**Methods.**

*Definitions*

There is currently no generally accepted definition of “minimally invasive” spine surgery. For purposes of this systematic review, “minimally invasive surgery” will operationally be defined as surgery conducted through a tube, cylindrical retractor blades or sleeves via a muscle dilating or muscle splitting approach and bundled as “minimal access spine surgery” (MAS).

Conventional or open spine surgery is defined as surgery conducted through an approach that includes elevating or stripping the paraspinal muscles to gain access to the spine even if by a limited midline incision. These definitions have been used in previous focus issues.1

*Electronic Literature Search*

A systematic search of PubMed, EMBASE, the Cochrane Collaboration data base, University of York Centre for Reviews and Dissemination (NHS-EED and HTA), and the Tufts CEA Registry was conducted to identify full economic studies conducted through December 24, 2013 based on the key questions and PICO criteria established *a priori* (Table 1). Search terms included spinal disorders (radiculopathy, stenosis, degeneration, scoliosis and spondylolisthesis) and the surgical treatments (minimally invasive or minimal access or open procedures) combined with terms specific to economic studies such as cost benefit, cost effectiveness, cost utility, QALYs and medical economics. The search strategy is further documented in the supplementary digital material. Studies in English published in peer reviewed journals or contained within health technology assessments (HTAs) were considered. Abstracts that did not overtly describe cost effectiveness or that did not explicitly state that the intervention was minimally invasive or through minimal access techniques, were excluded. Only economic studies that evaluated and synthesized the costs and consequences of MAS compared with conventional open procedures (i.e. cost-minimization, cost-benefit, cost-effectiveness, or cost-utility) were considered for inclusion.

*Data Extraction*

From the included articles, the following data were extracted: study design, funding source, patient demographics (if reported), treatment interventions, perspective of economic model, type of economic model (if used), follow-up duration and the rate of follow-up for each treatment group (if reported or calculable), time horizon of economic model, assumptions and specifications of the model, cost sources, discounting and currency type, source of clinical, outcomes and utility data, primary findings (including costs, QALYs, cost effectiveness information e.g. cost per surgery avoided, ICERs and sensitivity analysis information) and limitations or risk of bias within the study.

*Data Analysis*

Descriptive data and economic findings were reported as presented in the articles.

*Critical appraisal*

The Quality of Health Economic Studies (QHES) instrument developed by Ofman, et al. was used to provide an initial basis for critical appraisal of included economic studies.2 QHES is a sixteen 'yes' or 'no' question instrument that assesses multiple aspects of economic study design, modeling and reporting to determine internal validity (See Supplemental Digital Material). QHES was assessed prospectively2, 3 for content and construct validity by the developers and has been evaluated externally as well.4 Components are weighted by importance (as concluded by expert health economists) to yield a score from 0 (lowest quality) to 100 (highest quality). Items that are considered most important (based on their weighting) include

* use of data from best available sources (e.g. RCT),
* statistical analysis to address random events and use of sensitivity analysis to explore model,
* use of appropriate sources and methodologies for measuring and estimating costs,
* use of valid and reliable outcomes measures
* transparent description of economic modeling used including delineation and justification of main assumptions and limitations of the model
* extent to which conclusions and recommendations were justified and based on study results.

Some have suggested that a score of 75-100 points indicates a high quality economic study.5 The QHES does not provide insight into study external validity (generalizability) nor does it directly assess the validity of clinical assumptions and inputs. A study may receive a high score based on factors assessed in QHES, but ultimately may not be applicable to a broader range of clinical populations. Thus, in addition to assessment of criteria in the QHES, other factors are important in critical appraisal of studies from an epidemiologic perspective to assist in evaluation of generalizability and consideration of potential sources of bias related to clinical inputs into the economic model.

Two reviewers (KEM, ACS) independently applied the QHES to included studies. Discrepancies in ratings were discussed so that consensus could be reached and a final score obtained.

1. Fourney DR, Dettori JR, Norvell DC, et al. Does minimal access tubular assisted spine surgery increase or decrease complications in spinal decompression or fusion? Spine. 2010 Apr 20;35(9 Suppl):S57-65. PMID: 20407352.

2. Ofman JJ, Sullivan SD, Neumann PJ, et al. Examining the value and quality of health economic analyses: implications of utilizing the QHES. J Manag Care Pharm. 2003 Jan-Feb;9(1):53-61. PMID: 14613362.

3. Chiou CF, Hay JW, Wallace JF, et al. Development and validation of a grading system for the quality of cost-effectiveness studies. Med Care. 2003 Jan;41(1):32-44. PMID: 12544542.

4. Gerkens S, Crott R, Cleemput I, et al. Comparison of three instruments assessing the quality of economic evaluations: a practical exercise on economic evaluations of the surgical treatment of obesity. Int J Technol Assess Health Care. 2008 Summer;24(3):318-25. PMID: 18601800.

5. Spiegel BM, Targownik LE, Kanwal F, et al. The quality of published health economic analyses in digestive diseases: a systematic review and quantitative appraisal. Gastroenterology. 2004 Aug;127(2):403-11. PMID: 15300571.

