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Clinical Study

The cost effectiveness of minimally invasive spine surgery in the treatment of adult degenerative scoliosis: a comparison of transpsoas and open techniques

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Abstract

INTRODUCTION: Surgical treatment improves quality of life in patients with adult degenerative scoliosis (ADS). However, open ADS surgeries are complex, large magnitude operations associated with a high rate of complications. The lateral transpsoas interbody fusion technique is a less invasive alternative to open ADS surgery, but less invasive techniques tend to be more expensive. The objective of this study was to evaluate the cost effectiveness of the transpsoas technique for patients with ADS over a 12-month time horizon from a public payer perspective.

METHODS: A cost-effectiveness analysis was performed based on a consecutive case series of patients who underwent ADS surgeries between 2006 and 2012. Effectiveness was expressed as the difference in patient reported preoperative and 12-month postoperative health-related quality of life (HRQOL), which was measured in quality-adjusted life years. Health-care resource use was tabulated based on a clinical chart review on an item-by-item basis. Unit cost data were obtained from published provincial costs in Alberta, Canada. All costs were adjusted to 2015 Canadian dollars. The base case analysis included costs for the surgery, initial hospitalization, and treatment for complications over a 12-month follow-up period. The uncomplicated case analysis included costs for the surgery and initial hospitalization only. The joint uncertainty surrounding the cost and HRQOL differences was estimated using bootstrapping with 10,000 replicates.

RESULTS: A total of 10 open technique and 12 transpsoas technique T11−pelvis fusions were included in the analysis. In the base case analysis, the transpsoas technique was less costly compared with the open technique, total cost of $83,513 (95% CI: $72,772−$94,253) versus $111,381 (95% CI: $36,340−$186,423), respectively (incremental cost $27,869), and was associated with 0.06 more quality-adjusted life years and/or patient. However, in the uncomplicated case, the open technique was less costly compared with the transpsoas technique ($47,795 [95% CI: $39,003−$56,586] vs $76,510 [95% CI: $72,273−$80,746]), respectively, with an incremental cost of $28,715. Based on the probabilistic analysis of 10,000 bootstrap iterations for the base case analysis, the transpsoas technique was more effective and less costly compared with the open technique 57% of time. One-way deterministic sensitivity analysis by adjusting bone-morphogenetic protein-2 dosage further improved cost effectiveness of the transpsoas technique by lowering overall costs.

FDA device/drug status: not applicable

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CONCLUSIONS: Transpsoas surgeries were associated with better outcomes in terms of HRQOL and lower costs over 1-year follow-up period compared with more invasive open technique. This study should be viewed as a pilot evaluation and should be replicated in a larger prospective multicenter controlled study.

Keywords: Cost; Degenerative scoliosis; Economic evaluation; Minimally invasive surgical procedures; degenerative Scoliosis; Spinal fusion; Spine; Transpsoas.

Introduction

Adult degenerative scoliosis (ADS) is a disabling condition, causing severe back pain, inability to stand upright, possible neurologic loss, and severe restrictions in mobility and function. Health-related quality of life (HRQOL) values in ADS patients are much worse than most other health conditions measured in the general population, with disability increasing as patients age [1,2].

Fortunately, spinal fusion for ADS improves patients' HRQOL. Significant improvements have been noted in pain, spine-related disability, and general health status [3−5]. However, surgical procedures for ADS are associated with long duration and associated with substantial blood loss. Recently, appropriateness criteria developed for ADS surgery have affirmed the practice of extensive lumbar fusion and decompression in very symptomatic patients [6]. The prevalence estimates for ADS vary, but the incidence of ADS surgery has dramatically risen in the past decade (up to fourfold), as have the costs [7]. Understanding and controlling costs of these interventions is thus of significant importance to decision makers and payers.

One of the major cost drivers in ADS is perioperative and delayed complications [8]. Reported complication rates in ADS [9−12] are very high, and may result in reoperations and decreased HRQOL [13]. They also can increase costs to the payer, with longer length of stay (LOS) in hospital [14], and further direct costs related to medical- and surgical treatment of these complications [15,16].

In the past decade, because of the introduction of the lateral transpsoas interbody fusion technique [17], and the subsequent application of this technique to ADS surgery [18], surgeons have been increasingly adopting less invasive techniques to treat ADS [19,20]. The lateral transpsoas interbody fusion technique (transpsoas technique) is the engine of less invasive techniques, accomplishing decompression, deformity correction and a high fusion rate, when combined with posterior instrumentation. Although there are no high-quality prospective trials directly comparing newer techniques to traditional open techniques, the current literature suggests equivalent results with perhaps a lower complication rate [20−22]. Whereas not all patients have spinal deformities that are amenable to less invasive surgeries [23], the majority of de novo ADS patients do, which has led to a major shift in treatment patterns at some institutions, such as ours.

