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ORIGINAL ARTICLE

Defining modern iatrogenic flatback syndrome: examination of segmental lordosis in short lumbar fusion patients undergoing thoracolumbar deformity correction

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Abstract

Purpose Understanding the mechanism and extent of preoperative deformity in revision procedures may provide data to prevent future failures in lumbar spinal fusion patients.

Methods ASD patients without prior spine surgery (PRIMARY) and with prior short (SHORT) and long (LONG) fusions were included. SHORT patients were stratified into modes of failure: implant, junctional, malalignment, and neurologic. Baseline demographics, spinopelvic alignment, offset from alignment targets, and patient-reported outcome measures (PROMs) were compared across PRIMARY and SHORT cohorts. Segmental lordosis analyses, assessing under-, match, or over-correction to segmental and global lordosis targets, were performed by SRS-Schwab coronal curve type and construct length.

Results Among 785 patients, 430 (55%) were PRIMARY and 355 (45%) were revisions. Revision procedures included 181 (23%) LONG and 174 (22%) SHORT corrections. SHORT modes of failure included 27% implant, 40% junctional, 73% malalignment, and/or 28% neurologic. SHORT patients were older, frailer, and had worse baseline deformity (PT, PI-LL, SVA) and PROMs (NRS, ODI, VR-12, SRS-22) compared to primary patients ($p < 0.001$). Segmental lordosis analysis identified 93%, 88%, and 62% undercorrected patients at LL, L1-L4, and L4-S1, respectively. SHORT patients more often underwent 3-column osteotomies (30% vs. 12%, $p < 0.001$) and had higher ISSG Surgical Invasiveness Score (87.8 vs. 78.3, $p = 0.006$).

Conclusions Nearly half of adult spinal deformity surgeries were revision fusions. Revision short fusions were associated with sagittal malalignment, often due to undercorrection of segmental lordosis goals, and frequently required more invasive procedures. Further initiatives to optimize alignment in lumbar fusions are needed to avoid costly and invasive deformity corrections.

Level of evidence: IV Diagnostic: individual cross-sectional studies with consistently applied reference standard and blinding.

Keywords Adult spinal deformity · Revision · Mode of failure · Segmental lordosis · Sagittal malalignment

Introduction

Adult spinal deformity (ASD) represents a multifaceted surgical challenge characterized by a heterogeneous group of degenerative, post-traumatic/osteoporotic or iatrogenic alteration in spinal alignment [1]. Surgical correction of ASD can frequently restore global and segmental sagittal profile, mitigate pain, and improve functional outcomes [2]. However, despite our comprehensive understanding of optimal surgical techniques and utilization of modern instrumentation, repeat deformity correction is required in up to 53.7% of prior spine fusions [3–5].

Revision surgery may be required for a number of reasons, including inadequate previous correction, pseudoarthrosis, implant failure, or proximal junctional kyphosis

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[3]. Revision due to iatrogenic ASD, either from undercorrection during initial surgery or from loss of alignment following surgery, poses a major challenge in spine care. Restoration and maintenance of sagittal alignment in ASD patients to prevent flatback syndrome and subsequent compensation has been established with decades of data [6–11]. Prior findings on this topic, thus, offer an opportunity to improve outcomes of the index spinal fusion and potentially reduce the prevalence of iatrogenic flat segments or deformities.

Even though revision surgery has been associated with increased healthcare costs, prolonged hospital stays, and heightened postoperative risks, such as infection and reoperation, a thorough understanding of iatrogenic deformity in revision patients is lacking [12–15]. The purpose of this study is to characterize the prevalence and modes of failure of iatrogenic spinal deformity, compare their baseline spinopelvic alignment and outcome measures to primary surgery, and describe their alignment in relation to previously published lumbar lordosis segmental targets.

Methods

Study design

This retrospective cohort study examined prospectively collected, multicenter dataset of ASD patients across 24 spinal deformity centers in the United States and Canada. Institutional review board approval was obtained from all centers before data collection and informed consent was obtained from each patient included in the study.

