■ SPINE

# Frail patients require instrumentation of a more proximal vertebra for a successful outcome after surgery for adult spine deformity

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## Aims

**The aim of this study was to investigate the impact of the level of upper instrumented vertebra (UIV) in frail patients undergoing surgery for adult spine deformity (ASD).**

## Methods

**Patients with adult spinal deformity who had undergone T9-to-pelvis fusion were stratified using the ASD-Modified Frailty Index into not frail, frail, and severely frail categories. ASD was defined as at least one of: scoliosis ≥ 20°, sagittal vertical axis (SVA) ≥ 5 cm, or pelvic tilt ≥ 25°. Means comparisons tests were used to assess differences between both groups. Logistic regression analyses were used to analyze associations between frailty categories, UIV, and outcomes.**

## Results

**A total of 477 patients were included (mean age 60.3 years (SD 14.9), mean BMI 27.5 kg/m² (SD 5.8), mean Charlson Comorbidity Index (CCI) 1.67 (SD 1.66)). Overall, 74% of patients were female (n = 353), and 49.6% of patients were not frail (237), 35.4% frail (n = 169), and 15% severely frail (n = 71). At baseline, differences in age, BMI, CCI, and deformity were significant (all p = 0.001). Overall, 15.5% of patients (n = 74) had experienced mechanical complications by two years (8.1% not frail (n = 36), 15.1% frail (n = 26), and 16.3% severely frail (n = 12); p = 0.013). Reoperations also differed between groups (20.2% (n = 48) vs 23.3% (n = 39) vs 32.6% (n = 23); p = 0.011). Controlling for osteoporosis, baseline deformity, and degree of correction (by sagittal age-adjusted score (SAAS) matching), frail and severely frail patients were more likely to experience mechanical complications if they had heart failure (odds ratio (OR) 6.6 (95% CI 1.6 to 26.7); p = 0.008), depression (OR 5.1 (95% CI 1.1 to 25.7); p = 0.048), or cancer (OR 1.5 (95% CI 1.1 to 1.4); p = 0.004). Frail and severely frail patients experienced higher rates of mechanical complication than 'not frail' patients at two years (19% (n = 45) vs 11.9% (n = 29); p = 0.003). When controlling for baseline deformity and degree of correction in severely frail and frail patients, severely frail patients were less likely to experience clinically relevant proximal junctional kyphosis or failure or mechanical complications by two years, if they had a more proximal UIV.**

## Conclusion

**Frail patients are at risk of a poor outcome after surgery for adult spinal deformity due to their comorbidities. Although a definitively prescriptive upper instrumented vertebra remains elusive, these patients appear to be at greater risk for a poor outcome if the upper instrumented vertebra is sited more distally.**

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## Introduction

Adult spine deformity (ASD) is a spectrum of disorders characterized by malalignment of the thoracolumbar spine: these can be severely disabling.[1] It includes spinal stenosis, degenerative scoliosis, and kyphosis. Surgical intervention is often needed to correct the deformity and improve symptoms.[2] While such surgery can provide significant benefits, individual patient factors such as frailty can have a significant impact on postoperative outcome.

Frailty is a physiological state which predisposes affected individuals to being significantly vulnerable to relatively low-impact stressors.[3] ASD surgery is a high-impact physiological stressor which may make frail patients more prone to a poorer postoperative outcome. Greater frailty has been associated with worse postoperative complications and function.[4] Of particular concern is the risk of complications such as proximal junctional kyphosis (PJK), proximal junctional failure (PJF), and implant failure: frail patients have been shown to be at greater risk of these complications.[5] Frailty is associated with sarcopenia and osteoporosis, which are major factors for junctional failure even in appropriately aligned patients.[6,7]

The selection of the upper instrumented vertebra (UIV) in patients with ASD depends on many factors, and usually involves a balance between preserving motion in adjacent segments and reducing stress on the proximal segments outside the construct. The impact of the choice of upper instrumented vertebra on outcomes in frail patients has not been studied, and there is no consensus about it. Because of this, we sought to investigate the association between UIV and complication risk in patients with ASD stratified by severity of frailty, exclusive of radiological correction and severity of deformity.

