

Upper-thoracic versus lower-thoracic upper instrumented vertebra in adult spinal deformity patients undergoing fusion to the pelvis: surgical decision-making and patient outcomes

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OBJECTIVE Optimal patient selection for upper-thoracic (UT) versus lower-thoracic (LT) fusion during adult spinal deformity (ASD) correction is challenging. Radiographic and clinical outcomes following UT versus LT fusion remain incompletely understood. The purposes of this study were: 1) to evaluate demographic, radiographic, and surgical characteristics associated with choice of UT versus LT fusion endpoint; and 2) to evaluate differences in radiographic, clinical, and health-related quality of life (HRQOL) outcomes following UT versus LT fusion for ASD.

METHODS Retrospective review of a prospectively collected multicenter ASD database was performed. Patients with ASD who underwent fusion from the sacrum/ilium to the LT (T9–L1) or UT (T1–6) spine were compared for demographic, radiographic, and surgical characteristics. Outcomes including proximal junctional kyphosis (PJK), reoperation, rod fracture, pseudarthrosis, overall complications, 2-year change in alignment parameters, and 2-year HRQOL metrics (Lumbar Stiffness Disability Index, Scoliosis Research Society-22r questionnaire, Oswestry Disability Index) were compared after controlling for confounding factors via multivariate analysis.

RESULTS Three hundred three patients (169 LT, 134 UT) were evaluated. Independent predictors of UT fusion included greater thoracic kyphosis (odds ratio [OR] 0.97 per degree, $p = 0.0098$), greater coronal Cobb angle (OR 1.06 per degree, $p < 0.0001$), and performance of a 3-column osteotomy (3-CO; OR 2.39, $p = 0.0351$). While associated with longer operative times (ratio 1.13, $p < 0.0001$) and greater estimated blood loss (ratio 1.31, $p = 0.0018$), UT fusions resulted in greater sagittal vertical axis improvement (-59.5 vs -41.0 mm, $p = 0.0035$) and lower PJK rates (OR 0.49, $p = 0.0457$). No significant differences in postoperative HRQOL measures, reoperation, or overall complication rates were detected between groups (all $p > 0.1$).

CONCLUSIONS Greater deformity and need for 3-CO increased the likelihood of UT fusion. Despite longer operative times and greater blood loss, UT fusions resulted in better sagittal correction and lower 2-year PJK rates following surgery for ASD. While continued surveillance is necessary, this information may inform patient counseling and surgical decision-making.

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KEYWORDS adult spinal deformity; scoliosis; upper thoracic; lower thoracic; upper instrumented vertebra; proximal junctional kyphosis; complications; outcomes

ABBREVIATIONS 3-CO = 3-column osteotomy; ASA = American Society of Anesthesiologists; ASD = adult spinal deformity; CCI = Charlson Comorbidity Index; EBL = estimated blood loss; HRQOL = health-related quality of life; ISSG = International Spine Study Group; LL = lumbar lordosis; LSDI = Lumbar Stiffness Disability Index; LT = lower thoracic; ODI = Oswestry Disability Index; OR = odds ratio; PI = pelvic incidence; PJA = proximal junction angle; PJF = proximal junctional failure; PJK = proximal junctional kyphosis; PT = pelvic tilt; SRS-22r = Scoliosis Research Society 22-r questionnaire; SVA = sagittal vertical axis; TK = thoracic kyphosis; UIV = upper instrumented vertebra; UT = upper thoracic.

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SURGERY for adult spinal deformity (ASD) has been shown to improve both radiographic spinal alignment parameters and health-related quality of life (HRQOL) measures in appropriately selected patients,^{2,17,18,20} although it has also been associated with a substantial complication rate.^{3,9,19,21,22} Some complications, such as proximal junctional kyphosis (PJK) and proximal junctional failure (PJF), have been previously associated with choice of upper instrumented vertebra (UIV) level.^{1,5,10,13} However, despite an early understanding of appropriate patient selection metrics as well as expected outcomes following ASD surgery,^{4,15,17,23,24} there is no clear consensus as to which patient demographic, radiographic, and clinical factors should be used to determine whether to fuse to the lower-thoracic (LT) versus upper-thoracic (UT) spine.

