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CASE SERIES

Thoracolumbar fusions for adult lumbar deformity show superior QALY gain and lower costs compared with upper thoracic fusions

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Abstract

Purpose Adult spinal deformity (ASD) patients with sagittal plane deformity (N) or structural lumbar/thoraco-lumbar (TL) curves can be treated with fusions stopping at the TL junction or extending to the upper thoracic (UT) spine. This study evaluates the impact on cost/cumulative quality-adjusted life year (QALY) in patients treated with TL vs UT fusion.

Methods ASD patients with > 4-level fusion and 2-year follow-up were included. Index and total episode-of-care costs were estimated using average itemized direct costs obtained from hospital records. Cumulative QALY gained were calculated from preoperative to 2-year postoperative change in Short Form Six-Dimension (SF-6D) scores. The TL and UT groups comprised patients with upper instrumented vertebrae (UIV) at T9-T12 and T2-T5, respectively.

Results Of 566 patients with type N or L curves, mean age was 63.2 ± 12.1 years, 72% were female and 93% Caucasians. Patients in the TL group had better sagittal vertical axis (7.3 ± 6.9 vs. 9.2 ± 8.1 cm, $p = 0.01$), lower surgical invasiveness (− 30; $p < 0.001$), and shorter OR time (− 35 min; $p = 0.01$). Index and total costs were 20% lower in the TL than in the UT group ($p < 0.001$). Cost/QALY was 65% lower (492,174.6 vs. 963,391.4), and 2-year QALY gain was 40% higher, in the TL than UT group (0.15 vs. 0.10; $p = 0.02$). Multivariate model showed TL fusions had lower total cost (p = 0.001) and higher QALY gain ($p = 0.03$) than UT fusions.

Conclusion In Schwab type N or L curves, TL fusions showed lower 2-year cost and improved QALY gain without increased reoperation rates or length of stay than UT fusions.

Level of evidence III.

Keywords Adult spinal deformity · Thoracolumbar fusion · Upper thoracic fusion · Quality-adjusted life year · Cost

Introduction

The Schwab classification system has been used to characterize adult spinal deformity (ASD) based on curve type and sagittal modifiers [1, 2]. Patients with primary sagittal plane deformity (type N) or with structural lumbar or thoracolumbar (TL) curves can be treated with fusion to the TL junction or fusion that extends to the upper thoracic (UT) spine. Although more proximal fusion extension to the UT spine allows for additional fixation points and is associated with lower proximal junctional failure rates [3–6], fusion to the TL junction has shorter operative time and estimated blood loss [5, 7–10], decreased risk of infection [11–13], and fewer functional limitations [14–16]. Additionally, the increased number of fused segments in UT fusions results in higher total implant costs [17].

In their comparative analysis, O'Shaughnessy et al. [3] found increased perioperative complications, pseudoarthrosis rate, and incidence of revision surgery in patients fused to the UT compared to the lower thoracic spine. Other comparative studies found no significant difference with regard to clinical outcomes or revision rates when comparing patients with upper instrument vertebrae (UIV) in the upper or lower thoracic spine [8, 10, 18]. Mechanisms for proximal junctional kyphosis and failure, however, were found to vary by fusion level. Proximal junctional kyphosis and failure

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Extended author information available on the last page of the article in the proximal thoracic spine are attributed to subluxation and soft tissue failure, with compression fractures the most likely cause in the distal thoracic and TL spine [18, 19]. Despite these findings, choosing the ideal UIV in ASD surgery remains controversial.

Although numerous studies have examined total costs and cost-utility ratios associated with primary and revision ASD surgery [20–24], to our knowledge, an analysis comparing these economic metrics in ASD patients undergoing TL or UT fusions has not been reported. The purpose of this study was therefore to compare the impact on direct costs and quality-adjusted life-year (QALY) gains in ASD patients treated with TL or UT fusions.

Methods

Data from a prospective, multicenter registry of ASD patients who were treated surgically from February 2009 to February 2020 at one of 23 participating institutions in the United States were analyzed. Institutional review board approval was obtained at each institution.

Inclusion criteria were > 18 years of age; > 4-level posterior fusion; minimum of 2-year complete follow-up data; and diagnosis of ASD, defined as having a scoliosis curve ≥ 20°, sagittal vertical axis (SVA) ≥ 5 cm, pelvic tilt ≥ 25°, and/or thoracic kyphosis ≥ 60°. Patients with incomplete data; those whose deformity was caused by infection, malignancy, trauma, or neuromuscular disease; and patients with UIV at T6–T8 were excluded.