**Search Strategy.**

**PubMed Search**

Date: 12-24-13

Completed by: KEM

|  |  |  |
| --- | --- | --- |
| 1 | “Radiculopathy” [MeSH] OR “Spinal Stenosis” [MeSH] OR “Spondylolisthesis” [MeSH] OR “Scoliosis” [MeSH] OR “Intervertebral Disc Degeneration” [MeSH] OR “intervertebral disc disease” OR “spin\* trauma” OR “radiculopathy” OR “spin\* stenosis” OR “spondylolisthesis” OR “scoliosis” OR “brachial plexus neuritis” [MeSH] OR “cervicobrachial neuralgia” OR “vertebra\* stenosis” OR “neurogenic claudication” | 36,362 |
| 2 | “Laminectomy” [MeSH] OR “Foraminotomy” [MeSH] OR “Spinal Fusion” [MeSH] OR “Diskectomy” [MeSH] OR “Decompression, surgical” [MeSH] OR “laminectomy” OR “foraminotomy” OR “fusion” OR “discectomy” OR “diskectomy” OR “decompression” OR “lateral lumbar fusion” OR “laminoforamintomy” | 255,642 |
| 3 | “Diskectomy, Percutaneous” [MeSH] OR “Surgical Procedures, Minimally Invasive” [MeSH] OR “minimally invasive” OR “minimal surgery” OR “minimal access” OR (minimal\* AND invasive) OR (minimal\* AND surg\*) OR (minimal\* AND access\*) | 417,253 |
| 4 | (#1 OR #2) AND #3 | 7,669 |
| 5 | “Spine” [MeSH] OR “back” [MeSH] OR “neck” [MeSH] OR “lumbar” OR “cervical” OR “thoracic” OR “spin\*” OR “vertebra\*” | 595,604 |
| 6 | #4 AND #5 | 3,575 |
| 7 | "Cost-Benefit Analysis"[Mesh] OR "Quality-Adjusted Life Years"[Mesh] OR "cost utility" OR “Economics, Medical” [MeSH] OR “economic evaluation” OR “QALY” OR “cost benefit” OR “cost effective\*” | 114,836 |
| 8 | #6 AND #7 | 36 |
|  | Abstract available and Human and English | 27 |

**EMBASE Search\***

Date: 12-24-13

Completed by: KEM

Filters activated: Abstract available, Humans, English, As Explosive Keywords and Free Text

|  |  |  |
| --- | --- | --- |
| 1 | “Radiculopathy” OR “Cervicobrachial neuralgia” OR “Vertebral Canal Stenosis” OR “Spondylolisthesis” OR “Scoliosis” OR “Intervertebral Disc Disease” OR (intervertebral disc degeneration) OR (spin\* trauma) OR (spin\* stenosis) OR (brachial plexus neuritis) OR (vertebra\* stenosis) OR (neurogenic claudication) | 41,539 |
| 2 | “Laminectomy” OR “Foraminotomy” OR “Spine Fusion” OR “Intervertebral Diskectomy” OR “Spinal Cord Decompression” OR “Spine Surgery” OR (fusion) OR (discectomy) OR (discectomy) OR (decompression) OR (lateral lumbar fusion) OR (laminoforamintomy) | 33,630 |
| 3 | “Microsurgery” OR “Laparoscopy” OR “Minimally Invasive Procedure” OR (percutaneous) OR (minimal\* invasive) OR (tubular) OR (microdiscectomy) OR (minimal\* surg\*) OR (minimal\* access) | 95,388 |
| 4 | (#1 OR #2) AND #3 | 1,908 |
| 5 | “Spine” OR “back” OR “neck” OR (lumbar) OR (cervical) OR (thoracic) OR (spin\*) OR (vertebra\*) | 7,915,537 |
| 6 | #4 AND #5 | 1,908 |
| 7 | "Cost-Benefit Analysis" OR “Cost Effectiveness Analysis” OR “Cost Utility Analysis” OR Economic Evaluation” OR “Health Economics” OR (cost utility) OR (cost benefit) OR (cost effective\*) OR (QALY) OR (quality adjusted life year) OR (medical economics) | 256, 594 |
| 8 | #6 AND #7 | 87 |

\* Phrases in parentheses are not Emtree words or free text, they were searched using AND phrases (e.g. Neurogenic AND (claudication/exp OR claudication)).

**Cochrane Search**

Date: 12-24-13

Completed by: KEM

|  |  |  |
| --- | --- | --- |
| 1 | “Radiculopathy” [MeSH] OR “Spinal Stenosis” [MeSH] OR “Spondylolisthesis” [MeSH] OR “Scoliosis” [MeSH] OR “Intervertebral Disc Degeneration” [MeSH] OR “intervertebral disc disease” OR “spin\* trauma” OR “radiculopathy” OR “vertebra\* stenosis” OR “spin\* stenosis” OR “spondylolisthesis” OR “scoliosis” OR “brachial plexus neuritis” [MeSH] OR “cervicobrachial neuralgia” OR “neurogenic claudication” | 2,115 |
| 2 | “Laminectomy” [MeSH] OR “Foraminotomy” [MeSH] OR “Spinal Fusion” [MeSH] OR “Diskectomy” [MeSH] OR “Decompression, surgical” [MeSH] OR “laminectomy” OR “foraminotomy” OR “fusion” OR “discectomy” OR “diskectomy” OR “decompression” OR “lateral lumbar fusion” OR “laminoforamintomy” | 4,410 |
| 3 | “Diskectomy, Percutaneous” [MeSH] OR “Surgical Procedures, Minimally Invasive” [MeSH] OR “Microsurgery”[MeSH] OR “Laparoscopy”[MeSH] OR “percutaneous” OR “microsurgery” OR “laparoscopy” OR “tubular” OR “minimal\* invasive” OR “minimal\* surg\*” OR “minimal\* access” | 27,532 |
| 4 | (#1 OR #2) AND #3 | 548 |
| 5 | “Spine” [MeSH] OR “back” [MeSH] OR “neck” [MeSH] OR “lumbar” OR “cervical AND spin\*” OR “spin\*” OR “thoracic” OR “back” OR “neck” OR “vertebra\*” | 47,980 |
| 6 | #4 AND #5 | 388 |
| 7 | "Cost-Benefit Analysis"[Mesh] OR "Quality-Adjusted Life Years"[Mesh] OR "cost utility" OR “Economics, Medical” [MeSH] OR “economic evaluation” OR “QALY” OR “cost benefit” OR “cost effective\*” | 28,925 |
| 8 | #6 AND #7 | 75 |
|  | Abstract available and Human and English | 75 |