There is a need to more objectively determine the factors that are currently being used and those factors that should be used in the future to impact a surgeon's decision for a proximal endpoint. This study is a retrospective review of a prospectively collected multicenter database of patients with ASD designed to evaluate patient demographic, radiographic, and clinical variables associated with a surgeon's decision to fuse to the UT versus LT spine. Additionally, we evaluated patient outcomes in those undergoing fusion to the UT versus LT spine in terms of estimated blood loss (EBL), operative duration, perioperative complications, and 2-year HRQOL metrics.

Methods

Patient Population

A retrospective review of the prospectively collected multicenter International Spine Study Group (ISSG) database was performed. All patient care was provided by surgeons experienced in treating ASD, and IRB approval was obtained at all participating centers prior to data collection. For inclusion in the database, patients needed to meet at least one of the following criteria: age ≥ 18 years old, diagnosis of adult degenerative or idiopathic scoliosis with curvature $\geq 20^\circ$, sagittal vertical axis (SVA) > 5 cm, pelvic tilt (PT) $> 25^\circ$, or thoracic kyphosis (TK) $> 60^\circ$. Patients ≤ 18 years old and those with a diagnosis of scoliosis other than degenerative or idiopathic (e.g., neuromuscular, congenital, paralytic, traumatic) were excluded from the database. The decision regarding whether to fuse to the UT versus LT spine was determined by individual surgeons based on clinical judgment.

Data Collection

Demographic, radiographic, and surgical characteristics, as well as any perioperative or postoperative complications, were collected on all included patients. Demographic variables included age, sex, comorbidities, Charlson Comorbidity Index (CCI), American Society of Anesthesiologists (ASA) score, BMI, and presence of osteoporosis. HRQOL factors included Lumbar Stiffness Disability Index (LSDI), Oswestry Disability Index (ODI), and Scoliosis Research Society 22-r questionnaire (SRS-22r). Surgical characteristics collected included EBL and operative duration. Each radiograph was reviewed by at least

2 readers. The accuracy and reliability of this approach has been previously validated.¹¹ Radiographic measures included baseline and 2-year change in alignment parameters (SVA, pelvic incidence–lumbar lordosis [PI-LL], PT, TK) as well as incidence of PJK, PJF, pseudarthrosis, and rod fracture. PJK was defined as UIV to UIV+2 angle $> 10^\circ$ or change in UIV-UIV+2 angle $> 10^\circ$. PJF was defined by either proximal junction angle (PJA) $\geq 28.0^\circ$ and a change in PJA $\geq 21.6^\circ$ or listhesis (for LT UIV, listhesis and change ≥ 3 mm; for UT UIV, listhesis and change ≥ 8 mm).¹²

Statistical Analysis

UT and LT patients were compared for demographic, radiographic, and surgical characteristics. For bivariate analyses, the Wilcoxon rank-sum test and the chi-square test were used to compare continuous and categorical outcomes, respectively. Multivariate regression analysis was performed to evaluate independent demographic clinical and radiographic predictors of UT versus LT UIV fusion, as well as to compare clinical and radiographic outcomes following UT versus LT fusion. All regression analyses controlled for study site. Statistical significance was set a priori at $p < 0.05$.

Results

A total of 303 patients met the inclusion criteria. The baseline mean values were: SVA 81.1 ± 73.0 mm, PI-LL $20.9^\circ \pm 19.1^\circ$, PT $26.4^\circ \pm 9.8^\circ$, TK $-49.9^\circ \pm 17.6^\circ$, and coronal Cobb angle $40.5^\circ \pm 21.7^\circ$. The mean preoperative SRS score was 2.67 ± 0.6 , ODI was 47.8 ± 16.7 , and LSDI 35.8 ± 16.7 . Mean operative duration was 474 ± 169 minutes and mean EBL was 2237 ± 1703 ml (Table 1). Of 303 patients analyzed, 169 (55.8%) were fused to the LT and 134 (44.2%) to the UT spine. In total, 25.1% of patients underwent 3-column osteotomy (3-CO), 28.7% required reoperation, and 78.2% suffered a complication. The overall incidences of PJK, PJF, pseudarthrosis, and rod fracture were 29.0%, 20.5%, 23.2%, and 18.2%, respectively (Table 2).