Study population

We identified 1,299 ASD patients with five or more levels fused, with 826 patients (64%) having complete 2-year follow-up data. Of these, 566 (69%) had type N or L curves and were included for analysis. Patients were then assigned to the upper thoracic (UT) or thoracolumbar (TL) group based on whether the UIV were at T2–T5 or T9–T12, respectively. All patients qualified for either an UT or TL UIV, with the choice of UIV ultimately depending on the surgeon and variations in historical preferences among institutions.

Demographic information included age, sex, race, body mass index, and Charlson Comorbidity Index. Operative surgical characteristics included number of levels fused, bone morphogenetic protein-2 (BMP) use, ASD frailty index score [25], ASD surgical invasiveness index [26], reoperation rate, performance of 3-column osteotomy, estimated blood loss, and hospital length of stay. Preoperative and 2-year Oswestry Disability Index (ODI) scores were recorded (Table 1). ASD-related radiographic measurements were also recorded using 36-inch radiographs obtained preoperatively and at final follow-up (Table 2).

Index and total direct inpatient episode-of-care costs

Index and total direct inpatient episode-of-care (EOC) costs were mapped using average itemized direct costs obtained from administrative hospital records for all events in the inpatient EOC from participating institutions. All costs were then adjusted to account for inflation to reflect 2022-dollar estimates.

Itemized costs were averaged to obtain mean values for the following cost variables associated with index direct inpatient EOC: operating room (OR) (OR cost per unit time), hospital stay and surgical intensive care unit (SICU) stay (cost per unit time), pharmacy, radiology, inpatient therapy (physical, occupational, speech), phlebotomy services (packed red blood cells (PRBCs), fresh frozen plasma (FFP), blood type) and laboratory services. Implant costs were calculated by multiplying the number of units implanted by their associated mean cost (screws, hooks, wires, rods, cement, and interbody devices). BMP costs were calculated by multiplying the number of INFUSE kits (Medtronic Sofamor Danek, Memphis, TN) used by the mean cost of the type of kit(s) used (small 4.2 mg, medium 8.4 mg, large 12.0 mg). Revision costs were calculated using the same cost variables and were summed with index costs to reflect total inpatient EOC direct costs.

For institutions that did not have available total direct inpatient EOC costs, totals were calculated by summing all individual cost variable estimates based on resource utilization using the methods above (Fig. 1). This methodology has been previously utilized to account for institutions without total direct inpatient EOC costs [27].

Internal validation was performed by comparing estimated with reported total direct inpatient EOC costs in institutions that did not provide individual itemized costs and reported only total direct inpatient EOC costs.

Health-related quality-of-life assessment

Health-related quality-of-life (HRQoL) questionnaires were completed at baseline, 1-year, and 2-year follow-up visits. Patient responses to each of the 36-Item Short Form Health Survey (SF-36; RAND Corp., Santa Monica, CA: 1992) dimensions at each time point were weighted to calculate Short Form Six-Dimension (SF-6D) health utility scores [28]. Discounted incremental health utility changes between baseline and 2-year follow-up SF-6D scores were summed to calculate cumulative QALYs gained. Cost per QALY was calculated using direct costs to provide a microcosting perspective that allows for more granular cost analysis. While Medicare allowable rates,

Table 1 Demographic and surgical characteristics of patients undergoing surgery for Schwab type N/L adult spinal deformity curves