## Methods

This was a retrospective cohort study of prospectively enrolled patients to a single-centre database of patients with adult spinal deformity. It has previously been used to investigate various aspects of assessment and management of ASD.[8,9] Patients in the current study were recruited between January 2013 and December 2021. Institutional review board approval and informed consent were obtained prior to patient enrolment. ASD was defined as at least one of the following: scoliosis ≥ 20°, sagittal vertical axis (SVA) ≥ 5 cm, or pelvic tilt ≥ 25°. Indications for surgery included neurological deficit, persistent severe pain despite conservative measures, and intolerable, functionally limiting postural deformity.

Patients included in this study had undergone thoracolumbar fusion with an UIV between T9 and L1, and a lower instrumented vertebra (LIV) at the pelvis. According to the Scoliosis Research Society classification,[10] each patient had a primary lumbar sagittal plane deformity. Patients enrolled also had complete two-year data of clinical, demographic, and radiological factors. Demographic data collected included age, sex, race, and BMI. Osteoporosis was determined using dual-energy x-ray absorptiometry (DEXA) scanning of the hip and lumbar spine, and patients with a T-score of ≤ -2.5 were deemed to have osteoporosis. Clinical health-related quality of life (HRQoL) metrics included the Oswestry Disability Index (ODI),[11] the EuroQol five-dimension questionnaire (EQ-5D),[12] and the Scoliosis Research Society 22-item questionnaire (SRS-22).[13] These were collected at baseline, and at six weeks, one year, and two years postoperatively. The minimal clinically important difference in ODI was set at 11% as per previously published literature.[14] In this study, we defined a 'good outcome' as the absence of clinically relevant PJK or PJF, or of mechanical complications at two years. Clinically relevant PJK was defined as a proximal junctional angle of ≤ -28° and a change of ≤ -20°.[15] Each patient in the study underwent surgery using PJK prophylaxis techniques (such as percutaneous UIV screws, hook placement, and cement augmentation). Mechanical complications were defined as any rod breakage, screw loosening/breakage, implant pullout, or dislodgement of interbody devices.

Patients deemed to be candidates for surgery underwent a standard-of-care prehabilitation programme. This included targeted physical therapy for at least ≥ three weeks focusing on the lumbar and lower limb musculature, nutritional optimization (including dietetics assessment and dietary supplementation), bone density assessment (DEXA) and treatment as necessary, pain management optimization, and psychiatric evaluation, which included cognitive behavioural therapy exploring thoughts and expectations in relation to their forthcoming surgery. Each case was also discussed in a multidisciplinary team (MDT) meeting including anaesthetists, and each patient saw any relevant non-surgical personnel for preoperative optimization of comorbidities and medication (e.g. cardiologists, nephrologists). The MDT also considered the postoperative level of care. The anaesthetic protocol was standardized for all patients, and included general anaesthesia, arterial catheterization (for various physiological monitoring, e.g. haemodynamics, glucose), antibiotic prophylaxis, deep vein thrombosis prophylaxis, and neuromonitoring. Patients also underwent a standard-of-care enhanced recovery after surgery protocol which included multimodal pain management, continued optimization of nutrition, and early physical therapy.