Less invasive techniques are likely more expensive interventions, being more resource intensive in terms of interbody implants, fusion adjuncts, and operative time. To date, there are no published economic evaluation studies, or incremental cost-effectiveness ratio (ICER) estimates comparing the open and transpsoas techniques.

Methods

Overview

A cost-effectiveness analysis was performed using a consecutive case series of patients presenting with ADS. The overall costs and effectiveness of the transpsoas technique were compared with the open technique.

Study population and clinical outcomes

Adult patients with degenerative *de novo* scoliosis, operated upon consecutively at a single tertiary-care spine center over a 6-year period were included in this study. Open cases were performed between 2006 and 2010, and less invasive cases were performed between 2010 and 2012. After 2010, almost all such cases at our instruction were performed using less invasive technique, thereby imposing inherent limitations in patient numbers. We included patients who had had previous limited surgery, including decompressions and one-level fusions. Patients who had had previous multilevel fusions were excluded. All patients had failed conservative management and underwent scoliosis corrective surgery. Only patients received fusions extending from a cephalad level of T10/11/12 to a caudad level of S1 and/or ilium, using either completely open technique or a less invasive two-staged technique.

All patients received standard postoperative medical and rehabilitation management during the hospital admission and were followed for 12 months for assessment of adverse events and HRQOL. Adverse events were categorized using the previously validated Spine AdVerse Events Severity system [24], which grades events as: (0) no event; (I) events result in no or minimal treatment, and having a minimal effect (1−2 days) on hospital LOS; (II) events requiring treatment and/or increased LOS (3−7 days), but not associated with long-term (6 months) sequelae; (III) events requiring treatment and/or increased LOS (more than 7 days) and associated with long-term sequelae; and (IV) events resulting in death.

Effectiveness

Patient-reported HRQOL was assessed using preoperative and 12-month postoperative SF-6D scores. The SF-6D scores were derived from the SF-36(v2) [25]. The SF-6D utility scores are used as a utility index for economic analysis, ranging from 0.30 (least healthy) to 1.00 (full health), with a score of 0 being assigned to those who die. Subsequently, QALYs were obtained by multiplying utility score by the time spent in each health state. Patients were assumed to undergo a linear change in health states over the 12-month period. For scores obtained beyond 12 months, age- and gender-specific declines in utility were applied to calculate the health state at 12 months after the surgery [26].

Resource utilization and costs

The analysis adopted a health-care system (i.e. payer) perspective of the regional health-care authority in Alberta, Canada. Unit cost data for postoperative care and medical interventional complications were estimated from published provincial case costing data [27]. Facility and unit costs for physician billing and nursing care were obtained from the provincial regional health-care authority. Implant unit costs were obtained from hospital specific pricing, and based on a provincial-level contract. All costs were adjusted to 2015 Canadian dollars using the appropriate Canadian consumer price indices for material and health care consumables (http://www.statcan.gc.ca/). The analysis uses a 12-month time horizon, and therefore, it was not necessary to discount for future costs or health outcomes [28].

Health-care resource use was tabulated based on clinical charts' review on an item-by-item basis. The base case analysis included costs for the surgery, initial hospitalization, and the reported resource usage over the 12-month follow-up period, including re-hospitalizations and procedures (total cost) for all patients included in the analysis. The uncomplicated case analysis included costs for the surgery and initial hospitalization only (total uncomplicated cost) for all patients included in the analysis.

The overall cost for each patient was calculated by combining per patient costs of the initial surgery and hospitalization. We took special care in calculating the amount of recombinant bone-morphogenetic protein-2 (BMP-2; Infuse, Medtronic, Minneapolis, USA) used during the surgeries, as use typically was high and a significant driver of costs. The mean cost per patient was calculated as the total cost for the group, divided by the total number of patients in each group.