Characteristics	Thoracolumbar group ($n=397$)		Upper thoracic group ($n=169$)		p value
	n (%)	Mean ± SD	n (%)	Mean ± SD	
Demographic					
Age, years	–	64.20 ± 10.82	–	60.39 ± 14.55	**0.002**
Female sex	279 (70.3)	–	130 (76.9)	–	0.10
Caucasian race	365 (91.9)	–	161 (95.3)	–	0.42
Body mass index, kg/m^2	–	28.88 ± 5.69	–	28.69 ± 6.25	0.72
Frailty index score	–	3.65 ± 1.41	–	3.77 ± 1.50	0.37
CCI	–	2.02 ± 1.66	–	2.18 ± 1.94	0.35
Surgical					
Number of levels fused	–	9.20 ± 1.52	–	15.34 ± 2.22	**< 0.001**
BMP use	290 (73.0)	–	136 (80.5)	–	0.06
Surgical invasiveness index	–	84.85 ± 29.76	–	114.3 ± 35.09	**< 0.001**
Reoperation rate	129 (32.5)	–	52 (30.8)	–	0.69
Estimated blood loss, cc	–	1,537.19 ± 1,606.42	–	1,633.35 ± 1,472.09	0.34
Estimated blood volume, %	–	28.36 ± 1.57	–	34.74 ± 2.62	**0.04**
Hospital stay, days	–	8.13 ± 5.80	–	9.02 ± 5.07	0.07
Operating room time, min	–	368.27 ± 120.59	–	402.98 ± 142.12	**0.006**
Patient Reported Outcomes					
Preop ODI	–	47.18 ± 14.77	–	48.77 ± 17.73	0.31
2-Year ODI	–	29.86 ± 19.90	–	31.18 ± 21.00	0.48

Significant values shown in bold

3-CO 3-column osteotomy, *BMP* bone morphogenetic protein-2, *CCI* Charlson Comorbidity index, *ODI* Oswestry Disability Index, *SD* standard deviation, *SF-6D* short-form six-dimension

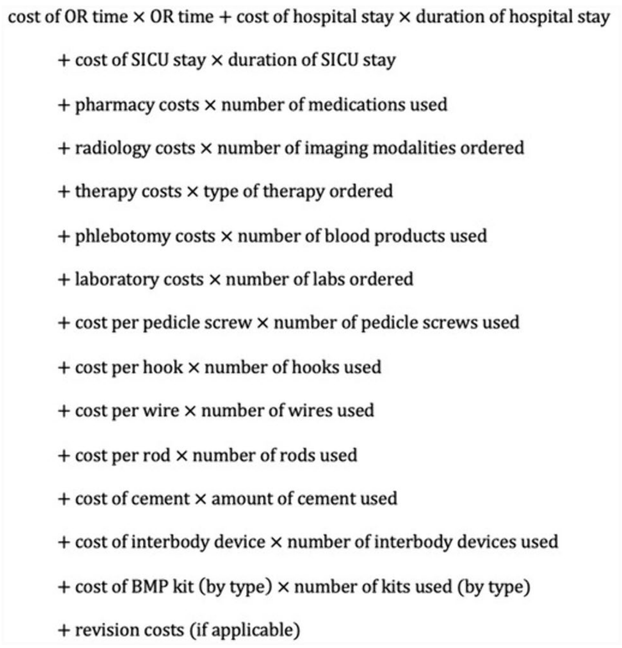
Table 2 Baseline radiologic measures of patients undergoing surgery for Schwab type N/L adult spinal deformity curves

Measure	Preoperative		
	Thoracolumbar group	Upper thoracic group	p value
Sacral slope, °	30.63 ± 11.31	28.15 ± 12.45	**0.02**
Pelvic tilt, °	25.30 ± 9.57	26.15 ± 12.66	0.43
Pelvic incidence, °	55.93 ± 12.24	54.30 ± 14.19	0.19
PI – LL, °	20.93 ± 18.36	17.33 ± 26.93	0.11
L1-S1 lordosis, °	35.00 ± 19.65	36.97 ± 24.58	0.36
C7-S1 SVA, cm	7.34 ± 6.94	9.22 ± 8.10	**0.01**

Significant values shown in bold

LL lumbar lordosis, *SVA* sagittal vertical axis

as calculated using Medicare Severity Diagnosis Related Groups (MS-DRGs), are traditionally used to provide a broader, societal perspective on cost estimation, Gum et al. [29] found that Medicare allowable rates underestimate the cost of ASD surgery by 17%. Utilizing direct costs, rather than MS-DRGs, in ASD cost-effectiveness analyses more appropriately accounts for the wide variability in costs incurred from differences in technique, instrumentation, and biologics at the hospital level [27, 29–33].



cost of OR time × OR time + cost of hospital stay × duration of hospital stay
+ cost of SICU stay × duration of SICU stay
+ pharmacy costs × number of medications used
+ radiology costs × number of imaging modalities ordered
+ therapy costs × type of therapy ordered
+ phlebotomy costs × number of blood products used
+ laboratory costs × number of labs ordered
+ cost per pedicle screw × number of pedicle screws used
+ cost per hook × number of hooks used
+ cost per wire × number of wires used
+ cost per rod × number of rods used
+ cost of cement × amount of cement used
+ cost of interbody device × number of interbody devices used
+ cost of BMP kit (by type) × number of kits used (by type)
+ revision costs (if applicable)