Most patients fused to UT levels had a UIV at T3 (15.5% of total patients) or T4 (19.5%), while the majority of patients fused to LT levels had a UIV at T10 (36.6%; Fig. 1).

At 2-year follow-up, mean values were: SVA 31.9 ± 55.1 mm, PI-LL $3.3^\circ \pm 14.9^\circ$, PT $22.6^\circ \pm 9.8^\circ$, TK $-59.4^\circ \pm 16.3^\circ$, and coronal Cobb angle $20.8^\circ \pm 16.1^\circ$. Mean postoperative SRS score was 3.63 ± 0.8 , ODI was 29.0 ± 20.2 , and LSDI was 32.9 ± 19.2 (Table 1).

Bivariable analyses for differences between the UT and LT groups are presented in Supplemental Tables 1 and 2. On multivariate analysis, the following factors were predictive of decision to fuse to the UT spine: performance of 3-CO (odds ratio [OR] 2.39, $p = 0.0351$), greater magnitude of preoperative TK angle (OR 0.97 per degree, $p = 0.0098$), and greater maximum preoperative coronal Cobb angle (OR 1.06 per degree, $p < 0.0001$; Fig. 2); note that TK is expressed in negative degrees, thus this result indicates that a greater absolute magnitude of baseline TK is associated with increased likelihood of decision to fuse to

TABLE 1. Descriptive statistics (continuous)

Variable	Mean	SD
Age	62.7	9.2
BMI	28.1	5.6
CCI	1.9	1.7
Baseline alignment & HRQOL		
SVA (mm)	81.1	73.0
PI-LL (°)	20.9	19.1
PT (°)	26.4	9.8
TK (°)	-49.9	17.6
Max Cobb angle (°)	40.5	21.7
Total SRS score	2.67	0.6
ODI	47.8	16.7
LSDI	35.8	16.7
2-yr alignment & HRQOL		
SVA (mm)	31.9	55.1
PI-LL (°)	3.3	14.9
PT (°)	22.6	9.8
TK (°)	-59.4	16.3
Max Cobb angle (°)	20.8	16.1
Total SRS score	3.63	0.8
ODI	29.0	20.2
LSDI	32.9	19.2
Δ (2-yr - baseline)		
SVA (mm)	-49.2	66.5
PI-LL (°)	-17.6	16.7
PT (°)	-3.8	8.1
TK (°)	-9.5	14.2
Max Cobb angle (°)	-19.7	14.7
Total SRS	0.97	0.7
ODI	-18.8	17.1
LSDI	-2.4	19.9
Op duration (mins)	474	169
EBL (ml)	2237	1703

the UT spine. Nonsignificant positive ORs were also noted for female sex (OR 2.14, $p = 0.0572$) and osteoporosis (OR 2.25, $p = 0.0712$; Fig. 2).

Bivariable analyses for the association of fusion to the UT spine with postoperative outcomes are presented in Supplemental Tables 3 and 4. Fusion to the UT spine was associated with a greater improvement in SVA (-59.5 vs -41.0 mm, $p = 0.0035$), greater operative duration (ratio 1.13, $p < 0.0001$), greater EBL (ratio 1.31, $p = 0.0018$), and lower rates of PJK (OR 0.49, $p = 0.0457$). There was a nonsignificant trend toward lower rates of PJF (OR 0.54, $p = 0.1384$) in patients with fusion to the UT spine. Among UT patients, the unadjusted incidence of PJK was 23.9%, with 17.9% experiencing PJF. In comparison, among LT patients, the PJK rate was 33.1%, with 22.5% experiencing PJF. There were no significant differences in postoperative HRQOL, PI-LL, PT, LSDI, PJF, pseudarthrosis, rod fracture, reoperation, or overall complication rates between UT and LT patients (all $p > 0.1$; Tables 3–5).