Patient selection

Patients were included in the database if they (i) were 18 years or older, (ii) had radiographic evidence of de novo or late complex ASD (defined as pelvic incidence-lumbar lordosis mismatch [PI-LL] $\geq$ 25°, T1 pelvic angle [TPA] $\geq$ 30°, sagittal vertical axis [SVA] > 15 cm, thoracic scoliosis $\geq$ 70°, lumbar scoliosis $\geq$ 50°, or global coronal malalignment > 7 cm), and (iii) required spinal deformity surgery in the next six months. Patients with active tumor or infection, deformity secondary to trauma, neuromuscular conditions, syndromic scoliosis, and inflammatory arthritis or autoimmune conditions were excluded. Patients were subsequently included in the current study if they had no prior spine surgery or any prior lumbar fusion between L1-ilium and preoperative full-body radiographs and patient-reported outcome measures (PROMs) available.

Data extraction

Patient demographics included age, sex, body mass index (BMI), race, Edmonton Frailty Score (EFS), SRS-Schwab coronal curve type, and preoperative uppermost (UIV) and lowermost (LIV) instrumented vertebrae. Radiographic measurements based on coronal and sagittal full-length standing films included sacral slope (SS), pelvic tilt (PT), pelvic incidence (PI), C2–C7 cervical lordosis (CL), T4–T12 thoracic kyphosis (TK), T10–L2 thoracolumbar lordosis (TL), L1–S1 lumbar lordosis (global LL, L1–L4 LL, and L4–S1 LL), PI-LL, SVA, T1 spinopelvic inclination (T1SPi), C2–C7 cervical apex, T4–T12 thoracic apex, and L1–S1 lordotic apex. PROMs included numerical rating scale (NRS) for back and leg pain, Oswestry Disability Index (ODI), Veterans RAND 12-item (VR-12) for Physical (PCS) and Mental Component Scores (MCS), and Scoliosis Research Society 22-item (SRS-22) for activity, pain, appearance, mental, satisfaction, and total scores. Procedural details included osteotomy (Smith-Peterson, 3-column osteotomy [3-CO]), decompression (anterior, posterior), interbody fusion (anterior, posterior, lateral), and implant removal. Surgical Invasiveness Score was, subsequently, calculated using the previously validated Adult Spinal Deformity-Surgical and Radiographical (ASD-SR) index [16]. Finally, age- or PI-adjusted alignment targets extracted from prior studies included PT, TL, LL (global LL, L1–L4 LL, L4–S1 LL), PI-LL, and SVA (Tables S1, S2) [6, 17].

Statistical analyses

Eligible patients were categorized into history of prior fusion, including PRIMARY (no prior fusion), SHORT (prior L1-ilium fusion or less), and LONG (prior fusion longer than L1-ilium). For the outcome analysis, only PRIMARY and SHORT patients were compared. SHORT patients were further stratified into common modes of failure: implant (e.g., symptomatic implant, implant failure, pseudoarthrosis), junctional (e.g., proximal junctional kyphosis, distal junctional kyphosis, vertebral fracture), malalignment (e.g., radiographic sagittal or coronal deformity), and neurologic (e.g., motor deficits, sensory deficits, radicular pain). Demographics, baseline spinopelvic alignment, offset from ideal alignment values (calculated by subtracting the measured alignment parameters from the extracted alignment targets), baseline PROMs, and procedural details were compared using χ^2 test for categorical variables and student's *t*-tests for quantitative variables. Segmental lordosis analyses, assessing under- (below 10% of target), match (within 10% of target), or over- (above 10% of target) correction to segmental and global lordosis targets, were performed by SRS-Schwab coronal curve type and construct length (i.e., L1–S1, L1–L4, and L4–S1 spanning constructs). All statistical analyses were conducted using SPSS Statistics for Windows, Version 29.0 (Armonk, NY: IBM Corp), with statistical significance defined as $p < 0.05$.