Fig. 1 Resource utilization model using individual estimates of costs

Statistical analysis

Fischer's *F* test was used to assess for equality of variances between the two cohorts. Pooled two-sample and Satterthwaite *t* tests were performed to compare patient-reported outcomes and preoperative, surgical, and radiographic characteristics between the two groups. Categorical variables were compared using chi-squared tests. Multivariate generalized linear models were used to estimate predicted costs and QALY gains between the UT and TL groups adjusted for patient, surgical, and sagittal deformity parameters. All statistical analysis was conducted using SAS software, version 9.4 (SAS Institute Inc., Cary, NC). Statistical significance was set at $p < 0.05$.

Results

Patient characteristics

For 566 patients with Schwab type N or L curves, the mean age was 63.2 ± 12.1 years, with 72% being female and 93% Caucasian. The UIV were at T2–T5 for 29.9% of patients. Patients in the TL group were significantly older (64.20 ± 10.82) than those in the UT group (60.39 ± 14.55) ($p = 0.002$). Index and 2-year SF-6D scores of 0.563 and 0.665, respectively, were used to calculate cumulative QALYs gained for each cohort. At baseline, the groups did not differ significantly with regard to age, sex, body mass index, mean ASD frailty index score, and Charlson Comorbidity Index (Table 1).

Surgical and radiographic characteristics

The groups did not differ significantly with regard to mean number of levels fused, BMP use, reoperation rate, estimated blood loss, or length of hospital stay (Table 1). Patients in the TL group had lower ASD surgical invasiveness index scores (84.85 vs. 114.3; $p < 0.001$), lower estimated blood loss as a percentage of estimated blood volume (28.36 vs. 34.74; $p = 0.04$), and shorter OR times (368.3 vs. 403.0; $p = 0.01$) than the UT group (Table 1).

At baseline, there was no significant difference in standard deformity-related radiographic measurements between the groups. Patients in the TL group had less thoracic kyphosis (34° vs. 48°; $p < 0.001$) and improved SVA (7.34 ± 6.94 cm vs. 9.22 ± 8.10 cm; $p = 0.01$) compared to patients in the UT group (Table 2).

Direct EOC costs

The index EOC cost was significantly lower for the TL group ($58,422.90 ± 17,941.40) than for the UT group ($73,112.00 ± 21,973.90) ($p < 0.001$). The total direct inpatient EOC costs were also significantly lower in the TL group ($64,391.80 ± 21,242.30) than in the UT group ($80,377.60 ± 26,914.20) ($p < 0.001$) (Table 3). Multivariate models showed that TL fusions were significantly associated with lower total direct inpatient EOC costs ($p = 0.001$) after adjusting for patient demographics, deformity type, and surgical characteristics (Table 3).

HRQoL changes

There was no significant difference in baseline or 2-year ODI scores between the two groups (Table 1). Cost per QALY was 65% lower ($492,174.60 vs. $963,391.40) and mean 2-year QALY gain was 40% higher (0.15 vs. 0.10; $p = 0.02$) in the TL group compared to the UT group (Fig. 2). Multivariate models showed that TL fusions were significantly associated with higher mean cumulative QALYs gained (0.140 vs. 0.083; $p = 0.033$) than with UT fusions after adjusting for patient demographics, deformity type, and surgical characteristics (Table 3).

Table 3 Episode-of-care costs and quality-adjusted life years of patients undergoing surgery for Schwab type N/L adult spinal deformity curves

Variable	Thoracolumbar group Mean ± standard deviation	Upper thoracic group Mean ± standard deviation	*p* value
Cost, USD			
Index EOC	$58,422.90 ± 17,941.40	$73,112.00 ± 21,973.90	**< 0.001**
Revision EOC	$24,943.60 ± 13,012.80	$30,697.20 ± 22,241.10	0.13
Total EOC	$64,391.80 ± 21,242.30	$80,377.60 ± 26,914.20	**< 0.001**
QALY			
Cost per QALY, USD	$492,174.60	$963,391.40	> 0.05
2-year QALY gain	0.15 ± 0.21	0.10 ± 0.21	**0.02**
Cumulative QALY gain	0.140	0.083	**0.03**

