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Complications of surgical intervention in adult lumbar scoliosis

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Abstract If nonoperative measures are unsuccessful in managing the pain and disability of adult spinal deformities, surgical correction may provide the potential for significant improvement in a patient's quality of life. However, these procedures have a relatively high risk of complications. Identifying patients that may benefit from surgical intervention requires a thorough understanding of potential complications and managing the risks of any individual patient. Complications do not necessarily result in poor outcomes, and good outcomes are not always complication free. Higher risk patients potentially have more to gain, even if they experience complications. With the rapidly expanding senior population and expanded capabilities to manage high-risk patients, it is helpful to consider the lessons provided by ever expanding databases of outcome measures to refine the surgical decision-making process.

Keywords Complication · Impact · Proximal junctional kyphosis · Durotomy · Infection · Pseudarthrosis

Defining complications

Without a standardized system for classifying and reporting complications, quantifying complications relies on heterogenous retrospective analysis that often underestimates incidence. Defining what constitutes a complication varies across studies. Attempts to accurately understand complications and their impact on patient outcomes and relation to preoperative risk factors ultimately depends upon a uniform method for categorizing and grading any "state, directly or indirectly resulting from a surgical operation that altered the anticipated recovery of the patient [1]." However, any method of categorizing and grading may oversimplify the wide-range of potential effects complications have on individual outcome measures.

With the establishment of numerous spine surgery outcome databases has evolved a more standardized consensus. Adult spinal deformity study group surgeons compiled a consensus agreement of complications and subdivided each into major and minor categories [2, 3]. Factors considered in forming these categories include permanency, alteration of anticipated recovery or hospital stay duration, and the degree of additional treatment required. Variables necessitating reoperation default to major complications (Table 1).

Incidence of complications

Deciding when operative treatment for adult spinal deformity is the best management strategy depends heavily on identifying a patient's individual risk and potential for complications. Until recently, quantifying complications is dependent upon retrospective cohorts with limited focus on complications. Despite the inherent bias of retrospective studies and self-reporting databases, this data can estimate the lower-end rate of complications. In 4,980 surgeon-reported cases of adult scoliosis correction surgery submitted to the Scoliosis Research Society (SRS) from 2004 to 2007, 10.5 % of patients experienced at least one perioperative complication, and only 0.3 % of cases resulted in death [4]. The most common complications reported were

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Table 1 Complication classification for patients undergoing ASD surgery [2, 3]

Complication classification for patients undergoing ASD surgery		
Type	Major	Minor
Infection	Deep	Superficial
	Pneumonia	Urinary tract infection
	Sepsis	*Clostridium difficile*
Implant	Hook dislodgement	Crosslink dislodgement
	Interbody fracture	Interbody subsidence
	Interbody migration	Painful implants
	Rod fracture	Prominence
	Rod dislodgement	Screw malposition
	Screw fracture	Screw-bone interface loosening
		Set screw dislodgement
Neurological	Bowel/bladder deficit	Delirium
	Brachial plexus injury	Neuropathy or sensory deficit
	Cerebrovascular accidents accident/stroke	Pain (radiculopathy)
	Nerve root injury with weakness	Peripheral nerve palsy
	Retrograde ejaculation	
	Spinal cord injury with complete deficit	
	Spinal cord injury with incomplete deficit	
	Visual deficit/blindness	
Cardiopulmonary	Acute respiratory distress syndrome	Arrhythmia
	Cardiac arrest	Coagulopathy
	Congestive heart failure	Pleural effusion
	Deep vein thrombosis	Pneumothorax
	Myocardial infarction	
	Pulmonary embolism	
	Reintubation	
	Respiratory arrest	
Gastrointestinal	Bleed requiring surgery	Bleed not requiring surgery
	Cholecystitis requiring surgery	Cholecystitis not requiring surgery
	Liver failure	Ileus
	Obstruction	Pancreatitis not requiring surgery
	Pancreatitis requiring surgery	
	Perforation	
	Superior mesenteric artery syndrome	
Radiographic	Distal/proximal junctional kyphosis requiring surgery	Distal/proximal junctional kyphosis not requiring surgery
	Pseudarthrosis	Sagittal imbalance
		Coronal imbalance
		Adjacent segment degeneration
		Curve decompensation
		Heterotopic ossification
		Adjacent segment degeneration
Renal	Acute renal failure requiring dialysis	Acute renal failure requiring medical intervention
Wound problems	Dehiscence requiring surgery	Hematoma/seroma not requiring surgery
	Hematoma/seroma with neurological deficit	Hernia
	Hematoma/seroma, no neurological deficit requiring	Dehiscence not requiring surgery
	Incisional hernia	
Operative	EBL > 4 L	Dural tear
	Retained sponge/instrument	Fixation failure (hook/screw)
	Unintended extension of fusion	Implant failure
	Vascular injury	Pedicle fracture
	Visceral injury	Posterior element fracture
	Wrong surgical level	Vertebral body fracture
Vascular	Vascular injury	Coagulopathy
		Thrombophlebitis