**CEA Registry 12-24-13**

Search “lumbar” – found 28 studies, 2 unique (plus duplicates from PubMed)

Search “cervical spine” – found 1 study (not of treatment interest, diagnostic)

**University of York, Centre for Reviews and Dissemination 12-24-13**

Search (minimally invasive) AND (cervical OR lumbar) AND (cost)

Found 14 studies, 1 unique (plus duplicates from CEA, Cochrane or PubMed)

**Table 1. Exclusion Table.**

|  |  |
| --- | --- |
| **Author, Date** | **Rationale for Exclusion** |
| **Excluded at abstract** |  |
| Ackerman SJ, Polly Jr DW, Knight T, Schneider K, Holt T, Cummings J. Comparison of the costs of nonoperative care to minimally invasive surgery for sacroiliac joint disruption and degenerative sacroiliitis in a united states medicare population: Potential economic implications of a new minimally-invasive technology. *ClinicoEconomics and Outcomes Research.* 2013;5(1):575-587. | Wrong patient population – sacroiliac joint |
| Charles YP, Vouaillat H, Marcaud M, Ihara Z. Minimally invasive surgery in spinal fusion : Clinical and economical impact from hospital perspective. *Value in Health.* 2012;15(7):A404. | Abstract only, not full study |
| Corbo M, Marchese E, Ihara Z. Mast (minimal access spinal technologies) versus open surgery: Activity-based cost analysis of spinal fusion procedure from hospital perspective. *Value in Health.* 2011;14(7):A247. | Abstract only, not full study |
| Nellensteijn, J., R. Ostelo, et al. (2010) Transforaminal endoscopic surgery for symptomatic lumbar disc herniations: a systematic review of the literature. European Spine Journal 181-204 | (Systematic review) Wrong study type, cost not in abstract |
| Rampersaud RY, Goldstein CL, Macwan K, Sundararajan K. Comparative clinical and economic outcomes of minimally invasive surgery for posterior lumbar fusion: A systematic review and meta-analysis. *Spine Journal.* 2013;13(9):151S. | Abstract only, not full study |
| Rodriguez, H. E., M. M. Connolly, et al. (2002). "Anterior access to the lumbar spine: laparoscopic versus open." The American surgeon 68(11): 978-982; discussion 982-983. | Wrong intervention – anterior approach |
| Slotman GJ, Stein SC. Laparoscopic L5-S1 diskectomy: A cost-effective, minimally invasive general surgery-neurosurgery team alternative to laminectomy. *American Surgeon.* 1996;62(1):64-68. | Wrong intervention – anterior approach |
| Slotman GJ, Stein SC. Laminectomy compared with laparoscopic diskectomy and outpatient laparoscopic diskectomy for herniated L5-S1 intervertebral disks. *Journal of Laparoendoscopic and Advanced Surgical Techniques - Part A.* 1998;8(5):261-267. | Wrong intervention – anterior approach |
| Smith, W., G. Christian, et al. (2011). "A comparison of perioperative charges and outcome between open anterior and mini-open lateral approaches for lumbar discectomy and fusion." Spine Journal 11(10): 102S. | Wrong intervention – anterior approach |
| Smith, W. D., G. Christian, et al. (2012) A comparison of perioperative charges and outcome between open and mini-open approaches for anterior lumbar discectomy and fusion. Journal of Clinical Neuroscience 673-680. | Wrong intervention – anterior approach |
| Spoor, A. B. and F. C. Oner (2013). "Minimally invasive spine surgery in chronic low back pain patients." Journal of Neurosurgical Sciences 57(3): 203-218. | (Systematic review) Wrong study type, literature review |
| Vertuani S, Ihara Z, Musayev A, Nilsson J. A cost-effectiveness analysis of minimally invasive versus open surgery techniques for lumbar spine fusion. *Value in Health.* 2012;15(7):A405. | Abstract only, not full study |
| **Excluded at full text** |  |
| Allen, R. T. and S. R. Garfin (2010). "The economics of minimally invasive spine surgery: The value perspective." Spine 35(SUPPL. 26S): S375-S382. | (Systematic review) Wrong study type, literature review |
| Dullerud, R., H. Lie, et al. (1999). "Cost-effectiveness of percutaneous automated lumbar nucleotomy. Comparison with traditional macro-procedure discectomy." Interventional Neuroradiology **5**(1): 35-42. | Doesn’t fit MAS definition |
| Huang, T. J., R. W. Hsu, et al. (1997). "Video-assisted thoracoscopic treatment of spinal lesions in the thoracolumbar junction." Surg Endosc 11(12): 1189-1193. | Wrong patient population –patients with metastatic disease |
| Lucio JC, van Conia RB, de Luzio KJ, Lehmen JA, Rodgers JA, Rodgers WB. Economics of less invasive spinal surgery: An analysis of hospital cost differences between open and minimally invasive instrumented spinal fusion procedures during the perioperative period. *Risk Management and Healthcare Policy.* 2012;5:65-74. | Wrong intervention – XLIF procedure |
| Parker, S. L., O. Adogwa, et al. (2011). Post-operative infection after minimally invasive versus open transforaminal lumbar interbody fusion (TLIF): literature review and cost analysis. *Minim Invasive Neurosurg* **54,** 33–37. | Preliminary subpopulation, updated report found for same population. |
| Pelton MA, Phillips FM, Singh K. A comparison of perioperative costs and outcomes in patients with and without workers' compensation claims treated with minimally invasive or open transforaminal lumbar interbody fusion. *Spine.* 2012(22):1914-1919. | Costing only |
| Singh K, Nandyala SV, Marquez-Lara A, et al. A Peri-Operative Cost Analysis Comparing Single-Level Minimally Invasive and Open Transforaminal Lumbar Interbody Fusion. *Spine J.* 2013;16(13):01723-01723 | Costing only |
| Stevens, C. D., R. W. Dubois, et al. (1997). "Efficacy of lumbar discectomy and percutaneous treatments for lumbar disc herniation." Soz Praventivmed 42(6): 367-379. | (Systematic review) Wrong study type, cost not included full text |
| Stevenson, R. C., C. J. McCabe, et al. (1995) An economic evaluation of a clinical trial to compare automated percutaneous lumbar discectomy with microdiscectomy in the treatment of contained lumbar disc herniation. Spine 739-742 | Doesn’t fit MAS definition |
| Wang, M. Y., M. D. Cummock, et al. (2010). "An analysis of the differences in the acute hospitalization charges following minimally invasive versus open posterior lumbar interbody fusion." J Neurosurg Spine **12**(6): 694-699. | Costing only |
| Wang, M. Y., J. Lerner, et al. (2012). "Acute hospital costs after minimally invasive versus open lumbar interbody fusion: Data from a US national database with 6106 patients." Journal of Spinal Disorders and Techniques **25**(6): 324-328. | Costing only |
| Zachary, A. M. and J. D. Fortin (2003). "Minimally invasive options to disc surgery." Pain Physician 6(4): 467-471. | (Systematic review) Wrong study type, cost not included full text |