TABLE 2. Descriptive statistics (categorical)

Variable	N	%
UIV		
LT	169	55.8
UT	134	44.2
Sex		
Male	63	20.8
Female	240	79.2
ASA classification		
Grade I–II	160	52.8
Grade III–IV	143	47.2
Osteoporosis		
No	255	84.2
Yes	48	15.8
3-CO		
No	227	74.9
Yes	76	25.1
Surgical approach		
Posterior only	206	68.0
Anterior only or anterior/posterior	97	32.0
PJK		
No	215	71.0
Yes	88	29.0
PJF		
No	241	79.5
Yes	62	20.5
Pseudarthrosis*		
No	162	76.8
Yes	49	23.2
Rod fracture		
No	248	81.9
Yes	55	18.2
Reoperation		
No	216	71.3
Yes	87	28.7
Any complication		
No	66	21.8
Yes	237	78.2

* Missing = 92.

Discussion

Surgery for ASD requires sophisticated surgical decision-making to optimize patient outcomes and minimize complications. While the impact of fusion level on patient outcomes has been investigated,^{1,6–8,14,16} there remains no clear consensus regarding optimal UIV in individual patients. In practice, this choice continues to vary widely based upon patient, regional, institutional, and surgeon variables. In this investigation, we sought to objectively investigate the surgical decisions made by a group of ASD surgeons in relationship to patient preoperative demographic, clinical, and radiographic factors. Furthermore,

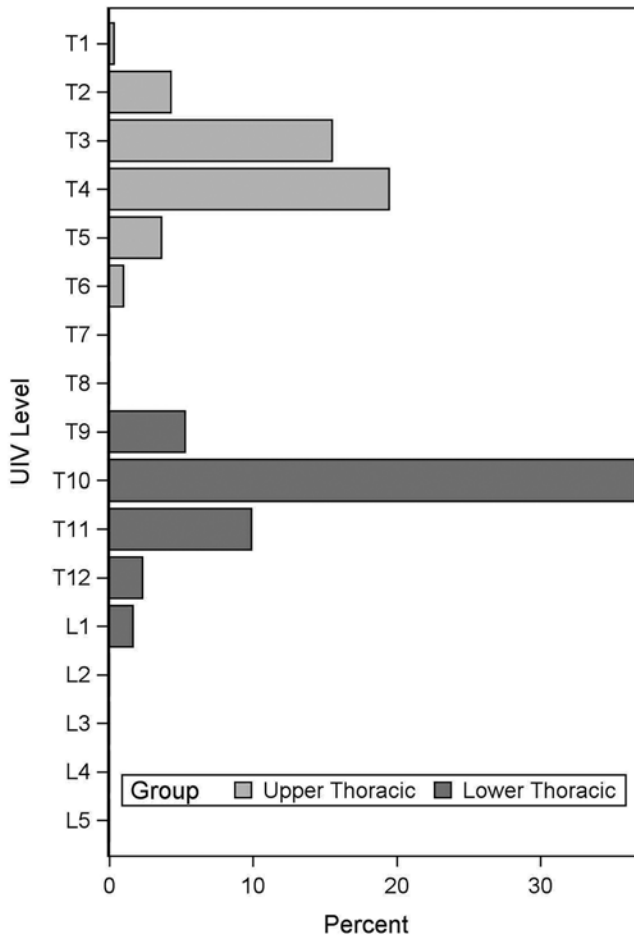


FIG. 1. Frequency distribution for UIV level among all patients.

we sought to evaluate the clinical and radiographic outcomes in those patients who underwent fusion to the UT compared to those with fusion to the LT spine. We found that surgeons more often chose UT endpoints when 3-COs were performed and when patients had worse baseline de-

formity in terms of TK and coronal Cobb angle. While patients with fusion to the UT spine had higher mean EBL, longer operative durations, and larger SVA corrections, they had significantly lower rates of PJK. Furthermore, while not statistically significant, UT patients trended toward lower rates of PJF. There were no significant differences between groups in terms of pseudarthrosis, rod fracture, overall complications, revision surgery, or HRQOL improvement.