Patients were stratified according to the ASD-Modified Frailty Index (ASD-mFI) into not frail, frail, and severely frail. The ASD-mFI is a frailty quantification and stratification method which has been validated in patients with ASD.[16,17]

**Radiological assessment.** Lateral spine radiographs were used to assess radiological parameters at baseline, and at six weeks, one year, and two years postoperatively. All images were analyzed with SpineView (ENSAM; Laboratory of Biomechanics, France).[16–18] The radiological parameters assessed included spinopelvic alignment metrics commonly used in the investigation of adult spine deformity.[19] Spine flexibility was assessed using bending radiographs as previously described.[20] The sagittal age-adjusted score (SAAS) was used to assess realignment postoperatively. The SAAS is a realignment system which determines ideal deformity correction (or 'matching') based on achieving age-adjusted targets in a combination of sagittal alignment metrics.[21] It was developed by building on previously established ASD assessment systems, including the global alignment and proportion score, SRS-Schwab classification, and age-adjusted alignment targets.[22–24]

**Stratification.** Patients were stratified according to the ASD-Modified Frailty Index (ASD-mFI) into not frail, frail, and severely frail. The ASD-mFI is a frailty quantifi-

**Table I.** Baseline comparisons between frailty categories.

| Variable | Not frail | Frail | Severely frail | p-value |
|---|---|---|---|---|
| Patients, n | 237 | 169 | 71 | |
| Mean age, yrs (SD) | 62.9 (13.6) | 65.7 (10.2) | 64.9 (8.7) | 0.046* |
| Mean BMI, kg/m² (SD) | 25.3 (3.8) | 29.2 (6.1) | 32.7 (6.1) | < 0.001* |
| Mean CCI (SD) | 1.37 (1.45) | 1.85 (1.44) | 3.06 (1.89) | < 0.001* |
| Osteoporosis, n (%) | 37 (15.6) | 29 (17.4) | 21 (29.6) | 0.039† |
| Mean ODI (SD) | 39.3 (15.3) | 50.1 (14.5) | 60.5 (12.8) | < 0.001* |
| Mean SRS-22 (SD) | 3.04 (0.58) | 2.61 (0.56) | 2.19 (0.58) | < 0.001* |
| Mean EQ-5D (SD) | 0.77 (0.62) | 0.72 (0.58) | 0.69 (0.05) | < 0.001* |
| Mean SVA, mm (SD) | 60.9 (58.1) | 80.2 (63.4) | 101.4 (72) | < 0.001* |
| Mean TK, ° (SD) | -31.3 (15.2) | -29.7 (16.8) | -29.7 (14.9) | 0.544* |
| Mean PT, ° (SD) | 23.6 (10.3) | 25.6 (9.5) | 24.8 (10.3) | 0.142* |
| Mean PI–LL, ° (SD) | 16.9 (17.8) | 22.8 (18.4) | 24.7 (18.8) | < 0.001* |
| Mean T1–PA, ° (SD) | 22.3 (11.4) | 25.5 (10.5) | 26.9 (12.2) | 0.002* |

*Analysis of covariance.
†Chi-squared test.
CCI, Charlson Comorbidity Index; EQ-5D, EuroQol five-dimension health questionnaire; ODI, Oswestry Disability Index; PI–LL, pelvic incidence–lumbar lordosis mismatch; PT, pelvic tilt; SRS-22, Scoliosis Research Society-22 item score; SVA, sagittal vertical axis; TK, thoracic kyphosis; T1–PA, T1–pelvic angle.

cation and stratification method which has been validated in ASD patients.[25,26]

**Patients.** Overall, 477 patients were included in the study. Their mean age was 60.3 years (SD 14.9), the mean BMI 27.5 kg/m² (SD 5.8), and the mean Charlson Comorbidity Index (CCI)[27] 1.67 (SD 1.66). In total, 74% of patients were female (n = 353). After stratification using the ASD-mFI, 49.6% of patients were deemed not frail (n = 237), 35.4% frail (n = 169), and 15% severely frail (n = 71). At baseline, the severely frail cohort had the highest mean BMI (32.7 kg/m² (SD 6.1); p < 0.001, analysis of covariance (ANCOVA)) and comorbidity burden (mean CCI 3.06 (SD 1.89); p < 0.001, ANCOVA) and the highest rates of osteoporosis (29.6% (n = 21); p = 0.039, chi-squared test) (Table I). Comparing HRQoL metrics, the severely frail cohort consistently had the worst scores in ODI, SRS-22, and EQ-5D. The severely frail cohort also had the worst radiological deformity metrics (mean pelvic incidence–lumbar lordosis mismatch 24.7° (SD 18.8°); p < 0.001, ANCOVA; mean T1–pelvic angle 26.9° (SD 12.2°); p = 0.002). There were no differences between frailty groups in terms of thoracic kyphosis measurements at baseline.