**Table 2. Detailed abstraction table of economic studies.**

| **Author (year)**  **Country**  **Funding**  **QHES** | **Population**  **Interventions** | **Design**  **Perspective**  **Time horizon**  **Model** | **Assumptions** | **Economic Model specifications** | **Year, Currency**  **Cost Sources**  **Discounting** | **Clinical Data Source  (e.g Utility, other)**  **source** | **Primary Findings**  (ICER (or other cost/outcome); dominance, Sensitivity analysis results) | **Limitations, risk of bias** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Van den Akker (2011)  Netherlands  **Funding of work:** Dutch Health Care Insurance Board  QHES: 79 | *From previously reported multicenter RCT\**  N= 325 assessed  % F/U: NR  **Tubular discectomy:**  n = 166  males: NR  age: NR  **Conventional microdiscectomy:**  n = 159  males: NR  age: NR  **Inclusion:**   * Patients between 18-70 years old * Patients with sciatica caused by LDH, lasting >6-8 weeks * Radiologically confirmed disk herniation with distinct nerve root compression   **Exclusion:**   * + - Patient with cauda equina syndrome, central canal stenosis, pregnancy, severe somatic or psychiatric diseases, inadequate knowledge of Dutch language or emigration planned w/in 1 year of inclusion | CUA  Societal (healthcare and non-healthcare costs)  Also report just healthcare costs  1 year F/U period  1 year time horizon  Economic model: NR | * Costs of anesthesia and use of awakening room were assumed to be equal for both procedures and therefore omitted | Economic model: NR   * 1 yr time horizon, divided into 4 quarters * Regression models used for clinical outcomes with imputation for missing values for cost or outcomes | 2008 Euros to US dollars  **Cost source:**   * + Cost diaries, patient reported   + Mean cost per operating room minute, provided by each participating hospital   + Cost of equipment based on initial purchasing prices, yearly use and depreciation   + Dutch standard prices to represent societal costs and standardize   **Costs used for analysis:**   * Including but not limited to: admission to hospital, operating room costs (staff, room, equipment, overhead), visits (specialists, general practitioner, physical therapy, alternative health care), home care, paid domestic help, informal care, drugs and aids, out of pocket expenses as a result of sciatica and hours absent from work, patients’ time and travel costs   **Cost discounted**: not discounted | **Clinical measures (derived from RCT data):**   * EuroQol EQ-5D * SF-36 (calculated for SF-6D utilities) * VAS (0-100) * Modified Roland Disability Questionnaire * Reoperation rate   EQ-5D and VAS measured at intake, randomization and 2,4,6,8,12,26,38,52 weeks after randomization  SF-36 measured at intake and 4,8,26,52 weeks after randomization | **Mean Societal Costs:**  Costs:  1 yr. cumulative costs per patient ($ US ± SD)†   * Tubular: 16,858 ± 12,759 * Conventional: 15,367 ± 12,165 * P = NS * ∆ Cost (95% CI): 1,491   (-1,335 – 4,318)  QALYs:  Utility measures similar for both groups, P = NS   * ∆ QALY (95% CI):   + US EQ-5D: -0.012   (-0.046 – 0.021)   * + Dutch EQ-5D: -0.014 (-0.056 – 0.029)   + SF-6D: -0.11   (-0.037 – 0.014)   * + VAS: -0.021   (-0.058 – 0.016)  **Sensitivity Analysis:**   * Willingness to pay per QALY   + Probability that tubular is cost-effective was stable, ranged from 15% -22% for various levels * Use of different utility measures (Dutch EQ-5D, SF-6D or VAS)   + Results not detailed; probability of being cost-effective favors conventional * Perspective (health care or societal)   + Results not detailed; tubular not preferred overs conventional from health care perspective | * Settings may differ between the 7 hospitals included in the study * Duration of study only 1 yr, very short time horizon * Costs of surgery used, instead of hospital prices * Details of one-way sensitivity analysis data presented graphically only; No sensitivity analysis regarding cost drivers * Conversion of Euros to USD may not accurately reflect actual costs in either country * Unclear to what extent future revisions may influence longer term * Substantial variability (large standard deviations) for cost and utility estimates |
| Parker (2013)  USA  Authors disclose no COI  **Funding of work:** NR  QHES: 52 | *Retrospective cohort study*  N= 54 assessed  males: 53.7%  age: 57 ± 11.4 years  % F/U: NR  **MAS multilevel hemilaminectomy:**  n = 27  males: 67%  age: 59.5 ± 9.3  **Open multilevel hemilaminectomy:**  n = 27  males: 41.7%  age: 54 ± 12.7  **Inclusion:**   * Patients age 18-70 years old * Unilateral radicular symptoms involving 2 or more nerve roots * MRI evidence of multilevel lumbar stenosis corresponding to radicular symptoms * Failed at least 6 weeks of conservation therapy   **Exclusion:**   * Mechanical instability * History of a previous back operation * Extraspinal cause of back or leg pain * Active medical or workman’s compensation lawsuit * Any preexisting spinal pathology * Unwilling or unable to participate in F/U | CUA  Societal  2 year