Results

Patient demographics

Among 785 eligible patients, 430 (54.7%) were PRIMARY and 355 (45.3%) were revision spinal fusions (Table 1). Revision procedures included 181 (23.1%) LONG and 174 (22.2%) SHORT corrections. Compared to PRIMARY, SHORT patients were older (SHORT = 66.31 years vs. PRIMARY = 60.63 years, $p < 0.001$), of higher BMI (29.43 kg/m^2 vs. 26.53 kg/m^2, $p < 0.001$), and frailer (4.35 vs. 2.81, $p < 0.001$) than PRIMARY patients. They frequently had no coronal curve > 30° (N Type: 76.4% vs. 34.4%, $p < 0.001$) and their prior lumbar construct commonly had a UIV at L3 (33.3%) and an LIV at S1 (50.0%). They were otherwise comparable in terms of sex and race ($p > 0.05$).

Modes of failure

SHORT modes of failure included 27% implant, 40% junctional, 73% malalignment, and 28% neurologic (Fig. 1, Table S3). The most common modes of failure in each category were pseudoarthrosis (19.0%), proximal junctional kyphosis (33.3%), sagittal malalignment (65.5%), and radicular pain (24.7%), respectively, [overlap exists between modes in some cases].

Baseline spinopelvic alignment

SHORT patients had higher PT (28.03° vs. 23.02°, $p < 0.001$), PI (57.88° vs. 52.85°, $p < 0.001$), CL (12.38° vs. 8.68°, $p = 0.013$), TK (−30.13° vs. −35.51°, $p = 0.003$), PI-LL (29.59° vs. 13.46°, $p < 0001$), SVA (106.34 mm vs. 50.83 mm, $p < 0.001$), and T1SPi (3.32° vs. −1.87°, $p < 0.001$) and lower LL (28.26° vs. 39.38°, $p < 0.001$)

Table 1 Patient characteristics

	Total (*N* = 604)	PRIMARY (*N* = 430)	SHORT (*N* = 174)	*P*-value
Age (years)	62.27 (15.10)	60.63 (16.29)	66.31 (10.64)	**< 0.001**
Female sex	401 (66.4)	294 (68.4)	107 (61.5)	0.107
BMI (kg/m^2)	27.36 (5.52)	26.53 (5.31)	29.43 (5.50)	**< 0.001**
Race	11 (1.8)	10 (2.3)	1 (0.6)	0.122
Asian	21 (3.5)	13 (3.0)	8 (4.6)	
Black/African	548 (90.7)	393 (91.4)	155 (89.1)	
White/Caucasian	24 (3.5)	14 (7.3)	10 (5.8)	
Other				
Edmonton Frailty Score	3.25 (2.36)	2.81 (2.17)	4.35 (2.46)	**< 0.001**
SRS-Schwab Type	5 (0.8)	3 (0.7)	2 (1.1)	**< 0.001**
T Type	181 (30.0)	151 (35.1)	30 (17.2)	
L Type	137 (22.7)	128 (29.8)	9 (5.2)	
D Type	281 (46.5)	148 (34.4)	133 (76.4)	
N Type				
Preoperative UIV	–	–	21 (12.1)	–
L1	–	–	57 (32.8)	–
L2	–	–	58 (33.3)	–
L3	–	–	28 (16.1)	–
L4	–	–	10 (5.7)	–
L5				
Preoperative LIV	–	–	2 (1.1)	–
L3	–	–	13 (7.5)	–
L4	–	–	55 (31.6)	–
L5	–	–	87 (50.0)	–
S1	–	–	17 (9.8)	–
Ilium				

Categorical variables are presented as count (frequency) and continuous variables are presented as mean (standard deviation)

Bold values denote statistical significance at the $p < 0.05$ level

BMI body mass index, *UIV* uppermost instrumented vertebrae, *LIV* lowermost instrumented vertebrae