Adapted with permission from Soroceanu et al. [25•]

durotomy (2.9 %), superficial or deep wound infection (2.4 %), implant complication (1.6 %), acute or delayed neurological deficits (1.5 %), epidural or wound hematoma (0.6 %), and deep venous thrombosis/pulmonary embolism (0.4 %) [4].

The table below (Table 2) are adapted from Sciubba and colleagues' 2015 meta-analysis of 93 (12 prospective) studies published after the year 2000 which consolidated data from 11,692 patients undergoing surgical correction of adult spinal deformity due to any etiology [5•]. With an average age of 53.3 and 3.5 years of follow-up, major perioperative complications were reported in 18.5 % of patients and minor perioperative complications occurred in 15.7 %. The most frequent perioperative complications were any infection (3.2 %), neurological deficit (3.1 %), need for further surgery (3.0 %), dural tears (3 %), (2.1 %) instrumentation/graft failure (1.3 %), and excessive bleeding (1.2 %). Ultimately 20.5 % of patients experienced a long-term instrumentation related or radiographic defined failure, most frequently pseudarthrosis (7.6 %), instrumentation/graft failure (3.3 %), proximal junction kyphosis (PJK) (2.9 %), adjacent segment degeneration (2.7 %), or symptomatic instrumentation (2.0 %) [5•]. The highest complications rates were seen in three-column osteotomies, where 66 % developed a complication. Even with a "non-3-column osteotomy" 45 % still developed a complication. [5•]. While this data contains larger number of patients and nearly twice the major complication rate of the SRS database, this meta-analysis relies predominantly on retrospective studies with varied follow-up that were as short as 6 weeks and almost certainly underestimate the true complication rates. This is especially true as none of the studies reported complications following re-operations.

Using a prospective study design with rigorous patient selection and standardized comprehensive data collection by on-site study coordinators at 11 centers, Smith and colleagues identified substantially higher complication rate in 291 adult spinal deformity patients who completed a minimum of 2-year postoperative follow-up [6•]. Inclusion criteria required at least one of the following deformities: >20° scoliosis, >5-cm sagittal vertical axis (SVA), > 25° pelvic tilt (PT), or >60° thoracic kyphosis. The patients averaged 1.9-L blood loss (EBL) during a 7.1-h operation on 11.1 vertebral levels with 64 % of patients undergoing an osteotomy. Eighty-two (28.2 %) patients required one or more re-operations and additional complications that resulted from reoperation were also counted. Overall, 69.8 % of patients had at least one complication. In the perioperative period, 52.2 % of patients experienced at least one complication (125 major and 145 minor, mean 0.93 complications per patient) and 42.6 % of patients developed at least one complication >6 weeks postop (137 major, 62 minor, mean 0.68 complications per patient) [6•].

Analyzing complications

Expanded use of standardized outcome assessments will help transform quantitative complication rates into studies that explore the true impact of complications and can help guide