**Statistical analysis.** All statistical analyses were performed using SPSS v. 28.1.1 (IBM, USA). Means comparisons tests (ANCOVA and chi-squared) were used to assess differences between frailty categories, factoring in baseline differences in demographics, disability, and radiological deformity factors. Logistic regression analyses were used to assess associations between frailty categories, UIV, and the primary outcome measure. p-values < 0.05 were considered statistically significant.

## Results

Surgical and perioperative characteristics did not differ significantly between groups. The frailty groups had similar estimated blood loss, operating time, length of stay, interbody fusions performed, and levels fused (anteriorly and posteriorly). There was also no significant difference between the groups in surgical invasiveness (osteotomies performed) (Table II).

**Postoperative outcomes.** Multivariable analyses controlling for osteoporosis, baseline deformity, and degree of correction (by being 'matched' in SAAS) revealed that the 'not frail' cohort consistently had the best scores in HRQoL metrics in ODI, SRS-22, and EQ-5D. Conversely, the 'severely frail' cohort consistently had the worst scores (Table II). There were no differences in the rates of being 'matched' by the SAAS criteria between the frailty groups (p = 0.210, chi-squared test).

The rates of mechanical complications by two years increased as frailty severity increased, with the severely frail cohort having double the incidence of the 'not frail' cohort (16.3% (n = 12) vs 8.1% (n = 19); p < 0.001, chi-squared test). The rates of reoperations also differed significantly by two years, with the severely frail cohort having 1.5 times that of the 'not frail' cohort (32.6% (n = 23) vs 20.2% (n = 48); p = 0.008, chi-squared test). When subanalyzing frailty categories, frail and severely frail patients experienced higher rates of mechanical complications than 'not frail' patients at two years (19.0% (n = 42) vs 11.9% (n = 29); p = 0.003, chi-squared test). Frail and severely frail patients had an increased likelihood of developing mechanical complications if they had the following concurrent diagnoses at baseline: heart failure with reduced ejection fraction (odds ratio (OR) 6.6 (95% CI 1.6 to 26.7); p = 0.008), untreated depression (OR 5.1 (95% CI 1.1 to 25.7); p = 0.048), and any concurrent cancer diagnosis (OR 1.5 (95% CI 1.1 to 1.4); p = 0.004).

The rates of good outcomes were significant between groups: 79% not frail, 51% frail, and 42% severely frail (p = 0.001, chi-squared test). When subanalyzing patients with UIVs proximal to the thoracolumbar junction (TLJ), the rates of good outcomes were 88% for 'not frail' patients (n = 209), 69% for frail patients (n = 117), and 66% for severely frail patients (n = 47; p = 0.001). Logistic regression analyses (factoring in age, BMI, ODI, and deformity severity) of the impact of the UIV on good outcomes in frail patients (frail and severely frail patients) showed that UIVs distal to the TLJ were associated with lower odds of a good outcome than UIVs proximal to the TLJ (OR 0.18 (95% CI 0.07 to 0.47); p < 0.001). When subanalyzing specific levels,