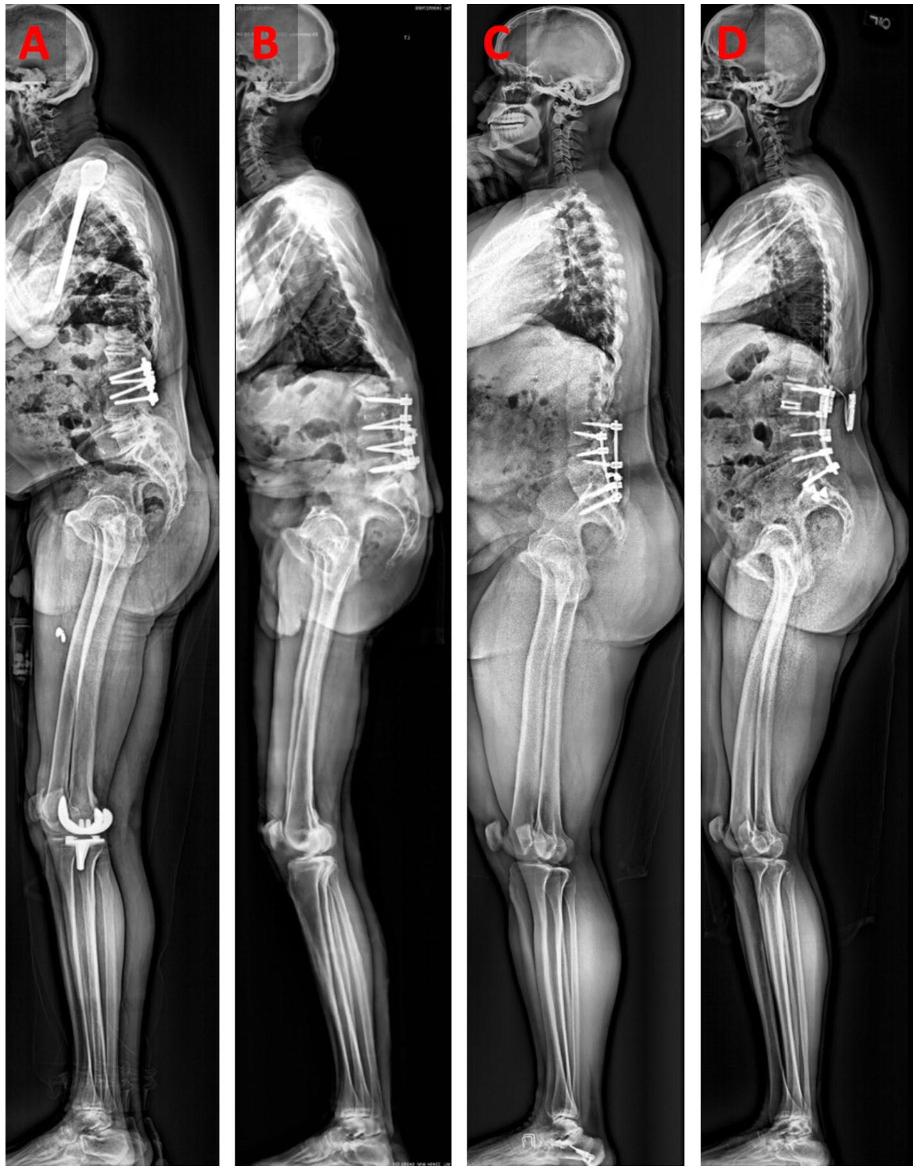

Fig. 1 Preoperative full-body lateral radiographs for patients with iatrogenic adult spinal deformity. Panel A: Patient with L2–L3 posterior spinal fusion presenting with symptomatic implant (Implant Failure), Panel B: Patient with L2–L5 posterior spinal fusion presenting with proximal junctional kyphosis (Junctional Failure), Panel C: Patient with L3-ilium posterior spinal fusion with flatback deformity (Malalignment), Panel D: Patient with L2–L5 posterior spinal fusion with radicular pain (Neurologic Failure)

resulting from a lower L4-S1 LL (26.17° vs. 36.23°, $p < 0.001$) (Table 2). Comparison to alignment goals revealed that SHORT patients had greater offset from ideal PT (3.93 vs. 0.78°, $p < 0.001$), LL (−29.53° vs. −15.62°, $p < 0.001$), specifically L4-S1 LL (−8.98° vs. 1.74°, $p < 0.001$), PI–LL (20.50° vs. 7.18°, $p < 0.001$), and SVA (57.89 mm vs. 13.52 mm, $p < 0.001$) (Table 2). Stratification by SHORT modes of failure revealed that alignment parameters were comparable across groups ($p > 0.05$), with the exception of a lower PT (Implant = 28.16°, Junctional = 30.03°, Malalignment = 29.15°, Neurologic = 25.41°, $p = 0.037$) and PI–LL (Implant = 29.89°, Junctional = 31.69°, Malalignment = 32.96°, Neurologic = 22.90°, $p = 0.037$) in the neurologic group compared to the malalignment group (Table S4).