Significant values shown in bold

EOC episode-of-care, *QALY* quality-adjusted life year, *USD* United States dollar

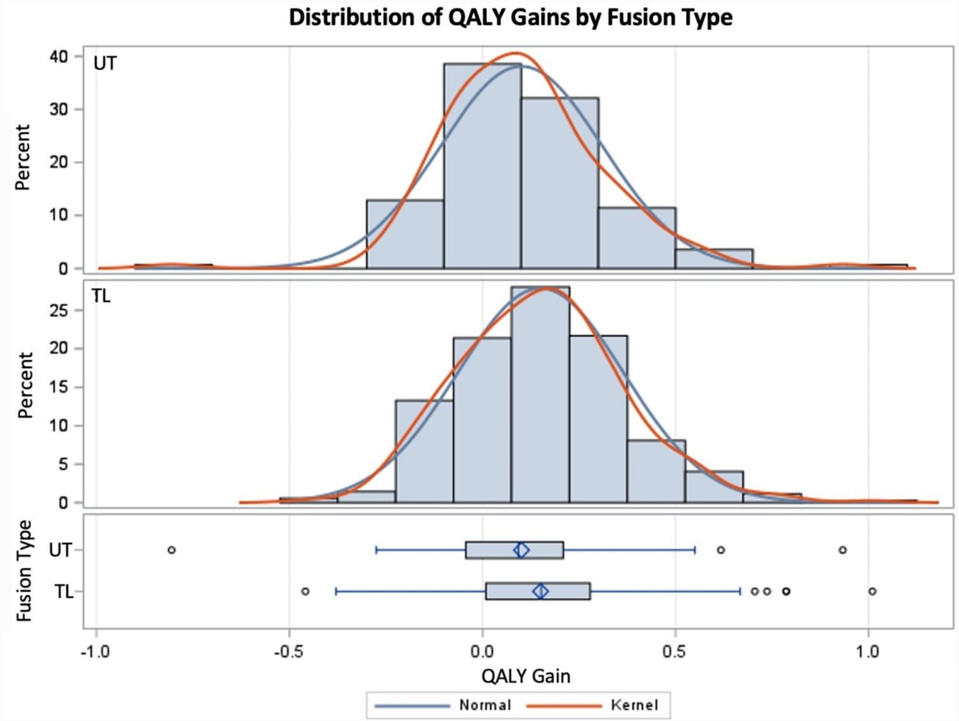


Fig. 2 Comparison of mean 2-year cumulative quality-adjusted life year gains between patients undergoing surgery for Schwab type N/L adult spinal deformity curves

Discussion

Our analysis revealed that TL fusions demonstrated lower index and total costs, higher 2-year QALY gains, and improved cost per QALY when compared to UT fusions in ASD patients with Schwab type N or L curves. There was also no significant increase in reoperation rates or length of hospital stay among patients undergoing TL fusions compared to UT fusions. Proximal junctional failure (27.9%) and pseudoarthrosis (34.6%) were the primary reasons for revision surgery in the TL and UT groups, respectively. To our knowledge, this is the first study to compare total direct costs and QALY gains in patients undergoing TL or UT fusions for ASD.

Although numerous studies have examined the impact of fusion level on complication rates and patient outcomes in ASD surgery [3, 18, 34], there is no standardized protocol with regard to optimal UIV level in treating sagittal deformities. The present study found no significant difference in reoperation rates (32.5% vs. 30.8%; $p = 0.687$) or hospital length of stay (8.13 vs. 9.02; $p = 0.067$) when comparing TL and UT fusions. Kim et al. [10] and O'Shaughnessy et al. [3] similarly concluded that there was no significant difference in complication rates between the two groups, despite a higher prevalence of complications in the UT group. Although Kim et al. [10] found a significantly longer length of hospital stay in their UT group, this was likely due to the greater number of complications observed in their cohort.

The present study also revealed significantly lower 2-year EOC costs in TL fusions than in UT fusions. While increased costs are associated with complication rates and revision surgeries, our study found no significant difference in these cost drivers between fusion types. The higher 2-year EOC costs observed in UT fusions are attributable to the greater number of fused vertebral levels and pedicle screws implanted, both independent predictors of increased cost [21, 24]. With reported totals of spinal deformity surgery reaching as high as $103,143 [21], surgeons should consider UIV levels when performing ASD surgery to mitigate resource utilization and potential costs with no increased risk of complications.