F/U period  2 year time horizon  Economic model: NR | Assumptions NR | Economic model: NR; provided formula for ICER; clinical outcome means, SD evaluated with t-test; nonparametric data with Mann-Whitney U; nominal data with chi-square | (Time NR) US  **Cost source:**   * + Patient reported resource utilization data   + Self-reported instances of medical resource use were multiplied by unit costs for each component, based on Medicare national allowable payment amounts   + Medication prices based on Redbook prices   + Surgeon costs based on Medicare allowable amounts using the resource-based relative value scale   + Indirect costs estimated using the standard human capital approach   **Costs used for analysis:**   * Direct costs (including but not limited to: outpatient visits (surgeons, chiropractors, other physicians, physical therapists, acupuncturists, or other health care providers), spine-related diagnostic tests (radiograph, computed tomographic scan, MRI, and electromyography), injections, devices (braces, canes, walkers, shoe inserts), emergency room visits, rehabilitation, nursing home days, medications * Indirect costs (including but not limited to: productivity losses due to spine-related problems, work or homemaking days)   **Cost discounted**: NR | **Clinical measures (derived from retrospective cohort data):**   * EQ-5D * Pre and post-op pain (VAS leg and LBP) * Disability (ODI) * SF-12 * Duration of narcotic use * Time to return to work * Complications | **Mean costs:**  Costs:  2 yr. cumulative costs per patient, $ US (95% CI)   * MAS: 23,109 (23,078 – 23,140) * Open: 25,420 (25,389 – 25,450) * P = NS * ∆ Cost: 2,311   QALYs  2 yr. cumulative QALYs per patient:   * MAS: 0.72 (CI NR) * Open: 0.72 (CI NR) * P = NS * ∆ QALY: 0   **ICER ∆$US/∆QALY:** NC, no difference in QALY  Indirect costs accounted for 43% of total cost for MAS and 63% for open  **Sensitivity Analysis:** NR | * Third party payer perspective (Medicare national allowable payments) may not be as accurate as hospital and private payer cost estimations, since hospitals may influence the decision whether an MAS versus open approach may be used * No sensitivity analysis performed * Retrospective patient interview conducted for outcome measures, may be biased since patients were aware of the treatment they had * Baseline characteristics similar between groups but potential for selection bias still exists * Small sample size may preclude ability to detect statistical differences * All procedures performed by one surgeon – unclear how variability across providers could influence results * No sensitivity analysis performed; model limitations or assumptions not described |
| Rampersaud (2011)  Canada  Authors do not disclose COI  **Funding of work:** The W. Garfield Weston Foundation  QHES: 74 | *Retrospective cohort*  N = 78 assessed  **% F/U for outcomes data:**  MAS fusion: 75.7%  Open fusion: 70.7%  **MAS fusion:**  n = 37  males: 48.6 %  age: 55.11 ± 14.98  **Open fusion:**  n = 41  males: 51.2%  age: 57.02 ± 13.38  **Inclusion:**   * Grade I-II degenerative or isthmic spondylolisthesis   **Exclusion:**   * Other causes of spondylolisthesis (iatrogenic) * High-grade spondylolisthesis   Revision surgery | CUA  Health care system/single payer  1 year F/U period  1 year time horizon  *Projected to 2 and 4 yrs*  Economic model: NR | * Because the groups were the same with regard to diagnosis, institution and health care system, costs of pre and post-op physician visits and imaging were assumed to be the same * Outcomes remain relatively stable for 4 years, thus cost utility should improve at 2 and 4 years | Economic model: NR; clinical outcomes used multivariate regression modeling   * 4 variables per model, predictor variables on total direct cost (primary), LOS and clinical outcome * Projected cost utility analysis for 2 and 4 years | 2011 $CDN  **Cost source:**   * + Hospital financial department, micro-case costing per individual patient   + Physician reimbursement NR   **Costs used for analysis:**   * Direct costs (including but not limited to: operative costs, nursing (post-anesthetic care, step-down unit, ICU and ward), medical imaging, laboratories, pharmacy, allied health, management of any inpatient adverse events * Indirect costs: NR   **QALY discounted** 5% per year | **Clinical measures (derived from retrospective cohort data):**   * SF-6D (derived from SF 36) at 1 year * Complications * ODI * Hospital LOS | **Mean case:**  Costs:  **1 yr. cumulative costs per patient ($CND ± SD)**   * MAS: 14,171.93 ± 3,269.73† * Open: 18,632.91 ± 6,197.32 * P = 0.0009 * ∆ Cost: 4,460.98   QALYs:  5% annual discount on QALY  **1 yr. cumulative QALYs gained per patient ± SD:**   * MAS: 0.113 ± 0.10 * Open: 0.079 ± 0.08 * P = 0.08 * ∆ QALY: 0.034   **2 yr. cumulative QALYs gained per patient:**   * MAS: 0.20 * Open: 0.15 * ∆ QALY: 0.05   **4 yr. cumulative QALYs gained per patient:**   * MAS: 0.38 * Open: 0.28 * ∆ QALY: 0.10   **Cost/QALY: (5% discount on QALY)**  **1 yr**   * MAS: $128,936 * Open: $232,912   **2 yr**   * MAS: $70,915 * Open: $122,585   **4 yr**   * MAS: $37,720 * Open: $67,510   **ICER ∆$CDN/∆QALY:**  Not performed; new strategy costs less or equivalent and NS difference in outcome  **Sensitivity Analysis:** NR | * Pre and post-op rehabilitation or other outpatient health system costs were not collected * Revision costs not included in 2 or 4 year projections * No sensitivity analysis * Range of SD was very large for costs and QALYs * Baseline differences in outcome measures, more disabled open fusion cohort * Costs only from institutional perspective, no indirect societal or direct out of pocket patient costs * % follow-up of <80% * Limited sample size * Detail of which variables were included in multivariate regression equations not provided * Discounted quality but not cost |
| Parker (2013)  USA  Individual authors disclose COI related to industry  **Funding of work:** NR  QHES: 70 | *Prospective cohort*  N= 100 assessed  males: 34%  age: 53 ± 12.0 years  % F/U: NR  **MAS TLIF:**  n = 50  males: 32%  age: 53.5 ± 12.5  **Open TLIF:**  n = 50  males: 36%  age: 52.6 ± 11.6  **Inclusion:**   * Patients aged 18-70 years old * Evidence on MRI of grade I DLS * Mechanical LBP and radicular symptoms * Nonresponse to ≥ 6 weeks of conservative therapy   **Exclusion:**   * History of previous back operation * Extraspinal cause of back pain or sciatica * An active medical or workmans’ compensation lawsuit * Any preexisting spinal pathology * Unwilling or unable to participate in f/u * Notable associated abnormalities (i.e. inflammatory arthritis or metabolic bone disease) | CUA  Societal  2 year F/U period  2 year time horizon  Economic model: NR | Assumptions NR | Economic model: NR; provided formula for ICER, describe 2 year change in mean EQ-5D; clinical outcome means, SD evaluated with t-test; nonparametric data with Mann-Whitney U; nominal data with chi-square | (Time NR) $US  **Cost source:**   * + Hospital accounting and billing office provided hospital expenditures for delivery of care   + Patient reported resource utilization data   + Self-reported instances of medical resource use were multiplied by unit costs for each component, based on Medicare national allowable payment amounts   + Medication prices based on Redbook prices   + Surgeon costs based on Medicare allowable amounts using the resource-based relative value scale   + Indirect costs estimated using the standard human capital approach   **Costs used for analysis:**   * Direct costs (including but not limited to: surgeons, chiropractors, other physicians, physical therapists, acupuncturists, or other health care providers, spine-related diagnostic tests (radiograph, computed tomographic scan, MRI, and electromyography), injections, devices (braces, canes, walkers, shoe inserts), emergency room visits, rehabilitation, nursing home days, medications) * Indirect costs (including but not limited to: productivity losses due to spine-related problems, work or homemaking days)   **Cost discounted**: NR | **Clinical measures (derived from prospective cohort data):**   * QoL (EQ-5D) * Pre and post-op pain (VAS leg and LBP) * Disability (ODI) * SF-12 (mental and physical component scores) * Zung depression index * Duration of narcotic use * Time to return to work * Complications | **Mean case:**  Costs:  2 yr. cumulative costs per patient, $US ± SD   * MAS: 38,563 ± 10,594 * Open: 47,858 ± 20,148 * P = 0.03 * ∆ Cost: $9,295   QALYs (2 year change in mean EQ-5D):  2 yr. cumulative QALYs per patient:   * MAS: 0.771 * Open: 0.695 * P = NS * ∆ QALY: 0.076   **ICER ∆$US/∆QALY:** NA, no significant difference in QALY  Indirect costs accounted for 28% of total costs for MAS, 41% for open  **Sensitivity Analysis:** NR | * Third party payer perspective (Medicare national allowable payments) may not be as accurate as hospital and private payer cost estimations, since hospitals may influence the decision whether an MAS versus open approach may be used * No sensitivity analysis * Differences in complication rates across providers may influence results * Retrospective patient interview conducted for outcome measures, may be biased since patients were aware of the treatment they had * Potential for selection bias – authors do not describe number of eligible and numbers excluded and rationale * Small sample size may preclude ability to detect statistical differences * Cost of MAS implant was excluded from cost analysis |
