accomplishing surgical goals. Though the goal is noble, the data thus far are insufficient to predestine this result. Nonetheless, there are features of MIS spine surgery that suggest that it at least has the potential to lessen the economic burden and resource utilization surrounding basic and complex spine cases, as seen in studies within this journal edition. There are perhaps larger scale societal and ethical concerns as well regarding large, open surgeries in difficult patient populations, and further study is warranted to determine what effect MIS spine surgeries may have on

Table 3. Historical Infection Rates

Author	Exposure	Approach	Procedure	Indication	No. Levels	Levels	N	Infections: Simple Decompression	Infections: Instrumented Decompression	Infections: Instrumented Fusion	Infections: Total
Rodgers *et al*[44]	MIS	Lateral, posterior	XLIF	DDD	1–4	L1–L5	600	—	—	0.0%	0.0%
Dakwar *et al*[50]	MIS	Lateral, posterior	XLIF	Scoliosis	1–6	T10–S1	25	—	—	0.0%	0.0%
O'Toole *et al*[9]	MIS	Mixed	Mixed	Mixed	1–4	C, T, L	1338	0.0%	0.44%	0.74%	0.22%
Dhall *et al*[40]	MIS	Posterior	TLIF	DDD	1	L	21	—	—	0.0%	0.0%
Villaviencio *et al*[56]	MIS	Posterior	TLIF	DDD	1–2	L	73	—	—	2.7%	2.7%
McAfee *et al*[54]	Endoscopic	Anterior	Decomp/ fusion	Mixed	Mixed	L	100	—	—	0.0%	0.0%
Brau[39]	MIS	Anterior	ALIF	DDD	1	L	686	—	—	0.4%	0.4%
Dhall *et al*[40]	Open	Posterior	TLIF	DDD	2	L	21	—	—	0.0%	0.0%
Rihn *et al*[55]	Open	Posterior	TLIF	DDD	1	L	119	—	—	6.1%	6.1%
Faciszewski *et al*[52]	Open	Anterior	Anterior surgery	Mixed	Mixed	C, T, L	1223	—	—	—	1.6%
Villaviencio *et al*[56]	Open	Posterior	TLIF	DDD	1–2	L	51	—	—	0.0%	0.0%
Jutte and Castelein[53]	Open	Posterior	PLF	DDD	1–7	L	105	—	4.7%	—	4.7%
Kalanithi *et al*[7]	Open	Posterior	PLF/PLIF/ TLIF	Spondylolisthesis	Mixed	L	66,601	—	—	—	0.4%
Villaviencio *et al*[56]	Open	Anterior	ALIF	DDD	1–2	L	43	—	—	9.3%	9.3%
Epstein[51]	Open	Posterior	PLF	DDD	Mixed	L	128	—	—	10.9%	10.9%

N indicates sample size; MIS, minimally invasive spine surgery; XLIF, extreme lateral interbody fusion; DDD, degenerative disc disease; C, cervical; T, Thoracic; L, Lumbar; TLIF, transforaminal interbody fusion; decomp, decompression; ALIF, anterior lumbar interbody fusion; PLF, posterolateral fusion; PLIF, posterior lumbar interbody fusion.

older patients with debilitating, complex spine disease and multiple medical comorbidities.

Indirect Costs

Low back pain is the most frequent and most expensive cause of work-related disability.[17,59] A recent systematic review of studies on the cost of LBP noted that costs due to lost productivity and early retirement were by far the largest component of total costs, representing a median 85% of overall costs.[27] The potential to more readily increase societal productivity may be one of the biggest potential advantages of MIS economics. In 2004, Fritzell *et al* reported that it was less expensive to treat a person with open lumbar fusion surgery than it was to have that person not contributing to societal productivity while being treated with conservative care.[22] Theoretically, those benefits would increase if the surgical intervention resulted in less in-hospitalization costs, fewer complications (less EBL, LOS, infection), and less extrahospital postdischarge resource utilization.[60] Unfortunately, high-level CE data comparing minimally invasive to open spine surgeries in support of these theoretical benefits have yet to be performed. But lack of strictly defined and standardized cost methods for spine care does not imply lack of evidence, as shown above for MIS procedures and in prior high-level costs analyses by Tosteson *et al*, Glassman *et al*, and others.[4,12–14] Strictly speaking, Fritzell *et al* noted that,

"...In all, almost twice as many patients "improved," and twice as many returned to work when fusion was offered instead of nonsurgical treatment. In other words, to get 10 patients "improved," 17 patients had to be offered lumbar fusion compared with 30 patients offered nonsurgical treatment. To get 10 patients to "return to work," 30 patients have to be offered lumbar fusion compared with 63 patients offered nonsurgical treatment."[60]

In surgical care of patients with spinal disorders, this may be the area where the potential benefit of well-performed, well-studied open and MIS spine procedures have the biggest effect on the future value of spine care.