Cost-effectiveness analysis

A cost-utility analysis was performed to obtain a cost per QALY gained for all patients. Mean preoperative and postoperative SF-6D utility scores, and total cost and total uncomplicated cost in the two groups were compared using Student *t* test to evaluate any significant differences. Incremental cost-effectiveness ratios were then calculated by dividing the difference in mean cost between the transpsoas and open groups by the difference in mean QALYs between the transpsoas and open groups.

$$\text{ICER} = \frac{\text{Cost}_{\text{trans-psoas}} - \text{Cost}_{\text{open}}}{\text{QALYs}_{\text{trans-psoas}} - \text{QALYs}_{\text{open}}}$$

The ICER represents the additional cost per one unit of QALY gained. A treatment is considered cost effective if it falls below the willingness-to-pay threshold. A treatment is considered cost saving if it is both more effective and less costly compared with the alternative, and dominated if it is both less effective and more costly than the alternative [29,30]. For the purpose of this study, we assessed cost effectiveness in relation to a willingness-to-pay threshold of $120,000 per QALY, as this has been advocated more recently to be a current, acceptable threshold for spine surgeries compared with the traditional $50,000/QALY threshold [31]. If one of the strategies was cost saving (ie, demonstrated lower costs and more QALYs) an ICER was not calculated.

Statistical analysis

Calculations and statistical analyses were performed using Microsoft Office Excel 2010 and Stata/IC V.11.2 (StataCorp Stata Statistical Software: Release 11.2. College Station, TX, USA: StataCorp LP, 2012).

Sensitivity analysis

More recently, we have been able to reduce amount of BMP-2 used during transpsoas technique surgeries by 40% as compared with the amount of BMP-2 used in surgeries performed during the analysis period. As such, a one-way deterministic sensitivity analysis was conducted, where we varied percentage of BMP-2 as compared with the actual amount of BMP-2 used for each patient (ie, 100%) in the transpsoas technique group and explored associated changes in mean costs per patient in the transpsoas technique group, as well as change in difference of means between transpsoas and open techniques groups.

To quantify the uncertainty surrounding the point estimate of the ICER, we examined the joint density of cost and QALYs differences [32]. The joint uncertainty surrounding the cost and injury rate differences was estimated using bootstrapping with 10,000 replicates plotted on a scatterplot (cost-effectiveness plane). We also estimated the probability of transpsoas technique compared with open technique being cost effective under $50,000 and $120,000 willingness-to-pay thresholds using a cost-effectiveness acceptability curve analysis.

Results

Study population

A total of 22 (10 open technique and 12 transpsoas technique) surgical procedures were included in the

Table 1
Baseline patient characteristics

	Transpsoas technique treatment group (n=12)	Open technique treatment group (n=10)
Mean age (years)	64.2±8.7 (48−77)	61.7±9.6 (44−74)
Women (%)	11 (91.7%)	10 (100%)
Mean body mass index (kg/m^2)	28.1±8.2 (20.0−49.4)	25.9±2.7 (23.8−31.6)
Mean number of comorbidities	1.5±1.2 (0−4)	1.5±1.3 (0−4)
SF-6D utilities (scale from 0 to 1)*	0.60 (SD 0.06)	0.58 (SD 0.12)

* SF-6D measures general health on a scale from 0 to 1, with "1" meaning full health and "0" meaning death (25).

analysis. Baseline characteristics of patients in the transpsoas technique treatment group and the open technique treatment group are presented in Table 1. Five patients in the transpsoas group and three patients in the open group had had previous limited surgeries. Overall, patients in the transpsoas technique group were slightly older (64.1years vs 61.7 years) and had lower body-mass index (25.9 kg/m^2 years vs 28.1 kg/m^2). These groups are very comparable to other ADS series, and similarly matched for comorbidities and obesity, which are both known to increase the rate of complications, and thus costs in spine surgery [33,34].

Surgical procedure

Surgical data are outlined in Table 2. The open technique group had significantly higher blood loss and subsequent transfusions, despite being carried out in a much shorter length of surgery.

In the transpsoas group, the techniques used were homogenous. All patients had lateral transpsoas fusions from a proximal level of T12 or L1 to a caudad level of L5, for a total of four- or five levels. During the second stage, all patients had an L5−S1 minimally invasive TLIF, whereas one patient had an additional L4−L5 transforaminal interbody fusion (TLIF). In addition, all patients had percutaneous screw placement from either T11−S1 or T11−Ilium. One patient had a one-level minimally invasive surgical decompression as well.

In the open technique group, techniques used were heterogeneous. All patients had decompressions, of between three- and seven levels. Two patients had pedicle subtraction osteotomies, and four patients had posterior column osteotomies. For anterior supplemental fusion at L5−S1, three patients had formal anterior lumbar interbody fusions, four patients had (TLIFs), whereas three patients had no anterior fusions.