Consistent with prior studies [22, 23, 35], patients who underwent surgery for ASD demonstrated positive QALY gains at 2-year follow-up. While previous studies examined QALY gains between operative versus nonoperative and primary versus revision surgery for ASD, our study compared TL versus UT fusions and found significantly higher 2-year QALY gains and superior cost per QALY in patients undergoing TL fusions. This finding corroborates efforts to minimize fusion levels when performing ASD surgery [10, 20, 36]. Although fusions extended to the UT spine are associated with lower rates of proximal junctional failure, they do not eliminate the risk of clinically significant proximal junctional kyphosis [19]. While substantial improvements in overall complication rates and patient-reported outcomes have contributed substantially to the cost-effectiveness and value of ASD surgery over the last decade [37], refinement and advancement of preoperative and decision-making tools will continue to optimize and improve cost per QALY [38–41]. Our results suggest that standardizing TL fusions in operative practice for ASD patients with Schwab type N or L curves can curb index and total EOC costs, while enhancing QALY gains and cost per QALY, without negatively affecting reoperation and complication rates.

The findings in this study should be interpreted in the context of its limitations. First, not all participating institutions provided true direct costs; therefore, a resource consumption accounting model was used to estimate institutional costs. Additionally, this analysis considered only direct hospital costs associated with index and revision surgeries. All non-hospital expenses, such as outpatient rehabilitation and treatment, were excluded from total cost calculations. Although this study analyzed prospectively gathered data at multiple participating centers, each institution did not gather an equal proportion of patients or enroll patients across the same study period, limiting the generalizability and applicability of outcomes found in this study to the entire ASD population. While the TL and UT cohorts were standardized with respect to sagittal plane deformity type, other factors, such as coronal modifiers or BMP dosage, may impact the cost-effectiveness of longer fusions and nonunion or revision rates among certain subsets of patients. Additionally, patients lost to follow-up may impact the true rate of proximal junctional failure or pseudoarthrosis in the treatment arm. Finally, subanalyses of individual institutions or surgeons were not performed to investigate the potential effects of patient selection and expertise bias in determining patient selection for TL or UT fusion. Although the surgeon and variations in historic preferences among institutions influence the choice for UIV level in long-segment fusions, the presence of greater sagittal deformity, as measured by SVA, may influence surgeons to fuse to the UT spine out of concern for proximal junctional kyphosis and maintenance of SVA correction.

Conclusion

In ASD patients with Schwab type N or L curves, TL fusions demonstrated lower index and total EOC costs compared to UT fusions. TL fusions were also associated with higher 2-year QALY gains and lower cost per QALY without increasing reoperation risk or complication rates. While the results of this study highlight the potential advantages of TL fusions in ASD patients with Schwab type N or L curves, the decision to perform an upper or lower UIV is ultimately multifactorial. For certain deformities and patients, a lower thoracic UIV may not be an appropriate option, whereas for others, the decision for an upper or lower thoracic spine UIV is more equivocal.

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Data availability The data used in this study is not publicly available, however, institution-specific data may be available upon request from the different institutions involved in this study.