■ Conclusion

By the year 2030, over ½ of the adults in the US population will be over aged 65 years. The economic effect of spine (and hip) disorders of this aging population will have profound implications on the future affordability and availability of quality spine care. Regardless of what changes occur in healthcare reform, resource allocation will likely favor those interventions that demonstrate both clinical efficacy and CE (value). For the diagnostic categories of lumbar disc herniation, and spinal stenosis without and with spondylolisthesis, open spine surgery procedures have shown both clinical efficacy and CE at 4 and 5 years from surgery.[4,14] Future studies in MIS need to place extra emphasis on the above indicators of economic value to result in more widespread adoption. Insight into the decision-making currency (*e.g.*, cost per QALY gained) of the government, payers, and policymakers may be essential for the viability and growth of this and other surgical specialties.

As the number of MIS procedures increases, and demand grows, advances in techniques and instrumentation will increase, as will costs. Despite increased equipment and instrumentation costs, current data (albeit limited) suggest that acute care costs for MIS spine surgery are lower than for open surgical interventions, and thus may offset potential higher upfront costs of many MIS implants and equipment. Although data are sparse, the cumulative effects of lower complication and infection rates, shorter LOSs, less EBL, and potentially lower postdischarge resource utilization, combined with a potentially quicker RTW, will clearly alter the direct and indirect costs of spine care. These reported benefits must be studied in higher level investigations, because they are important not only to each stakeholder in the spine healthcare community but, most importantly, are essential to our patients' well being.

■ Key Points

- Although the cost effectiveness (CE) of spine surgery, as measured by cost per quality-adjusted life-year gained, has been shown in several high-quality studies, examinations of minimally invasive spine surgery (MIS) are rare and of relatively low quality.
- Factors that may increase the incremental CE for MIS over conventional open procedures include decreased complications, shorter length of hospital stay, and faster return to work, homemaking, and productivity.
- High-quality research examining the CE of emerging technologies, including MIS and open spine surgery, is increasingly needed. This information will be used to determine the utility of these interventions, guiding surgeons, payers, and healthcare policy makers toward procedures that most benefit patients and society.