**Table II.** Surgical factor and postoperative outcome comparisons.

| Variable | Not frail | Frail | Severely frail | p-value |
|---|---|---|---|---|
| Mean EBL, ml (SD) | 1,064.1 (1,202.2) | 1,012.7 (1,150.6) | 1,141.7 (1,297) | 0.724* |
| Mean surgical time, mins (SD) | 352.2 (134.3) | 329.1 (124) | 365.3 (136.5) | 0.061* |
| Mean LOS, days (SD) | 6.7 (3.9) | 7.2 (4) | 7.1 (3.2) | 0.400* |
| Mean posterior levels fused, n (SD) | 7.7 (1.51) | 7.7 (1.47) | 7.9 (1.50) | 0.795* |
| **Mean interbody fusion levels, n (SD)** | | | | |
| ALIF | 2.2 (1.52) | 1.8 (1.02) | 1.9 (1.34) | 0.346* |
| TLIF/PLIF | 2.6 (0.68) | 2.3 (0.58) | 2.5 (0.54) | 0.365* |
| Osteotomy performed, n (%) | 132 (55.6) | 94 (55.9) | 39 (54.5) | 0.980† |
| **Postoperative deformity correction by sagittal age-adjusted score, n (%)** | | | | 0.889† |
| Matched | 70 (29.6) | 57 (33.5) | 24 (34.2) | |
| Under-corrected | 55 (23.2) | 36 (21.6) | 17 (23.7) | |
| Over-corrected | 112 (47.3) | 76 (44.8) | 30 (42.1) | |
| Implant failure, n (%) | 19 (8.1) | 26 (15.1) | 12 (16.3) | 0.035† |
| Reoperations, n (%) | 48 (20.2) | 39 (23.3) | 23 (32.6) | 0.011† |
| **Mean ODI (SD)** | | | | |
| 1 yr | 20.6 (16.5) | 30.2 (20.2) | 43.3 (20.3) | < 0.001* |
| 2 yrs | 20.8 (16.8) | 30.7 (19.6) | 42.9 (22.8) | < 0.001* |
| **Mean SRS-22 (SD)** | | | | |
| 1 yr | 3.81 (0.71) | 3.52 (0.77) | 3.07 (0.79) | < 0.001* |
| 2 yrs | 3.79 (0.73) | 3.46 (0.78) | 3.06 (0.82) | < 0.001* |
| **Mean EQ-5D (SD)** | | | | |
| 1 yr | 0.84 (0.09) | 0.80 (0.1) | 0.74 (0.1) | < 0.001* |
| 2 yrs | 0.84 (0.09) | 0.80 (0.09) | 0.75 (0.11) | < 0.001* |
| **Mean PI–LL, ° (SD)** | | | | |
| 1 yr | 1.55 (15.12) | 5.08 (11.70) | 6.29 (11.13) | 0.014* |
| 2 yrs | 1.91 (13.98) | 5.54 (12.12) | 7.99 (13.04) | 0.020* |
| **Mean SVA, mm (SD)** | | | | |
| 1 yr | 22.4 (42.68) | 38.98 (39.96) | 55.30 (52.63) | < 0.001* |
| 2 yrs | 28.96 (46.66) | 49.44 (49.08) | 54.73 (52.93) | 0.001* |
| **Mean T1–PA, ° (SD)** | | | | |
| 1 yr | 16.28 (9.97) | 18.82 (8.11) | 20.30 (9.30) | 0.004* |
| 2 yrs | 17.36 (9.43) | 19.55 (8.58) | 21.54 (9.46) | 0.028* |

*Analysis of covariance.
†Chi-squared test.
ALIF, anterior lumbar interbody fusion; EBL, estimated blood loss; EQ-5D, EuroQol five-dimension health questionnaire; LLIF, lateral lumbar interbody fusion; LOS, length of stay; ODI, Oswestry Disability Index; PI–LL, pelvic incidence-lumbar lordosis mismatch; PLIF, posterior lumbar interbody fusion; SRS-22, Scoliosis Research Society-22 item score; SVA, sagittal vertical axis; TLIF, transforaminal lumbar interbody fusion; T1–PA, T1–pelvic angle.

distal UIVs were consistently associated with lower odds for good outcomes: L1 vs T12 (OR 0.12 (95% CI 0.02 to 0.89); p = 0.039), T12 vs T11 (OR 0.40 (95% CI 0.21 to 0.80); p = 0.009), T11 vs T10 (OR 0.57 (95% CI 0.33 to 0.98); p = 0.042), and L1 vs T11 (OR 0.10 (95% CI 0.01 to 0.78); p = 0.010). Good outcome odds were not significant for T9 versus T10–T12 UIV comparisons. There were no significant differences between frailty categories in PJK or PJF prophylaxis techniques used.