Three patients in each group had revision surgeries within the first year. In the transpsoas group, two patients underwent revision surgery during the initial admission, one for a medically misplaced pedicle screw, and one for a set screw that became disengaged. One patient in the transpsoas group underwent revision surgery at 11 months postoperative for symptomatic proximal junctional kyphosis.

In the open group, two patients underwent revision surgery during the initial admission, both for Irrigation and Debridement procedures for deep wound infections. One patient underwent revision surgery at 5-months after the index procedure, for proximal junctional kyphosis, undergoing removal of the proximal implants and extension of the fusion to the proximal thoracic spine.

Table 2
Surgical details

	Transpsoas technique treatment group (n=12)	Open technique treatment group (n=10)	*p* value
Number of procedures staged	12 (100%)	5 (50%)	0.01
Length of procedure (minutes)	1,079±176(785−1,415)	696±192 (334−968)	0.0001
Estimated blood loss (mL)	1,075 (SD 619)	4,472 (SD 2,897)	0.017
Number of units PRBCs transfused	0.9±1.0 (0−2)	5.0±4.4 (0−13)	0.005
Number of cases with BMP-2 use	12 (100%)	8 (80%)	0.20
Amount of BMP-2 used (mg)	25.3±7.1 (16−36)	15.0±5.6 (12−24)	0.003
Number of cases with post-Op ICU stays	0	2	0.3
Length of stay (days)	15.6±5.4 (11−29)	32.6±57.5 (5−195)	0.60
Uncomplicated	14.4±3.5 (11−22)	12.6±6.3 (5−22)	0.82
With complications*	29.0±0 (29)	79.3±100.3 (16−195)	0.65
Number of patients with complications	9 (75%)	10 (100%)	0.22
Grade I	3	6	0.19
Grade II	7	7	0.68
Grade III	3	7	0.08
Grade IV	0	0	
Number of reoperations within first year	3	3	

* Complications (≥Grade 2) affecting length of primary stay.

Table 3
Health-care resource use by unit costs for treatment of complications ($CAD, 2015)

Resource used	Cost per unit	Mean length of stay (days)	Mean cost
Regular hospital stay	$789	8	$6,311
ICU Stay	$1,508	-	-
Transfusions	$598	-	$598
Chronic heart failure	$820	10	$8,198
Myocardial infarction (life threatening, required hospitalization to ICU)	$1,284	20	$25,677
Non-ST-elevation myocardial infarction, ventricular tachycardia	$1,307	7	$9,151
Heart block and/or dysrhythmia (serious, required monitoring)	$1,039	9	$9,352
Chest pain (required work-up)	$944	3	$2,832
Atrial fibrillation	$950	5	$4,752
Transient ischemic attack	$1,039	4	$4,154
Deep vein thrombosis	$821	7	$5,746
Serious pulmonary effusions (pleural edema)	$1,656	9	$14,907
Average pulmonary effusions (pleural edema)	$977	5	$4,885
Acute renal failure (life threatening, required hospitalization to ICU)	$1,581	24	$37,940
Liver failure	$1,056	8	$8,451
Ischemic gut (required hospitalization ICU)	$1,770	23	$40,710
Malnutrition (required gastrostomy)	$1,532	16	$24,519
Esophagogastroduodenoscopy	$667	-	$667
Clostridium difficile colitis	$865	4	$3,460
Urinary tract infection	$900	6	$5,398
Multisystem sepsis (life threatening)	$2,263	35	$79,202
Postoperative delirium	$702	7	$4,914

Clinical outcomes and quality of life

At 12-month postsurgery, compared with baseline, mean SF-6D utility value increased in both the transpsoas technique treatment group and the open technique treatment group (from 0.60 [95% CI: 0.56−0.63] to 0.65 [95% CI: 0.57−0.72] and 0.58 [95% CI: 0.50−0.65] to 0.59 [95% CI: 0.46−0.72], respectively). Over 12 months, patients in the transpsoas technique treatment group gained on average of 0.06 QALYs compared with the patients in the open technique treatment group as shown in Table 4.