Table 2 Comprehensive review of complications

Major perioperative complication [5•]	*n* (%)
All major complications	1,379 (18.5)
Neurological deficit (not transient, not full recovery, resolved with reoperation, or classified as "major")	322 (3.1)
Unspecified requiring surgery	148 (3.0)
Wound infection requiring debridement and/or reoperation (especially deep)	232 (2.4)
Instrumentation/graft failure requiring revision (breakage, dislodgement, or resulting in inadequate correction)	62 (1.3)
Excessive bleeding	122 (1.2)
Unspecified pulmonary	43 (0.9)
Pulmonary embolism or thrombosis of major vessel	71 (0.7)
Respiratory distress syndrome/respiratory failure	28 (0.6)
Pneumonia/lung infection	27 (0.6)
Vascular injury (intraoperative)	22 (0.5)
Death	44 (0.4)
Epidural hematoma	39 (0.4)
Wound hematoma or seroma	38 (0.4)
Pleural effusion or pneumothorax (requiring intervention)	15 (0.3)
Reintubation	15 (0.3)
Stroke	15 (0.3)
Vertebral compression fracture	12 (0.2)
Sepsis	23 (0.2)
Myocardial infarction/cardiac arrest	22 (0.2)
Misplaced screw possibly causing nerve-related pain (requiring reoperation)	10 (0.2)
Congestive heart failure or unspecified cardiac	9 (0.2)
Compartment syndrome ± shock (abdominal or extremity)	7 (0.1)
Cardiorespiratory (non-pleural effusion)/systemic	6 (0.1)
Visual acuity change	12 (0.1)
Pedicle or laminar fracture (intraoperative)	4 (0.1)
Wound dehiscence requiring surgery	4 (0.1)
Fistula	3 (0.1)
Gastrointestinal complication (bleeding, ischemia, or other)	3 (0.1)
Line-related infection	3 (0.1)
Post-thoracotomy syndrome or other pain-related issues	3 (0.1)
Breakdown of L5–S1 disc (perioperative not long term)	2 (0.0)
Cerebral edema	2 (0.0)
Incision abdominal hernia (reoperation)	2 (0.0)
Painful rib remnant requiring excision	2 (0.0)
Renal failure	2 (0.0)
Ischemia in extremities	1 (0.0)
Massive fluid overload	1 (0.0)
Multiple-organ failure	1 (0.0)
Pancreatitis	1 (0.0)
Retroperitoneal hematoma	1 (0.0)
Minor perioperative complications [5•]	***n* (%)**
All Minor complications	1,215 (15.7)
Unspecified or other	302 (3.1)
Dural tear	292 (3.0)
Ileus/gastrointestinal complication	101 (2.1)
Transient neurological deficit (foot drop, brachial plexopathy, peroneal nerve palsy, radiculopathy, cauda equina, partial spinal cord injury, etc.)	148 (1.5)
Wound infection (medical/interventional treatment) or superficial	99 (1.0)
Deep vein thrombosis	66 (0.7)
Urinary tract infection	32 (0.7)
Delirium	28 (0.6)
Cerebrospinal fluid leak	20 (0.4)
Arrhythmia or tachycardia	15 (0.3)
Unspecified or miscellaneous infection (e.g., yeast)	15 (0.3)
Pleural effusion	12 (0.3)

Table 2 (continued)

Major perioperative complication [5•]	*n* (%)
Pneumothorax	11 (0.2)
Pulmonary congestion	10 (0.2)
Hemothorax	7 (0.2)
Hypotension	7 (0.2)
Other intraoperation	7 (0.2)
Instrumentation failure (managed conservatively)	6 (0.1)
Unspecified pulmonary (resolved via simple measures)	6 (0.1)
Wound healing complications (nonsurgical)	6 (0.1)
Other iatrogenic damage	4 (0.1)
Pedicle infraction (intra)	4 (0.1)
Subluxation or translation at surgical site (intraoperative)	3 (0.1)
Fever of unknown origin	2 (0.0)
Hematoma, seroma, or bursa (no surgery)	2 (0.0)
Miscellaneous cutaneous complications	2 (0.0)
Retained drain	2 (0.0)
Reversible coagulopathy	2 (0.0)
Exacerbation of carpal tunnel requiring release	1 (0.0)
Revision (intraoperative)	1 (0.0)
Symptomatic gallstones	1 (0.0)
Thrombophlebitis	1 (0.0)
Long-term complications	***n*** **(%)**
All long-term complications	1,021 (20.5)
Pseudarthrosis	337 (7.6)
Instrumentation/graft failure (breakage, dislodgement, screw loosening, or resulting in sagittal/coronal decompensation)	295 (3.3)
Proximal junctional kyphosis, especially requiring extension	119 (2.9)
Adjacent segment degeneration	105 (2.7)
Symptomatic screws/skin impingement/prominent hardware/painful graft possibly requiring removal	80 (2.0)
Vertebral compression fracture	33 (0.8)
Late deep infection	18 (0.5)
Neurological deficit	8 (0.2)
Superficial wound infection or other wounds	7 (0.2)
Other fracture (e.g., sacral, pelvic)	5 (0.1)
Iliac stress fracture or sacroiliac joint degeneration	3 (0.1)
Unspecified revision	3 (0.1)
Disc herniation	3 (0.1)
Deep vein thrombosis	2 (0.1)
Death	1 (0.0)
Hearing loss	1 (0.0)
Pneumonia	1 (0.0)