References

1. Rihn JA, Berven S, Allen T, et al. Defining value in spine care. *Am J Med Qual* 2009;24:4S–14S.
2. Kim DH, Jaikumar S, Kam AC. Minimally invasive spine instrumentation. *Neurosurgery* 2002;51:S15–25.
3. Smith HE, Rihn JA, Brodke DS, et al. Spine care: evaluation of the efficacy and cost of emerging technology. *Am J Med Qual* 2009;24:25S–31S.
4. Glassman SD, Polly DW, Dimar JR, et al. The cost effectiveness of single-level instrumented posterolateral lumbar fusion at five years after surgery. *Spine*. In press.
5. Junge A, Frohlich M, Ahrens S, et al. Predictors of bad and good outcome of lumbar spine surgery. A prospective clinical study with 2 years' follow up. *Spine* 1996;21:1056–64.
6. Slover J, Abdu WA, Hanscom B, et al. The impact of comorbidities on the change in short-form 36 and oswestry scores following lumbar spine surgery. *Spine* 2006;31:1974–80.
7. Kalanithi PS, Patil CG, Boakye M. National complication rates and disposition after posterior lumbar fusion for acquired spondylolisthesis. *Spine* 2009; 34:1963–9.
8. Deluzio KJ, Lucio JC, Rodgers WB. Value and cost in less invasive spinal fusion surgery: lessons from a community hospital. *SAS J* 2010;4:37–40.
9. O'Toole JE, Eichholz KM, Fessler RG. Surgical site infection rates after minimally invasive spinal surgery. *J Neurosurg Spine* 2009;11:471–6.
10. Villavicencio AT, Burneikiene S, Roeca CM, et al. Minimally invasive versus open transforaminal lumbar interbody fusion. *Surg Neurol Int* 2010;1:12.
11. Wang MY, Cummock MD, Yu Y, et al. An analysis of the differences in the acute hospitalization charges following minimally invasive versus open posterior lumbar interbody fusion. *J Neurosurg Spine* 2010;12:694–9.
12. Tosteson AN, Skinner JS, Tosteson TD, 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* 2008;33:2108–15.
13. Tosteson AN, Lurie JD, Tosteson TD, et al. Surgical treatment of spinal stenosis with and without degenerative spondylolisthesis: cost-effectiveness after 2 years. *Ann Intern Med* 2008;149:845–53.
14. Tosteson AN, Tosteson TD, Lurie JD, et al. Factors affecting 4-year cost-effectiveness of surgery for stenosis with or without degenerative spondylolisthesis in the Spine Patient Outcomes Research Trial (Sport). In: International Society for the Study of the Lumbar Spine, Annual Meeting; April 13, 2010; Auckland, New Zealand.
15. Laupacis A, Feeny D, Detsky AS, et al. How attractive does a new technology have to be to warrant adoption and utilization? Tentative guidelines for using clinical and economic evaluations. *CMAJ* 1992;146:473–81.
16. Laupacis A, Feeny D, Detsky AS, et al. Tentative guidelines for using clinical and economic evaluations revisited. *CMAJ* 1993;148:927–9.
17. Martin BI, Deyo RA, Mirza SK, et al. Expenditures and health status among adults with back and neck problems. *JAMA* 2008;299:656–64.
18. Sacristan JA, Obenchain RL. Reporting cost-effectiveness analyses with confidence. *JAMA* 1997;277:375.
19. Siegel JE, Weinstein MC, Russell LB, et al. Recommendations for reporting cost-effectiveness analyses. Panel on Cost-Effectiveness in Health and Medicine. *JAMA* 1996;276:1339–41.
20. Stinnett AA, Mullahy J. The negative side of cost-effectiveness analysis. *JAMA* 1997;277:1931–2.
21. Deyo RA, Mirza SK, Martin BI, et al. Trends, major medical complications, and charges associated with surgery for lumbar spinal stenosis in older adults. *JAMA* 2010;303:1259–65.
22. Fritzell P, Hagg O, Wessberg P, et al. 2001 Volvo Award Winner in Clinical Studies: lumbar fusion versus nonsurgical treatment for chronic low back pain: a multicenter randomized controlled trial from the Swedish Lumbar Spine Study Group. *Spine* 2001;26:2521–32.
23. Kuntz KM, Snider RK, Weinstein JN, et al. Cost-effectiveness of fusion with and without instrumentation for patients with degenerative spondylolisthesis and spinal stenosis. *Spine* 2000;25:1132–9.
24. Malter AD, Larson EB, Urban N, et al. Cost-effectiveness of lumbar discectomy for the treatment of herniated intervertebral disc. *Spine* 1996;21: 1048–54.
25. Soegaard R, Christensen FB, Christiansen T, et al. Costs and effects in lumbar spinal fusion. A follow-up study in 136 consecutive patients with chronic low back pain. *Eur Spine J* 2007;16:657–68.
26. Soegaard R, Bunger CE, Christiansen T, et al. Determinants of cost-effectiveness in lumbar spinal fusion using the net benefit framework: a 2-year follow-up study among 695 patients. *Eur Spine J* 2007;16:1822–31.
27. Dagenais S, Haldeman S, Polatin PB. It is time for physicians to embrace cost-effectiveness and cost utility analysis research in the treatment of spinal pain. *Spine J* 2005;5:357–60.
28. Deyo RA, Ciol MA, Cherkin DC, et al. Lumbar spinal fusion. A cohort study of complications, reoperations, and resource use in the Medicare population. *Spine* 1993;18:1463–70.
29. Katz JN. Lumbar spinal fusion. Surgical rates, costs, and complications. *Spine* 1995;20:78S–83S.
30. Katz JN. Lumbar disc disorders and low-back pain: socioeconomic factors and consequences. *J Bone Joint Surg Am* 2006;88(suppl 2):21–4.
31. Bijen CB, Vermeulen KM, Mourits MJ, et al. Costs and effects of abdominal versus laparoscopic hysterectomy: systematic review of controlled trials. *PLoS One* 2009;4:e7340.
32. Newton PO, Wenger DR, Mubarak SJ, et al. Anterior release and fusion in pediatric spinal deformity. A comparison of early outcome and cost of thoracoscopic and open thoracotomy approaches. *Spine* 1997;22:1398–406.
33. Rodriguez HE, Connolly MM, Dracopoulos H, et al. Anterior access to the lumbar spine: laparoscopic versus open. *Am Surg* 2002;68:978–82.
34. Hoogland T, Schubert M, Miklitz B, et al. Transforaminal posterolateral endoscopic discectomy with or without the combination of a low-dose chymopapain: a prospective randomized study in 280 consecutive cases. *Spine* 2006;31:E890–7.
35. Ruetten S, Komp M, Merk H, et al. Full-endoscopic interlaminar and transforaminal lumbar discectomy versus conventional microsurgical technique: a prospective, randomized, controlled study. *Spine* 2008;33:931–9.
36. Okuda S, Miyauchi A, Oda T, et al. Surgical complications of posterior lumbar interbody fusion with total facetectomy in 251 patients. *J Neurosurg Spine* 2006;4:304–9.
37. Dekutoski MB, Norvell DC, Dettori JR, et al. Surgeon perceptions and reported complications in spine surgery. *Spine* 2010;35:S9–21.
38. Brau SA. Mini-open approach to the spine for anterior lumbar interbody fusion: description of the procedure, results and complications. *Spine J* 2002; 2:216–23.
39. Chung SK, Lee SH, Lim SR, et al. Comparative study of laparoscopic L5–S1