Health-care resource use and cost

The health-care resources consumed by patients in the intervention and control groups are presented in Table 2. In the uncomplicated case analysis, when accounting for the initial surgery and hospitalization costs (total uncomplicated costs) only, the transpsoas technique treatment group was associated with the higher average cost per patient ($76,510 [95% CI: $72,273−$80,746] vs $47,795 [95% CI: $39,003−$56,586]), an incremental cost of $28,715, as shown in Table 3. This difference in cost was mostly driven by a more than a twofold higher per patient implant cost ($27,722 [95% CI: $26,485−$28,959] vs $13,532 [95% CI: $11,077−$15,986]) and BMP-2 cost ($14,967 [95% CI: $13,157−$16,777] vs $6,385 [95% CI: $3,727−$9,044]) in the transpsoas technique treatment group (Table 3). However, in the base case analysis, when accounting for costs incurred over the 12-month follow-up period, open surgery resulted in much higher costs of complications management and thus higher overall total costs. Consequently, the transpsoas technique treatment group had lower mean overall total costs per patient by −$27,869 (95% CI: −$101,491 to $45,755; Table 4).

In the one-way deterministic sensitivity analysis, estimating the use of BMP-2 from 0% to 100% in transpsoas technique procedures, the difference in mean costs per patient increased to −$30,542 and −$32,481 when using 75% and 50% of BMP-2, respectively (6) in favor of the transpsoas technique.

Incremental cost-effectiveness analysis

The transpsoas technique was associated with lower mean overall total costs ($27,868 [95% CI: −$101,491 to $45,755]) and with 0.06 more QALYs per patient (95% CI: −0.04 to 0.15) when compared with the open technique over a period of 1 year (Table 4). This point estimate demonstrates that the transpsoas technique is dominant (both more effective and less costly compared with the alternative), and therefore, ICERs were not calculated.

The transpsoas technique was more effective and less costly compared with the open technique 57% of time (Fig. 1) based on the cost-effectiveness acceptability curve. The transpsoas technique was cost effective in 65% and 77% of cases under the thresholds of willingness-to-pay of $50,000 and $120,000, respectively (Fig. 2).

Discussion

As the body of literature-supporting clinical effectiveness of ADS surgery grows, justifying higher implant costs with different techniques has become an important consideration for both surgeons and payors. Reported ICERs associated with ADS surgery are almost an order of magnitude

Table 4
Average health-care cost over 12-month period by type of health-care resource by treatment group

		Transpsoas group (n=12) Mean cost per patient $CAD 2015 (95% CI)	Open group (n=10) Mean cost per patient $CAD 2015 (95% CI)
Implants			
	Hardware	$27,722 ($26,485−$28,959)	$13,532 ($11,077−$15,986)
	BMP-2 (100% of BMP-2 used)	$14,967 ($13,157−$16,777)	$6,385 ($3,727−$9,044)
Operating room		$14,642 ($13,774−$15,510)	$12,395 ($9,237−$15,552)
Room and/or personnel		$6,340 ($5,771−$6,909)	$4,376 ($3,523−$5,229)
Hospital stay		$12,839 ($11,160−$14,517)	$11,107 ($8,298−$13,916)
Total uncomplicated case		$76,510 ($72,273−$80,746)	$47,795 ($39,003−$56,586)
Complications			
• Grade 1 (any deviation from the normal postoperative course without the need for pharmacologic treatment or surgical, endoscopic, and radiological interventions)		$119 (−$13.5 to $251)	$1,002 ($298−$1,706)
• Grade 2 (requiring pharmacologic treatment with drugs)		$535 (−$513 to $1,582)	$444 (−$318 to $1,207)
• Grade 3 (requiring surgical, endoscopic or radiological intervention)		$5,727 (−$1,844 to $13,298)	$48,571 (−$6,001 to $103,143)
• Grade 4 (life-threatening complication requiring IC and/or ICU management)		$0	$0
ICU stay		$0	$8,409 (−$8,073 to $24,891)
Blood products		$622 ($240−$1,005)	$5,160 ($2,073−$8,248)
Total complications, ICU stay, and blood transfusions costs		$7,003 (−$512 to $14,518)	$63,587 (−$9,813 to $136,987)
Overall total cost (base case analysis)		$83,513 ($72,772−$94,253)	$111,381 ($36,340−$186,423)

higher than other common cost-effective operations such as total hip replacements [43]. Upfront direct costs for ADS surgeries have been previously reported to be high, ranging from USD $67,000 [35] to $390,000 [36]. It has also been suggested that costs of ADS vary by subdiagnosis, with costs being higher when the fusion extends to the pelvis and by increased number of levels [35]. Over 60% of total costs in ADS surgery relate to odds ratio (OR) costs [36,37]. Assuming improvement in patients' HRQOL is durable, ADS surgery reaches accepted cost-effectiveness thresholds of $90,000−$100,000 per QALY only when modeled over a 5- or 10-year time horizon [31,37,38].