Adapted with permission from Sciubba et al. [5•]

complex management decisions. Both the patient's and the surgeon's perspective of complications should be considered, since even commonly reported complications can have little correlation with patient-reported outcomes. [7]. Patients with major perioperative complications still have significant improvements in early clinical outcome measures, but when followed for 3 to 5 years the complications correlated with significant impacts in ODI and SRS scores [8]. Some complications may be insignificant in patient quality-adjusted life years (QALY), but may have a significant cost, and can negatively impact the potential incremental cost-effectiveness ratio (ICER). Multidimensional and longitudinal assessment methods are needed to understand how particular complications impact outcomes.

Neurological injury is a rare but inherent risk of spine surgery. Since some of these will be permanent, they have the potential to have substantial impact on both outcomes and cost. Overall, 27.8 % of patients experienced a neurological complication in the International Spine Study Group (ISSG) multi-center prospective study and these complications contributed to 7.2 % of all study patients undergoing reoperation [6•]. Most common were radiculopathy (8.9 %), motor deficit (4.8 %), sensory deficit (3.8 %), and nerve root deficit (2.7 %) [6•]. While only 1.84 % of patients developed new neurological deficits in the SRS database, the degenerative scoliosis subgroup rate increased to 2.49 % [9]. While most deficits improve or resolve, 1.7 % of nerve root deficits, 6.1 % of spinal cord deficits, and 25 % of cauda equina syndromes failed to improve in the SRS study [9]. In addition, on average, Yadla et al. found new neurological deficits significantly increased the length of stay by 9.1 days [10].

Incidental durotomy is a common complication of lumbar spine surgery. The rate likely increase with increasing degree of deformity, revision surgery and degenerative pathology. In the SRS registry, unintended durotomy was reported in 2.2 % of degenerative scoliosis patients [11]. The rate of reported dural tears reached 10.7 % (31/291) in the ISSG multi-center prospective study by Smith and colleagues. [6•]. Incidental durotomy has been associated with the potential for prolonged hospital stay, hematomas, and neurological and respiratory complications [12, 13]. In assessing 802 incidental durotomies during short-segment lumbar fusions, Stewart et al. found an average of a 1.4-day increase in hospital stay resulting in an additional $10,885 in total hospital charges [13]. Another study found that 19 % (9/48) of durotomies ultimately led to a revision surgery [14].

Infection is a leading cause of morbidity for many surgical procedures. The use of implants and instrumentation can result in infections having even greater consequences. Surgical site infections have been reported in approximately 2–4 % of instrumented spine operations [15–17]. While the incidence is relatively low, infection is responsible for 46 % of readmissions following de novo adult deformity operations [18] and 14.5 % of revision deformity cases [19]. In the SRS database of more than 100,000 operations, higher infection rates were seen with use of implants (28 % greater, 2.3 vs 1.8 %), spinal fusion (33 % greater, 2.4 vs 1.8 %), and revision surgery (65 % greater, 3.3 vs 2.0 %) [20]. Surgical variables included inadequate antibiotic dosing, longer operative time/number of levels, pelvic fixation, and blood transfusions and have all been associated with surgical site infections [17, 19, 21, 22]. Obesity, smoking, diabetes/serum glucose, and MRSA colonization are potentially modifiable risk factors associated with increased rates of surgical site infections [16]. Given that correction of scoliosis is dependent upon the stability of implanted instrumentation, surgical site infections present unique

challenges. Instrumentation can reliably be preserved 88.2–89.3 % of the time if detected early and managed aggressively with debridement [23, 24]. Overall, surgical site infections have been reported to increase length of hospital stay by an average of 9.7 days and admission costs by $20,842 [15, 16].