| Parker (2011)  USA  Surgical site infections‡  Authors do not disclose COI  **Funding of work:** NR  QHES: 55 | *Retrospective review of case series literature (SSI)*  % F/U: NR  **MAS TLIF:**  n = 362  males: 42.4%  age: 53.6 years  **Open TLIF:**  n = 1,133  males: 46.4%  age: 47.8 years  **Inclusion (literature):**   * MAS vs. open TLIF for treatment of grade I-II spondylolisthesis or DDD * First-time TLIF only * English articles, 1975 – 2009 * TLIF with tubular retractor and supplemented with pedicle screws were considered MAS   **Exclusion:**   * Case reports, technical notes, animal or lab studies * PLIF studies * Patients with revision surgery * Not mentioning SSI   *Retrospective cohort from own institution (costs)*  % F/U: NR  **MAS TLIF:**  n = 0  **Open TLIF:**  n = 120  males: 41.7%  age: 48.4 ± 13.2  **Inclusion (cost):**   * Open TLIF procedures for treatment of DDD or grade I spondylolisthesis   **Exclusion:**   * NR | CEA  Single provider perspective (Hospital)  Time horizon NR  Economic model: NR | * Direct medical costs were defined at 70% of billing values | Economic model: NR; clinical outcomes were assessed using multivariate analysis | (Time NR) $USA  **Cost source:**   * + Institutional billing and accounting records   + Physician reimbursement not included   **Costs used for analysis:**   * Direct costs (including but not limited to: all SSI related hospital charges ) * Indirect costs: NR   **Cost discounted** NR | **Clinical measures (derived from literature):**   * Incidence of reported SSI, MAS vs open cohorts and institutional rates for open TLIF   **Clinical measures (derived from retrospective cohort):**   * Length of hospitalization * CT, MRI scans and radiographs * Complications (DVT, dermatological reaction) * Length of intravenous antibiotics | **Mean case:**  Costs:  (Time NR) Cumulative costs per 6 patients ($US)   * MAS: NR * Open: $29,110   3.4% decrease in reported SSI incidence for MAS vs. Open  Cost savings of $98,974 per 100 MAS-TLIF procedures, $989 per MAS-TLIF performed  **Sensitivity Analysis:** NR | * Literature review data are from case series and indirect comparison of MAS vs. open procedures is subject to bias * Cost of SSI extrapolated from 6 open-TLIF patients who developed SSI at the author’s institution * Analysis does not consider other minimally invasive tubular approaches * No model completed, costs were projected based on risk of SSI from literature and costs of patients with SSI from institutional case review * Unclear definition of MAS procedure * SSI represents 1 possible complication or outcome; To evaluate broader cost-effectiveness of MAS, efficacy and other outcomes should be considered * SSI appears to be a rare event and sample size of 362 may not adequately capture infection risk * No sensitivity analysis performed |
| McGirt (2011)  USA  Surgical site infections\*\*  Individual authors disclose COI; some authors employed by industry  **Funding of work:** NR  QHES: 66 | *Administrative data base study*  % F/U: NR  **MAS T/PLIF:**  **1 level**  n = 848  males: 45%  age: 52.4 ± 13.4  **2 level**  n = 588  males: 46%  age: 51.9 ± 13.4  **Open T/PLIF:**  **1 level**  n = 1,595  males: 45%  age: 53.7 ± 13.7  **2 level**  n = 2,139  males: 46%  age: 56.7 ± 13.7  **Inclusion:**   * Patients undergoing 1 or 2 level T/PLIF procedures between 2003 – 2009 * Presence of all ICD-9-CM codes: 81.08, 81.62 and 84.51 * Patients with lumbar spondylotic disease, disc degeneration or spondylolisthesis   **Exclusion:**   * Fusion revision * Deformity diagnosis * Concurrent anterior fusion * > 2 level fusion | CEA  Single provider perspective (Hospital)  8 week post-op F/U  Economic model: NR | Assumptions NR | Economic model: NR; clinical outcomes used univariate and multivariate logistical regression for evaluation of associations between factors and presence of SSI | 2009 $USA  **Cost source:**   * + Hospital discharge and billing records obtained from Premier Perspective Database   + Physician reimbursement not included   **Costs used for analysis:**   * Direct costs (including but not limited to: infection costs incurred by the hospital for care provided during inpatient or hospital-outpatient encounters) * Indirect costs (including but not limited to: )   **Cost discounted** NR | **Clinical measures (derived from retrospective cohort):**   * Incidence of SSI * Charlson Comorbidity Index | **Mean case:**  Direct Costs:  Cumulative SSI-associated cost per procedure ($US)  **1 level:**   * MAS: $684 * Open: $724 * P = NS * ∆ Cost: $40   **2 level:**   * MAS: $756 * Open: $1,140 * P = 0.030 * ∆ Cost: $384   Adjusted OR for increased SSI with open 1.5 (1.0-2.3) (any level assumed)  For 1 level fusion:  SSI risk 4.5% MAS vs. 4.8% with open  For 2 level fusion:  SSI risk 4.6% MAS vs. 7.0% with open  Cost savings of $4,000 per 100 MAS-T/PLIF procedures for 1-level fusion  Cost savings of $38,400 per 100 MAS-T/PLIF procedures for 2-level fusion  **Sensitivity Analysis:** NR | * Only evaluates perioperative infections (w/in 8 weeks of surgery) * Administrative database used, potential for misclassification * Identification of surgery type by ICD-9-CM codes and number of pedicle screws for number of levels fused * Very short time horizon, in-hospital costs only included * Not designed to detect infection after 8 weeks * Unclear definition of MAS technique (hospital charge field had US FDA approval for percutaneous   posterior fusion)   * For multivariate regression, unclear what factors were used in final model * SSI represents one possible complication or outcome; To evaluate broader cost-effectiveness of MAS, efficacy and other outcomes should be considered |