While the overall rates of both PJK and PJF were lower in patients with fusion to the UT spine, this difference was only statistically significant for PJK. After controlling for confounding variables, the ORs for PJK (0.49) and PJF (0.54) exhibited a similar trend toward decreased risk in UT patients. However, the absolute magnitude of the unadjusted difference between UT and LT rates was 9.3% for PJK versus only 4.6% for PJF. The lack of statistical significance for PJF may thus be related to limited power for detection of true differences in this relatively less common complication. Further surveillance is currently underway and data from larger cohorts of patients with ASD may elucidate this matter in the future.

This study revealed that the preoperative degree of radiographic TK is an important factor for surgeons deciding between UT and LT UIV and is likely related to both the desire to correct TK and to mitigate the risk of PJK, which is known to be higher in patients with elevated thoracic and thoracolumbar kyphosis. This is consistent with previous literature; an earlier review of 198 patients in the ISSG database published by Kim et al. in 2014 found that preoperative coronal and sagittal deformity were worse in those with fusion to the UT spine.⁸ Similarly, a 2012 retrospective review of 58 patients by O’Shaughnessy et al. found greater TK and coronal Cobb values in their UT fusion group.¹⁶ Further factors predicting UT fusion were performance of a 3-CO and larger coronal Cobb angle. Three-column osteotomies allow substantial sagittal deformity correction, and the potential for increased risk of PJK/PJF with large focal corrections may explain the choice of UT fusions in this group. Furthermore, the inherent spinal instability created during 3-COs may require

TABLE 3. Association between UIL and postoperative outcomes (radiographic and HRQOL)

Outcome*	LT		UT		p Value
	Mean	95% CI	Mean	95% CI	
Alignment parameters					
SVA (mm)	-41.0	-48.4 to -33.6	-59.5	-68.1 to -51.0	0.0035
PI-LL (°)	-18.8	-20.6 to -16.9	-16.0	-18.1 to -13.9	0.0813
PT (°)	-3.3	-4.4 to -2.2	-4.4	-5.6 to -3.1	0.2724
TK (°)	-9.6	-11.4 to -7.7	-9.4	-11.6 to -7.3	0.9333
Max Cobb angle (°)	-20.1	-21.8 to -18.3	-19.3	-21.3 to -17.3	0.5925
HRQOL					
Total SRS	0.9	0.8 to 1.0	1.0	0.9 to 1.1	0.4083
ODI	-17.7	-20.6 to -14.8	-20.2	-23.5 to -16.9	0.3099
LSDI	-1.8	-6.7 to 3.2	-1.2	-6.5 to 4.2	0.8753

Boldface type indicates statistical significance.

* Δ = 2-yr - baseline.