fusion versus open mini-ALIF, with a minimum 2-year follow-up. *Eur Spine J* 2003;12:613–17.
40. Dhall SS, Wang MY, Mummaneni PV. Clinical and radiographic comparison of mini-open transforaminal lumbar interbody fusion with open transforaminal lumbar interbody fusion in 42 patients with long-term follow-up. *J Neurosurg Spine* 2008;9:560–5.
41. Kaiser MG, Haid RW Jr, Subach BR, et al. Comparison of the mini-open versus laparoscopic approach for anterior lumbar interbody fusion: a retrospective review. *Neurosurgery* 2002;51:97–103.
42. Kim JS, Kang BU, Lee SH, et al. Mini-transforaminal lumbar interbody fusion versus anterior lumbar interbody fusion augmented by percutaneous pedicle screw fixation: a comparison of surgical outcomes in adult low-grade isthmic spondylolisthesis. *J Spinal Disord Tech* 2009;22:114–21.
43. Knight RQ, Schwaegler P, Hanscom D, et al. Direct lateral lumbar interbody fusion for degenerative conditions: early complication profile. *J Spinal Disord Tech* 2009;22:34–7.
44. Rodgers WB, Gerber EJ, Patterson JR. Intraoperative and early postoperative complications in extreme lateral interbody fusion (XLIF): an analysis of 600 cases. *Spine*. In press.
45. Park Y, Ha JW. Comparison of one-level posterior lumbar interbody fusion performed with a minimally invasive approach or a traditional open approach. *Spine* 2007;32:537–43.
46. Rodriguez-Vela J, Lobo-Escolar A, Joven-Aliaga E, et al. Perioperative and short-term advantages of mini-open approach for lumbar spinal fusion. *Eur Spine J* 2009;18:1194–201.
47. Schuster JM, Rechtine G, Norvell DC, et al. The influence of perioperative risk factors and therapeutic interventions on infection rates after spine surgery: a systematic review. *Spine* 2010;35:S125–37.
58. Taheri PA, Butz DA, Greenfield LJ. Length of stay has minimal impact on the cost of hospital admission. *J Am Coll Surg* 2000;191:123–30.
49. Regan JJ, McAfee PC, Guyer RD, et al. Laparoscopic fusion of the lumbar spine in a multicenter series of the first 34 consecutive patients. *Surg Laparosc Endosc* 1996;6:459–68.
50. Dakwar E, Cardona RF, Smith DA, et al. Early outcomes and safety of the minimally invasive, lateral retroperitoneal transpsoas approach for adult degenerative scoliosis. *Neurosurg Focus* 2010;28:E8.
51. Epstein NE. Do silver-impregnated dressings limit infections after lumbar laminectomy with instrumented fusion? *Surg Neurol* 2007;68:483–5.
52. Faciszewski T, Winter RB, Lonstein JE, et al. The surgical and medical perioperative complications of anterior spinal fusion surgery in the thoracic and lumbar spine in adults. A review of 1223 procedures. *Spine* 1995;20:1592–9.
53. Jutte PC, Castelein RM. Complications of pedicle screws in lumbar and lumbosacral fusions in 105 consecutive primary operations. *Eur Spine J* 2002;11:594–8.
54. McAfee PC, Regan JR, Zdeblick T, et al. The incidence of complications in endoscopic anterior thoracolumbar spinal reconstructive surgery. A prospective multicenter study comprising the first 100 consecutive cases. *Spine* 1995;20:1624–32.
55. Rihn JA, Patel R, Makda J, et al. Complications associated with single-level transforaminal lumbar interbody fusion. *Spine J* 2009;9:623–9.
56. Villavicencio AT, Burneikiene S, Bulsara KR, et al. Perioperative complications in transforaminal lumbar interbody fusion versus anterior-posterior reconstruction for lumbar disc degeneration and instability. *J Spinal Disord Tech* 2006;19:92–7.
57. Khan NA, Quan H, Bugar JM, et al. Association of postoperative complications with hospital costs and length of stay in a tertiary care center. *J Gen Intern Med* 2006;21:177–80.
58. Berven SH, Deviren V, Smith JA, et al. Management of fixed sagittal plane deformity: outcome of combined anterior and posterior surgery. *Spine* 2003;28:1710–15.
59. Lahiri S, Markkanen P, Levenstein C. The cost effectiveness of occupational health interventions: preventing occupational back pain. *Am J Ind Med* 2005;48:515–29.
60. Fritzell P, Hagg O, Jonsson D, et al. 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* 2004;29:421–34.