Implant-related complications (IRC) and radiographic-identified complications (RIC) have been reported to be the most common reason for reoperation in adult spinal deformity surgery [6•, 25•]. Twenty-four percent (71/291) of patients required reoperation in a recent prospective study, primarily due to RIC and/or IRC [6•]. Soroceanu et al. [25•] reported that 32 % (78 of 246) of adult spinal deformity patients with more than 20 degrees of scoliosis developed an IRC or RIC, of which 53 % required reoperation. Rod breakage and proximal junctional kyphosis (PJK) were the major causes. Greater preoperative pelvic tilt (PT), mismatch between pelvic incidence and lumbar lordosis (PI-LL), and greater sagittal malalignment were found to lead to a higher incidence of these complications [25•]. In two ISSG prospective studies the reported incidences of rod fracture were 9.0 % (18/200) and 13.7 % (40/291). In patients who underwent a pedicle subtraction osteotomy (PSO), the rate was 22 % [26]. Significant risk factors included older age, greater BMI, history of previous spine surgery, PSO, greater baseline sagittal spinopelvic malalignment (SVA, PT, and PI-LL mismatch), and greater magnitude of sagittal spinopelvic malalignment correction with surgery (SVA and PI-LL mismatch) [26].

Recognition of the importance of spinal and pelvic alignment parameters in patient outcomes as well as instrumentation failure has led to the development of optimal thresholds for radiographic alignment parameters. This provides tools patient evaluation and defines operative goals to help maximize patient outcomes [27–32]. Restoration of sagittal alignment utilizing advanced lumbosacral fixation can significantly improve patient outcomes and help to reduce revision surgical rates [31]. Multiple-rod constructs across 3-column osteotomy sites reduce rates of implant failure and pseudoarthrosis [33]. PJK and pseudarthrosis may be reduced in many cases by fusing to the sacrum, ensuring that the patient has adequate bone density preoperatively, and by choosing the appropriate correction techniques to achieve an ideal spinal pelvic alignment. A more comprehensive discussion of these topics can be found elsewhere in this issue (Tables 3 and 4).

Table 3 Radiographical and implant-related complications from 246 patients [25•]

Complication	*N*	%
Implant-related		
Rod breakage	16	47
Prominence	5	14.70
Painful implant	4	11.70
Screw breakage	3	8.80
Screw loosening	2	5.90
Screw malposition	2	5.90
Implant dislodgement	2	5.90
Total	34	13.82
Radiographical		
Proximal junctional kyphosis	24	54.50
Pseudarthrosis	5	11.40
Adjacent segment disease	5	11.40
Distal junctional kyphosis	5	11.40
Sagittal malalignment	3	6.80
Implant fracture	2	4.60
Flatback	1	2.30
Total	45	18.29
Total (radiographical + implant-related)	79	31.7

Adapted with permission from Soroceanu et al. [25•]

Table 4 Rates of implant and radiographic complications in 291 adults surgically treated for spinal deformity with minimum 2-year follow-up [6•]

Complication	Minor	Major	Required re-op
All Implant *n* (%)	14 (4.8)	67 (23)	32 (11)
Rod breakage	0	40 (13.7)	15 (5.2)
Implant prominence	6 (2.1)	5 (1.7)	4 (1.4)
Painful implant	2 (0.7)	5 (1.7)	5 (1.7)
Screw breakage		6 (2.1)	1 (0.3)
Screw loosening	4 (1.4)	2 (0.7)	1 (0.3)
Interbody spacer dislodgement		3 (1)	1 (0.3)
Screw medial breach	1 (0.3)	1 (0.3)	1 (0.3)
Implant failure		1 (0.3)	1 (0.3)
Rod dislodgment		1 (0.3)	1 (0.3)
Screw dislodgement		1 (0.3)	1 (0.3)
Crosslink dislodgement	1 (0.3)		
Fixation failure		1 (0.3)	1 (0.3)
Hook dislodgement		1 (0.3)	
All Radiographic *n* (%)	29 (10)	52 (17.9)	39 (13.4)
Proximal junctional kyphosis	18 (6.2)	21 (7.2)	18 (6.2)
Pseudarthrosis		15 (5.2)	10 (3.4)
Adjacent segment disease	6 (2.1)	4 (1.4)	2 (0.7)
Coronal imbalance	4 (1.4)	4 (1.4)	4 (1.4)
Sagittal imbalance	1 (0.3)	4 (1.4)	3 (1)
Distal junctional kyphosis		4 (1.4)	2 (0.7)