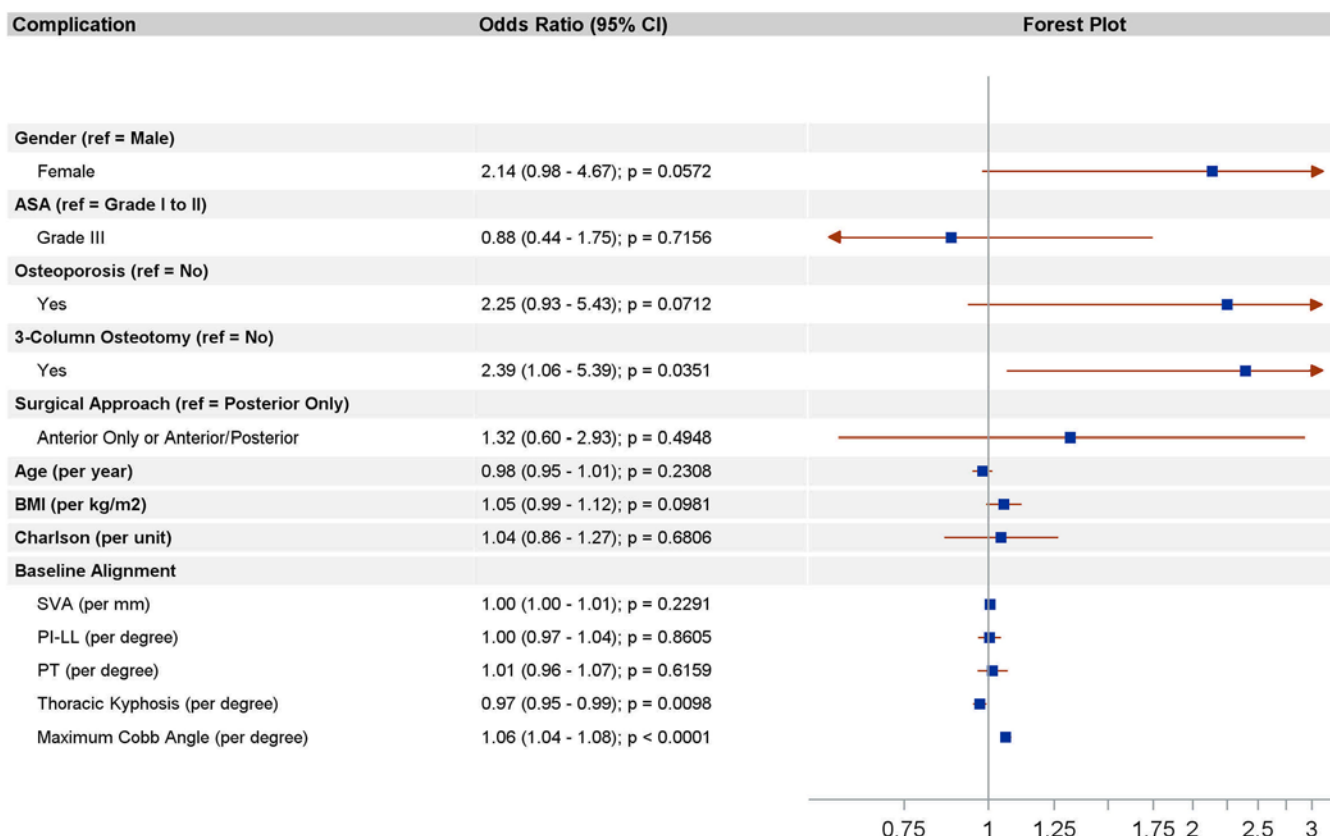


FIG. 2. Forest plot of predictors of UT UIV level. Note: as TK is expressed in negative degrees, this result indicates that a greater absolute magnitude of baseline TK is associated with increased likelihood of being a UT patient. Figure is available in color online only.

more extensive construct choices, including fusion to the UT spine. The association between preoperative coronal Cobb angle and UT fusion can be best explained by the necessity for constructs extending above the apex of the curve for deformity correction.

Consistent with prior studies, fusion to the UT level was associated with significantly increased operative time and EBL.^{7,16} Nonetheless, we found no significant difference in overall complication rates or HRQOL improvement, and therefore these factors may be of little clinical significance. For example, the change in LSDI from preoperative to 2-year postoperative was not significantly different for

UT versus LT patients; therefore, concerns about a more extensive surgery and more functional stiffness and complications in UT patients may not be warranted.

Our study is one of the largest to date comparing UT versus LT UIV in patients with ASD. Strengths of this study include the relatively large number of patients included as well as our use of the well-established prospectively collected ISSG database. Potential limitations include those inherent to any retrospective study design; specifically, there is risk of selection bias. No randomization took place, and whether to fuse to the LT or UT spine was determined through a shared decision-making process between patient and surgeon. While our statistical analysis controlled for potential confounders, it is possible that there are confounding variables that were either not anticipated or not collected. Additionally, while we can evaluate the patient demographic and clinical factors that

TABLE 4. Association between UIL and postoperative outcomes (complications)

Outcome	OR	95% CI	p Value
PJK	0.49	0.24 to 0.99	0.0457
Reoperation	1.11	0.58 to 2.11	0.7532
Any complication	1.12	0.56 to 2.27	0.7483
PJF	0.54	0.24 to 1.22	0.1384
Pseudarthrosis	0.96	0.33 to 2.79	0.9412
Rod fracture	1.55	0.71 to 3.41	0.2731

Boldface type indicates statistical significance.