## Discussion

The impact of frailty on postoperative outcomes has become increasingly recognized in recent years, with frailer patients being at risk of poorer outcomes. A systematic review by Chan et al[28] of 32 studies (including 127,813 patients) reported that frailty was consistently associated with increased risk of mortality, readmission, adverse events, extended hospitalization, and discharge to facilities other than home. Despite the increased risk of adverse events, frail patients have still been reported to gain significant benefit in terms of improvement in various quality-of-life metrics.[29] Therefore, it is important to investigate factors which contribute to improving outcome in frail patients.

Previous studies have investigated the impact of UIV level on implant-related complications after surgery for adult spinal deformity. Metcalf et al[30] studied 127 ASD patients undergoing ≥ five-level fusion stratified into a T9–T10 cohort and T11–L2 cohort, and found that the T11–L2 cohort had higher rates of PJK and proximal junctional failure (PJF). Another study by Chen et al[31] compared patients with upper thoracic (C7–T4), mid-thoracic (T5–T8), and lower thoracic (T9–L2) UIVs, and found that patients with mid-thoracic UIVs had more pseudarthroses and reoperations than patients with upper thoracic UIVs. Luo et al's[32] meta-analysis of upper thoracic versus lower thoracic UIV similarly indicated that upper thoracic UIVs were associated with decreased rates of radiological and surgical PJK. It is difficult to draw widely applicable recommendations

about UIV from these studies, due to the notable heterogeneity in sample and deformity characteristics. However, these have shown a reduced risk of worse outcomes by using a more proximal UIV. To our knowledge, no studies have investigated this in frail patients.

Although this study did not compare different thoracic UIV segments, we found similarly positive trends with more proximal UIVs. Frail patients in our study consistently had a lower risk of symptomatic PJK and PJF with more proximal UIVs. The greatest differences were seen between T12 versus L1 and T11 versus L1 UIVs. We did not find any difference when comparing T9 to more distal thoracic UIVs. The reason for this lack of significant difference in outcomes with UIVs proximal to T10 in the lower thoracic spine has been reported to be due to the fact that T10 is the lowest immobile vertebra in the thoracic spine. There is little benefit to fusing higher in the thoracic spine in the absence of a more proximal deformity.[33–35] To the best of our knowledge, there is no literature about the impact of UIV selection in frail patients. Our findings indicate that there are less implant-related complications when the UIV is more proximal in the lower thoracic spine.

We recognize the limitations of this study. The retrospective, single-centre design potentially subjects findings to selection and expertise bias. Although we included patients with specific surgical and radiological characteristics, there still remains the potential for residual confounding. The use of a frailty index to categorize patients that is not yet widely used may also limit the generalizability of findings. However, the frailty index used has been validated in patients with ASD. Furthermore, the decision on which UIV to choose depends on multiple factors. Therefore, our findings are currently exploratory in nature and will need validation in larger, controlled trials in order to develop more definitive recommendations for clinical practice.

Frail patients are at notable risk of implant-related complications after surgery for adult spinal deformity. Patients at the extremes of frailty are at even higher risk. Although definitive recommendations remain elusive, these patients are at higher risk of implant-related complications when the UIV is sited more distally.

### Take home message

- Frail patients are at risk for implant complications following instrumentation for adult spine deformity.
- This study demonstrates that when treating lumbar deformity curves, the implant complication risk in frail patients is decreased with upper instrumented vertebra proximal to the thoracolumbar junction.

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Institutional Review Board approval was obtained before enrolling patients in the prospective database. Informed consent was obtained from each patient prior to enrollment.

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