Adapted with permission from Smith et al. [6•], published online February 26, 2016; DOI: 10.3171/2015.11.SPINE151036

Table 5 Association between complications and change in patient-centered outcome scores [3, 34]

Results

Author (year)	Study design	Population	Diagnosis	HRQoL measure	Complication group	Change in score	P^a
Glassman (2007)	Case control	$N = 138$, 17 % male, mean age: 57 years, prospectively accrued registry	Surgical treatment for adult spinal deformity	SF-12 general health	Major	−2.10	0.02
					Minor	4.19	
					None	1.46	
				SRS total	Major	3.53	0.99
					Minor	3.41	
					None	3.48	
				ODI	Major	14.29	0.57
					Minor	17.81	
					None	15.25	
				NRS back pain	Major	3.14	0.65
					Minor	3.69	
					None	3.64	
				NRS leg pain	Major	2.32	0.90
					Minor	2.08	
					None	1.97	

Table reproduced with permission from Dekutoski et al. [34]

[a] Based on ANOVA for rate change in mean scores comparing complication groups

HRQoL health-related quality of life

Overall impact of complications

Quantifying the impact of complications on patient-reported outcomes versus the impact of adult deformity correction is very difficult. Patients with disabling pain often are willing to accept the risks of complications in hopes of a better quality of life. Until recently, few data was available to assess what effect complications had on the patient's quality of life in the long term. Implementation of outcome and cost measures has started to explore these problems and some have even yielded unexpected results.

In 2007, Glassman presented evidence that complications do not necessarily impact clinical outcomes at one year post-operative [3]. Using a case–control study of prospectively accrued adult spinal deformity corrections, patients were grouped according to whether they had major, minor, or no complications and clinical outcomes assessed 1-year postop by the SF-12, ODI, and the numerical rating scales for leg and back pain. Regardless of the complication severity, all groups had similar improvements in the SRS, ODI, and the numerical pain rating scales. The only statistically significant difference detected was in the SF-12 general health subscale. In this

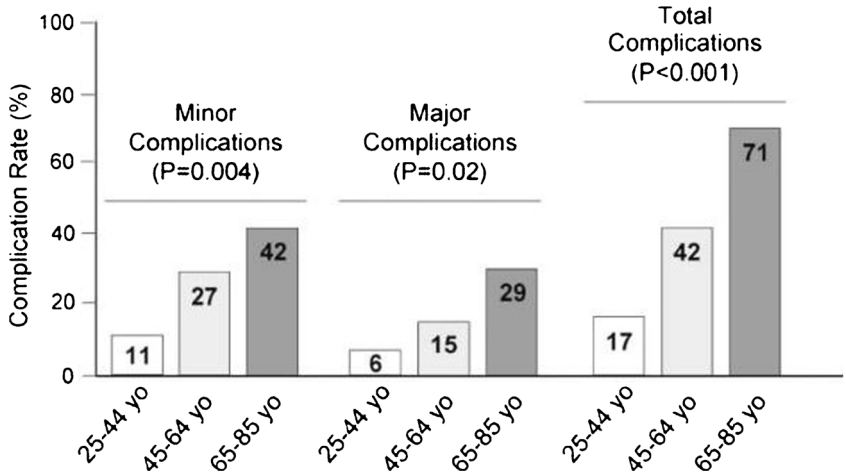

Fig. 1 Complication rates associated with adult spinal deformity surgery with patients stratified by age from the Spinal Deformity Study Group multi-institutional database [35]. Figure reproduced with permission from Smith et al. [35]