TABLE 5. Association between UIL and postoperative outcomes (surgical outcomes)

Outcome	Ratio	95% CI	p Value
Op duration	1.13	1.06 to 1.19	<0.0001
EBL	1.31	1.11 to 1.55	0.0018

Boldface type indicates statistical significance.

make surgeons more or less likely to choose a UT UIV, we cannot determine the reason for them doing so in each case.

Conclusions

Factors associated with the decision to fuse to the UT spine in patients with ASD included performance of a 3-CO, larger TK, and larger coronal Cobb angle. UT patients had a significantly lower rate of radiographic PJK at 2-year follow-up, but reoperation rates and overall complication rates, including pseudarthrosis and rod fracture, were not significantly different. The decision regarding UIV level among spine surgeons may currently be guided by the anticipated risk of PJK versus operative risk and the ability to perform larger corrections with UT fusions. While our study provides evidence that the incidence of radiographic PJK is likely lower in those with fusion to the UT spine, we failed to detect a difference in clinical outcomes, including reoperation, HRQOL, lumbar stiffness-related disability, or overall complication rates. Further surveillance for complications including PJK, PJF, pseudarthrosis, and rod fracture, as well as outcomes-based research comparing UT versus LT fusion level, is still necessary before any firm treatment recommendations can be made.

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Disclosures

Dr. Daniels reports a nonfinancial personal relationship with Stryker, Orthofix, Spineart, EOS, Springer, and Southern Spine. Dr. Passias reports being a consultant for Medtronic and SpineWave, and being on the Scientific Advisory Board, receiving speaking/teaching arrangements, and receiving grants from Terumo BCT, Zimmer Biomet, and the Cervical Spine Research Society. Dr. Lafage reports direct stock ownership in Nemaris Inc.; being a consultant for Globus Medical; receiving royalties from NuVasive; speaking/teaching arrangements with DePuy Synthes Spine/The Permanente Medical Group; serving on the Executive Committee of ISSG; and serving on the editorial board of the *European Spine Journal*. Dr. Smith reports being a consultant for Zimmer Biomet, K2M/Stryker, NuVasive, AlloSource, and Cerapedics; receiving royalties from Zimmer Biomet and NuVasive; clinical or research support for this study from DePuy Synthes; support of non-study-related clinical or research effort from DePuy Synthes and AOSpine; and fellowship support from NREF and AOSpine. Dr. Shaffrey reports being a consultant for NuVasive, Medtronic, Eos, and Siemens; direct stock ownership in NuVasive; and being a patent holder for NuVasive, Medtronic, and Zimmer Biomet. Dr. Gupta reports being a consultant for DePuy and Medtronic; direct stock ownership in J & J and P & G; receiving royalties, serving on the advisory board, and travel arrangements from DePuy; receiving royalties from Innomed; receiving stock options from perForm Biologics; receiving travel arrangements from Alphatec, SRS, and Medtronic; being on the advisory board of Medtronic; and grants from AOSpine and OMeGA paid directly to the institution for a fellowship. Dr. Klineberg reports being a consultant for DePuy, Stryker, and Medtronic; receiving honoraria from K2M and AOSpine; and receiving a fellowship grant from AOSpine. Dr. Schwab reports being a consultant for Globus Medical, Zimmer Biomet, MSD, and K2M; direct stock ownership in Nemaris Inc; support of non-study-related clinical or research effort from DePuy, K2M, NuVasive, Medtronic, Globus, AlloSource, Orthofix, and SIBone; and speaking/teaching arrangements from Globus Medical, Zimmer Biomet, MSD, and K2M. Dr. Burton reports receiving clinical

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Supplemental Information

Online-Only Content

Supplemental material is available with the online version of the article.

Supplemental Tables 1–4. <https://thejns.org/doi/suppl/10.3171/2019.9.SPINE19557>.

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