In this study, we evaluated cost effectiveness of two techniques for ADS surgery—open and less invasive transpsoas techniques. The study showed that average initial surgery and hospitalization costs per patient for the open

Table 5
Comparison of total health-care costs and quality adjusted life years (QALYs) at 12 months postsurgery for in the transpsoas technique treatment group and the open technique treatment group based on results of the probabilistic sensitivity analysis using bootstrapping with 10,000 replicates

		Transpsoas group (n=12)	Open group (n=10)
Cost*	Mean ($C; 95% CI)	$83,513 ($72,772−$94,253)	$111,381 ($36,340−$186,423)
	Incremental cost ($C; 95% CI)†	−$27,868 (−$101,491 to $45,755)	
QALYs	Mean (95% CI)	0.65 (0.60−0.70)	0.59 (0.50−0.67)
	Incremental QALYs (95% CI)†	0.06 (−0.04 to 0.15)	

* Overall cost including costs associated with complications over 1-year period.
†** Calculated as the difference between the transpsoas technique treatment group and the open technique treatment group costs and QALYs.

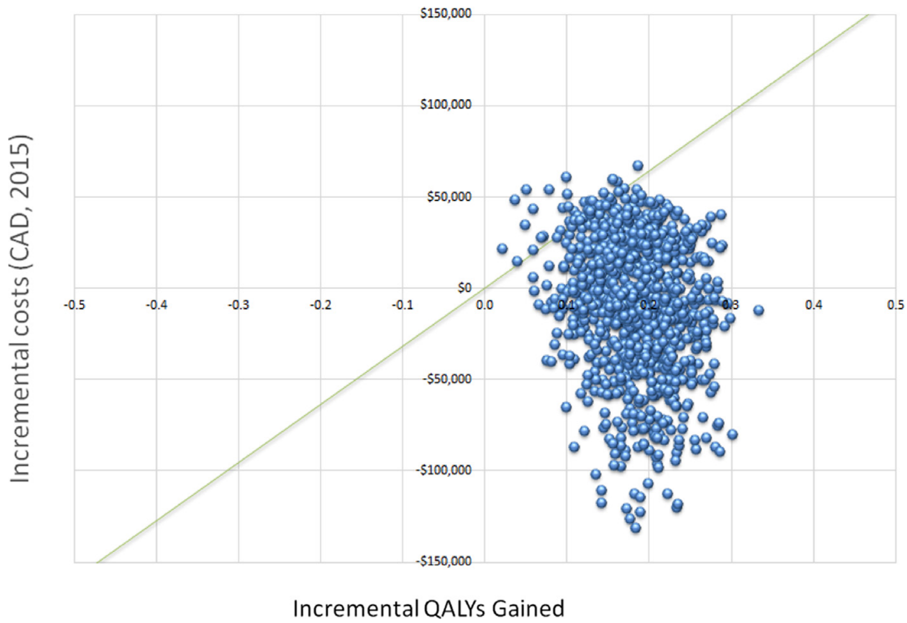

Fig.1. Cost-effectiveness plane scatterplot displaying costs and quality adjusted life-years (QALYs) for the transpsoas technique treatment group and compared with the open technique treatment group for 10,000 bootstrap iterations.

In this figure, 57% of 10,000 bootstrap iterations fall into South East (SE) quadrant, showing that the transpsoas technique was more effective and less costly compared with the open technique 57% of the time; the rest 43% of iterations fall into North East (NE) quadrant, showing that the transpsoas technique was more effective and more costly 43% of the time.

Point-estimates for incremental cost and incremental QALYs are −$27,868 (95% CI: −$101,491 to $45,755) and 0.06 (95% CI: −0.04 to 0.15), respectively.

technique ADS surgeries were 38% less compared with the transpsoas technique. However, when we considered costs related to complications over a 12-month follow-up, the transpsoas technique tended to be 25% less costly compared with the open technique with the total cost of $83,513 (95% CI: $72,772−$94,253) versus ($111,381 [95% CI: $36,340−$186,423], respectively. We also found greater improvement in patients' HRQOL in the transpsoas group. However, in this cohort, postoperative quality of life in the open group was not significantly improved, which is not in keeping with other similar studies. For example, Scheer et al. found an improvement from 0.60 to 0.65 with