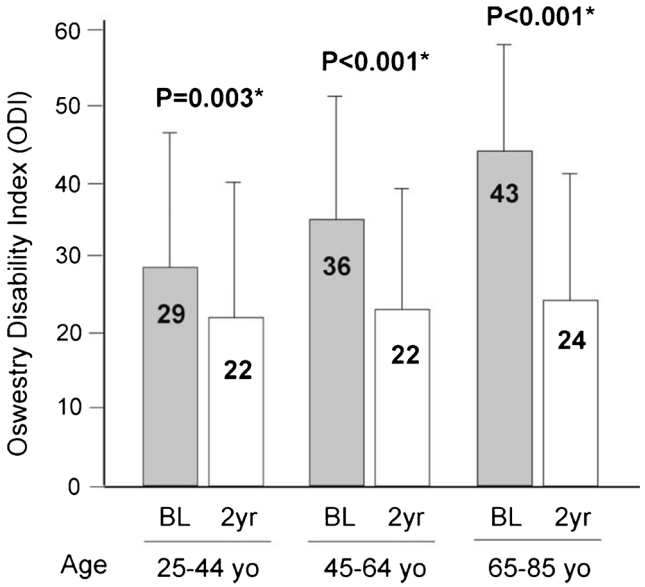

Fig. 2 "Relationship of patient age to improvement of disability in adults with spinal deformity following surgical treatment. Bars indicate standard deviations. *P values are from paired t tests" [35]. Figure reproduced with permission from Smith et al. [35]

subscale, patients with no complications improved by 1.5 points and patients with minor complications improved by 4.2 points; however, patients with major complications deteriorated by 2.1 points (Table 5).

Using the Spinal Deformity Study Group (SDSG) multi-institutional database, Smith et al. demonstrated that despite a complication rate of 71 % in the elderly, these patients experienced a significantly greater benefit from spinal deformity surgery than the younger patients that had a significantly lower complication rate of 17 % [35]. Consistent with these findings, Scheer et al. reported that despite elderly patients experiencing significantly more complications (74 vs 56 %) and revisions (24 vs 16.8 %) compared to the young, elderly patients actually had a shorter and improved recovery period as measured by normalized HRQOL scores. This seemingly counterintuitive result originates from the higher baseline disability of the elderly, meaning that greater magnitude of surgery and greater occurrence of complications may have had less impact on their function and perception of disability (Figs. 1 and 2).

Every year in the USA, nearly $100 billion is spent related to spine care, with spinal fusions accounting for approximately $13 billion of this cost [36]. In an era of increased attention to cost containment, no discussion of complications would be complete without exploring how complications influence the cost-effectiveness of the surgical correction of adult spinal deformity. In a single-center retrospective analysis of 448 consecutive adult spinal deformity surgeries from 2005 to 2011, McCarthy et al. found an average cost of $103,143 [37]. One hundred thirty (27 %) patients ultimately required readmission averaging an additional $67,262 of cost, representing a 70 % cost increase. Patients 60 years of age or more incurred, on average, nearly $40,000 (40 %) more in cost than patients <45 years of age. In a projected cost-effectiveness analysis of adult spinal deformity surgery based on 541 patients, Terran et al. found that with an estimated 24.3 % of patients requiring reoperation, the average cost per QALY at 5-year follow-up was $120,311 [38]. Forty percent of patients ultimately had <$100,000 cost per QALY gained. Patients with higher baseline ODI and lower baseline SRS scores were significantly more cost-effective [38]. In a retrospective analysis to quantitate the incremental cost-effectiveness ratio (ICER) of adult spinal deformity surgery in 120 patients over 10 years, 19 % of patients required readmission resulting in a 63 % higher average hospital cost ($183,000 compared to $112,000) [39]. Ultimately Mcarthy et al. estimated an overall ICER of $80,387 per QALY at 10-year follow-up suggesting that surgery for adult spinal deformity is cost-effective. However, it is clear that complications can substantially increase cost and easily shift the balance to unfavorable cost per QALY.

Conclusion

Although more likely to experience complications, the older and more disabled patients may actually stand to gain the most from surgical intervention. Expanded use of standardized outcome assessments with rigorous reporting standards will help further clarify how preoperative variables impact the incidence and management of surgical complications. Ultimately, by using multidimensional and longitudinal assessment methods, the clinical significance of these complications and preoperative variables can lead to management strategies that minimize cost while maximizing surgical outcomes.

Compliance with ethical standards

Conflict of interest Peter A. Christiansen, Michael LaBagnara, and Durga R Sure declare that they have no conflict of interest.

Christopher I Shaffrey reports personal fees from Medtronic, personal fees from Nuvasive, personal fees from Zimmer-Biomet, personal fees from K2M, personal fees from Stryker, grants from NIH, grants from Department of Defense, grants from NACTN, grants from ISSG, grants from AO, grants from NREF, outside the submitted work. In addition, Dr. Shaffrey has a patent Medtronic with royalties paid, a patent Nuvasive with royalties paid, and a patent Zimmer-Biomet with royalties paid.

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Human and animal rights and informed consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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