Declarations

Conflict of interest Andrew H. Kim, BS: None. Richard Hostin, MD: None. Samrat Yeramaneni, MBBS, PhD: None. Jeffrey L. Gum, MD: Consultant: Acuity, Depuy, Medtronic, NuVasive, Stryker, FYR Medical, Expanding Innovations; Royalties: Acuity, Medtronic, NuVasive; Honorarium: Broadwater, NASS; Advisory Board: Medtronic, National Spine Health Foundation, FYR Medical; Journal Reviewer: The Spine Journal, Spine Deformity, Global Spine Journal; Research Support: Alan L. & Jacqueline B. Stuart Spine Center, Biom'Up, Cerapedics, Inc., Empirical Spine, Inc. Medtronic, National Spine Health Foundation, Scoliosis Research Society, Stryker, The International Spine Study Group; Speaking: KyANA; Stock: Cingulate Therapeutics, FYR Medical; Shared Patents: Medtronic; Grants: Fischer Owen Fund – Travel Funds. Pratibha Nayak, PhD: None. Breton G. Line, BSME: None. Shay Bess, MD: Research support for this study includes Nuvasive, k2m Stryker, DePuySynthes, and International Spine Study Group Foundation. Peter G. Passias, MD: Medtronic advisory board, Globus design team, Cerapedics advisory board.D. Kojo Hamilton, MD: None. Munish Gupta, MD: Consulting: DePuy (Medical Device Services Inc.); Medtronic; Globus; SMAIO; Alphatec, began and ended 2019; Royalties: DePuy (ended 2021), Innomed, Globus (to begin 2024); Travel: DePuy (Medical Device Services Inc.); Medtronic; Alphatec, 2019; Medicrea, 2019; Mizuho, 2019; SRS; AO Spine; Globus; Zimmer, 2022; SMAIO, 2023; Broadwater; Stock/Stock options: J&J; P&G (sold 2020); SMAIO; Boards of Directors: Scoliosis Research Society, Twentieth Century Orthopedic Association; Grants: AO Spine; OMeGA paid to the institution for fellowship; Advisory: DePuy; Honorarium: AO Spine, 2020; LSU Grand Rounds, 2020, Wright State, 2021; Malaysia Spine Society, 2021; SMAIO, 2024; Voluntary: National Health Spine Foundation Scientific Advisory. Justin S. Smith, MD, PhD: Consulting: Medtronic, SeaSpine, ZimVie, Cerapedics, Carlsmed, DePuy Synthes; Royalties: ZimVie, Thieme, NuVasive; Research grant support: DePuy Synthes/ISSG, AOSpine; Fellowship grant support: SeaSpine, NREF, AOSpine. Renaud Lafage, MS: Consultant for Carlsmed. Bassel Diebo, MD: Consultant for Clariance, SpineVision, Spineart. Virginie Lafage, PhD: Consultant: Globus Medical, Alphatec Spine; Stock/Shareholder (self-managed); Speaker's Bureau; DePuy Synthes, Stryker Spine; Advisory Board, ISSG; Other Financial or Material Support (royalties, patents, etc.): NuVasive. Eric O. Klineberg, MD: Consultant for DePuy Synthes, Stryker Spine, Medtronic, Relatable, SeaSpine, SI Bone, and Agnovos; receives royalties from Stryker Spine; is a speaker for AONA Spine; has stock ownership in MMI; is Chair - Board of Directors for IMAST and AONA Spine; is on the Board of Directors of SRS; has Endowments from UTHealth Houston (paid to institution), Fellowship support grant (paid to previous institution) from AONA Spine; and Fellowship support (paid to previous institution) from Medtronic. Alan Daniels, MD: Grants/Research Support: Orthofix, Spineart; Consultant: Orthofix, Medtronic, Stryker Spine, Spineart; Other Financial or Material Support (royalties, patents, etc.): Stryker Spine. Themistocles S. Protopsaltis, MD: Grants/Research Support: Medtronic, 3Spine; Consultant: Globus Medical, NuVasive, Stryker Spine, Medtronic; Other Financial or Material Support (royalties, patents, etc.): Altus, one point Surgical, Medtronic, 3Spine. Frank J. Schwab, MD: Consultant: Zimmer Biomet, Medtronic; Mainstay Medical; Stock/Shareholder (self-managed): VFT Solutions, Sea Spine; Advisory Board: ISSG; Other Financial or Material Support (royalties, patents, etc.): Stryker Spine, Zimmer Biomet, Medtronic. Christopher I. Shaffrey, MD: Consulting and royalties: NuVasive, SI Bone; consulting: Medtronic, Proprio. Christopher P. Ames, MD: None. Douglas Burton, MD: Grants/Research Support: DePuy Synthes; Consultant: DePuy Synthes, Globus, Blue Ocean; Stock/Shareholder (self-managed): Progenerative Medical; Other Financial or Material Support (royalties, patents, etc.): DePuy Synthes, Globus, Blue Ocean. Khaled M. Kebaish, MD: Consultant: DePuy Synthes. Royalties from Depuy Synthes, Stryker, Orthofix, and SpineCraft. ISSG: Grants/Research Support from DePuy Synthes, Stryker Spine, Medtronic, Globus Medical, NuVasive, SI Bone, Carlsmed, SeaSpine.

Ethical review statement Institutional review board approval was obtained at each institution.

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