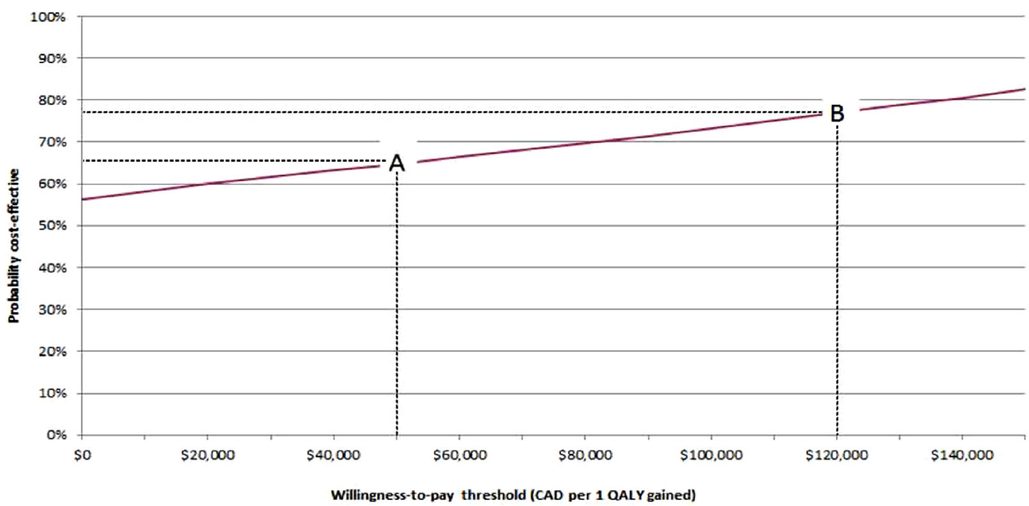

Fig.2. Cost-effectiveness acceptability curve displaying probability of transpsoas technique compared with open technique being cost-effective under varying willingness-to-pay thresholds

*This cost-effectiveness acceptability curve shows that the probability of transpsoas technique compared with open technique being cost-effective (A) was 0.65 for a $50,000 per QALY willingness-to-pay threshold and (B) was 0.77 for a $120,000 per QALY willingness-to-pay threshold.

QALY, quality adjusted life-year.

Table 6
Deterministic one-way sensitivity analysis of mean overall cost over 12-month period—amount BMP-2 used

		Percentage of BMP-2 used*				
		No BMP-2 used	25% of BMP-2 used	50% of BMP-2 used	75% of BMP-2 used	100% of BMP-2 used
Mean cost (95% CI)	**Transpsoas group (n=12)**	$68,545 ($58,447−$78,644)	$76,045 ($65,278−$86,362)	$78,900 ($68,337−$88,796)	$80,839 ($69,735−$91,192)	$83,512 ($72,772−$94,253)
	Open group (n=10)	$111,381 ($36,340−$186,423)	$111,381 ($36,340−$186,423)	$111,381 ($36,340 to $186,423)	$111,381 ($36,340−$186,423)	$111,381 ($36,340−$186,423)
Incremental cost ($CAD; 95% CI)**		−$42,836 (−$116,335−$30,663)	−$35,336 (−$108,920−$38,248)	−$32,481 (−$106,005−$41,043)	−$30,542 (−$104,163−$43,079)	−$27,869 (−$101,491−$45,755)

BMP-2, bone-morphogenetic protein-2.
* Percentage of BMP-2 used was taken from the actual amount of BMP-2 used for each patient (ie, 100%) and was measured in packs of BMP-2 with small 4 mg, mediums 8 mg, and large 12 mg packs available. This means that if a patient required 24 mg of BMP-2 during the surgery (100%), 75% of this amount of BMP-2 will be 18 mg, which will require one large 12 mL and two small 4 mL packs of BMP-2.
** Calculated as the difference between the trans-psoas technique treatment group and the open technique treatment group costs.

operative treatment, with a standard deviation of approximately 0.01 [39]. Likely, this is caused by the high complication rate in this relatively small cohort, raising the importance of the bootstrapping sensitivity analysis performed.

Both lower costs in the transpsoas group over a 1-year follow-up and significantly lower postoperative quality of life in the open group were likely driven by a much higher major complication rate in the open group. Higher rate of major complication in the open group was associated with a nearly ninefold increase in costs related to complications.. This finding is not novel; Hellsten et al. documented a dramatic increase in incremental costs when Grade 3 complications are incurred, with per case increase of $147,000 [16]. As the Hellsten study was carried out in Canada, the dollar costs are directly comparable to our study. Given the unacceptably high perioperative complication rate in ADS surgery [3,10,12,33], the open group's complication rate in our study is likely representative of a more broad cohort, and thus we believe the results of this study are valid despite our small sample size.