CES: cost effectiveness study; CI: confidence interval; COI: conflicts of interest; CUA: cost utility analysis; DDD: degenerative disc disease; DLS: degenerative lumbar spondylolisthesis; DVT: deep venous thrombosis; ICER: incremental cost effectiveness ratio; LBP: low back pain; LDH: lumbar disc herniation; LOS: length of stay; MAS: minimal access surgery; NC: not calculable; NR: not reported; ODI: Oswestry Disability Index; PLIF: posterior lumbar interbody fusion; QALY: quality-adjusted life years; QHES: Quality of Health Economic Studies; RCT: randomized control trial; SD: standard deviation; TLIF: transforaminal lumbar interbody fusion; VAS: visual analog scale; SR: systematic review; SSI: surgical site infections

\* Demographic information from RCT is not reported in economic study.

† Mean cost of MAS is inconsistently reported throughout the article text.

‡ Definition of surgical site infection, as defined by Parker et al. (2011): erythematous or purulent wound that was culture-positive requiring long term intravenous antibiotics or surgical debridement.

\*\* Definition of surgical site infection, as defined by McGirt et al. (2011): an ICD-9-CM diagnosis code indicative of a postoperative infection during or within 8 weeks of the index hospitalization for lumbar fusion, or administration of parenteral antibiotics 7 or more days after index fusion surgery within the 8-week postoperative period

**Table 3. Quality of Health Economic Studies (QHES) score of included articles**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **QHES Question (pts possible)** | **Van den Akker**  **2011** | **Parker 2013**  **(Hemi)** | **Parker 2013 (TLIF)** | **Rampersaud 2011** | **McGirt 2011** | **Parker 2011** |
| 1. Was the study objective presented in a clear, specific, and measurable manner? (7 pts) | 7 | 7 | 7 | 7 | 7 | 7 |
| 1. Were the perspective of the analysis (societal, third-party payer, etc.) and reasons for its selection stated? (4 pts) | 4 | 4 | 4 | 4 | 4 | 4 |
| 1. Were variable estimates used in the analysis from the best available source (i.e. randomized controlled trial = best, expert opinion = worst)? (8 pts) | 8 | 0 | 0 | 0 | 0 | 0 |
| 1. If estimates came from a subgroup analysis, were the groups prespecified at the beginning of the study? (1 pt) | 1 | 1 | 1 | 1 | 1 | 1 |
| 1. Was uncertainty handled by (1) statistical analysis to address random events, (2) sensitivity analysis to cover a range of assumptions? (9 pts) | 0 | 0 | 0 | 0 | 0 | 0 |
| 1. Was incremental analysis performed between alternatives for resources and costs? (6 pts) | 6 | 6 | 6 | 6 | 6 | 6 |
| 1. Was the methodology for data abstraction (including the value of health states and other benefits) stated? (5 pts) | 5 | 5 | 5 | 5 | 5 | 0 |
| 1. Did the analytic horizon allow time for all relevant and important outcomes? Were benefits and costs that went beyond 1 year discounted (3% to 5%) and justification given for the discount rate? (7 pts) | 7 | 0 | 0 | 7 | 7 | 0 |
| 1. Was the measurement of costs appropriate and the methodology for the estimation of quantities and unit costs clearly described? (8 pts) | 8 | 8 | 8 | 8 | 8 | 8 |
| 1. Were the primary outcome measure(s) for the economic evaluation clearly stated and did they include the major short-term, long-term and negative outcomes included? (6 pts) | 0 | 0 | 6 | 0 | 6 | 6 |
| 1. Were the health outcomes measures/scales valid and reliable? If previously tested valid and reliable measures were not available, was justification given for the measures/scales used? (7 pts) | 7 | 7 | 7 | 7 | 7 | 7 |
| 1. Were the economic model (including structure), study methods and analysis, and the components of the numerator and denominator displayed in a clear, transparent manner? (8 pts) | 8 | 0 | 8 | 8 | 8 | 8 |
| 1. Were the choice of economic model, main assumptions, and limitations of the study stated and justified? (7 pts) | 7 | 0 | 7 | 7 | 7 | 0 |
| 1. Did the author(s) explicitly discuss direction and magnitude of potential biases? (6 pts) | 0 | 6 | 0 | 6 | 0 | 0 |
| 1. Were the conclusions/recommendations of the study justified and based on the study results? (8 pts) | 8 | 8 | 8 | 8 | 0 | 8 |
| 1. Was there a statement disclosing the source of funding for the study? (3 pts) | 3 | 0 | 3 | 0 | 0 | 0 |
| **Total QHES score:** | **79** | **52** | **70** | **74** | **66** | **55** |
| **Cost-Effectiveness Analysis Registry, Quality Score\*:** | **3 / 7** | **3.5 / 7** | **NR** | **NR** | **NR** | **NR** |

\*Scale of 1 (low) to 7 (high), organized by the Tufts Medical Center, Institute for Clinical Research and Health Policy Studies, The Center for Evaluation of Value and Risk in Health