There are few other reports of cost comparisons between less invasive and open approaches to ADS surgery. Uddin et al. found that less invasive surgery for ADS (including lateral interbody fusions and percutaneous screw placement) was in fact less costly [36]. Overall inpatient costs, which included OR costs and complication costs, were significantly lower in the less invasive group ($269,807vs $391,889). Interestingly, and in contrast to our findings, OR costs were also significantly less in the less invasive group ($202,622vs $253,014). As expected, there were also significantly more complications in the open group, which were likely a driver of inpatient costs. It is important to note that this study reported billed charges, which are not necessarily true costs or payer-payments [36], in contrast to the current study where only true costs in a public system are reported. In addition, we based our costing analysis on a chart review to capture detailed resource consumption on a case-by-case basis.

Moreover, experience of surgeons in the particular type of surgery at the time the study may impact resource utilization. For example, our BMP-2 use currently is less than when the surgeries were carried out, using approximately 3mg of BMP-2 per level. We have found this dose to suffice in achieving solid fusions (total 15−18 mg), and suspect the dose could be safely lowered even further. In our sensitivity analysis varying BMP-2 total dose, we could lower the transpsoas cost by approximately $4,500, which would represent approximately a 5% savings. Furthermore, if fusion rates using transpsoas cages remained high whereas avoiding BMP-2 use altogether (using other bone-graft substitutes), the transpsoas procedure becomes more dominant (Table 6).

The small sample size is a limitation to this investigation, and is driven by the small number of patients with ADS at our institution who underwent multilevel open surgery. Before the introduction of the transpsoas technique at our institute, many patients and clinicians were deterred from surgical intervention caused by the known high morbidity rate in open fusions. In addition, the experienced surgeons who performed the operations in this study would all refuse to randomize patients, believing it to be unethical to submit patients to a higher complication rate. Our study could be considered a pilot study providing data to structure larger multicenter studies, which would be required to make final decisions about cost effectiveness of the open and transpsoas ADS surgery techniques.

The 12-month time-horizon could be considered as another limitation, as it does detract from the potential true costs, as the delayed complication rate in ADS surgery is quite high, and thus durability of the surgery is highly variable. Soroceanu et al. recently reported the delayed complication rate at 2-year follow-up as being 31%, with over 50% of those patients requiring additional surgery [40]. However, we have no evidence that the delayed complication rate between the open and less invasive groups would be different at 2 years. We hypothesize that the delayed complication rate may be lower in the less invasive group caused by lower pseudarthrosis and rod breakage rates. Others have reported that the proximal junctional kyphosis rate is also lower in less invasive surgery [44] although this finding has not yet been replicated. If either pseudarthrosis or proximal junctional kyphosis were to be lower with less invasive surgery, it would magnify the cost-effectiveness differences between the groups in favor of the transpsoas group.

Despite these limitations, we believe our study addresses a major limitation of the cost-effectiveness ADS literature to date, which tends to group together different patients with different levels of disability, different indications, and different surgery [31,38]. The patient population and underlying subdiagnosis, which predict the magnitude of the intervention, should be carefully considered in economic evaluations of ADS surgery. For example, a simple revision for flatback via pedicle subtraction osteotomy, in a fully fused spine, may be coded as a multilevel revision surgery. However, costs may be minimal if there are no new implants placed, minimal blood loss and uncomplicated surgery. In contrast, primary degenerative scoliosis (or de novo scoliosis) may involve a multilevel decompression, full set of implants, interbody cage, and bone graft substitutes. Thus, it is not surprising that this indication has been found to be the most expensive intervention within ADS surgery [35]. In our study, we selected only patients with de novo ADS, with no previous fusion interventions. All patients underwent the same, large magnitude surgery with fusion levels of T10−pelvis. In all patients, decompression was achieved, either directly, or indirectly [41,42]. The comorbidity profile was similar between groups, and comparable to other studies. Thus, we believe that despite the small number of patients in this study, the groups are highly specific and well matched, and the comparison between groups thus valid.

Conclusions

In summary, the less invasive approach to ADS surgery, is associated with better HRQOL outcomes, fewer complications and lower costs over 12-month follow-up compared with more invasive open techniques. The study needs replication using larger data sets with a controlled study design, and the current study provides strong pilot data to structure such a study.

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