Segmental lordosis

Segmental lordosis analyses of SHORT patients revealed that 92.4%, 87.1%, and 63.7% patients were undercorrected and only 3.5%, 4.1%, and 19.9% patients were matched at LL, L1–L4, and L4-S1, respectively (Table 3). Of note, 64.6% type *N* and 63.3% type *L* patients were undercorrected at L4–S1, and only 20.0% in each category were matched to L4–S1 targets. Likewise, 92.7%, 89.5%, and 58.9% patients were undercorrected and only 4.0%, 3.2%, and 25.0% were

Table 2 Baseline radiographic spinopelvic and patient-reported outcomes

	PRIMARY (*N* = 430)	SHORT (*N* = 174)	*P*-value
Radiographic spinopelvic parameters			
SS (°)	29.83 (13.04)	29.73 (13.66)	0.932
PT (°)	23.02 (10.85)	28.03 (9.13)	**< 0.001**
PI (°)	52.85 (12.55)	57.88 (13.85)	**< 0.001**
CL (°)	8.68 (16.32)	12.38 (15.47)	**0.013**
TK (°)	−35.51 (21.27)	−30.13 (17.57)	**0.003**
TL (°)	−14.34 (19.66)	−12.17 (20.81)	0.230
LL (°)	39.38 (23.95)	28.26 (21.10)	**< 0.001**
L1–S1	3.15 (20.10)	2.10 (19.38)	0.556
L4–S1	36.23 (15.21)	26.17 (13.79)	**< 0.001**
PI–LL (°)	13.46 (21.95)	29.59 (18.52)	**< 0.001**
SVA (mm)	50.83 (61.54)	106.34 (66.84)	**< 0.001**
T1SPi (°)	−1.87 (5.92)	3.32 (6.86)	**< 0.001**
C2–C7 Apex	C4–C5	C4–C5	0.390
T4–T12 Apex	T8	T8	0.596
L1-S1 Apex	L3-L4	L3-L4	0.237
Offset from spinopelvic alignment targets			
PT (°)	0.78 (9.53)	3.93 (9.35)	**< 0.001**
TL (°)	−10.42 (19.15)	−9.31 (20.14)	0.525
LL (°)	−15.62 (22.39)	−29.53 (18.81)	**< 0.001**
L1–S1	−17.36 (18.87)	−20.54 (17.42)	0.057
L4–S1	1.74 (15.14)	−8.98 (13.84)	**< 0.001**
PI–LL (°)	7.18 (19.11)	20.50 (19.12)	**< 0.001**
SVA (mm)	13.52 (55.66)	57.89 (68.83)	**< 0.001**
Patient-reported outcome measures			
NRS	6.88 (2.38)	7.61 (1.97)	**< 0.001**
Back pain	4.16 (3.45)	4.86 (3.15)	**0.023**
Leg pain			
ODI	41.03 (18.06)	50.45 (15.02)	**< 0.001**
VR-12	30.07 (11.12)	25.16 (8.97)	**< 0.001**
PCS	49.20 (12.63)	46.49 (12.87)	**0.021**
MCS			
SRS-22	3.04 (0.87)	2.55 (0.69)	**< 0.001**
Activity	2.60 (0.83)	2.22 (0.74)	**< 0.001**
Pain	2.49 (0.71)	2.33 (0.71)	**0.017**
Appearance	3.63 (0.84)	3.47 (0.84)	**0.046**
Mental	2.90 (1.00)	2.78 (1.08)	0.204
Satisfaction	2.94 (0.60)	2.66 (0.52)	**< 0.001**
Total			

Variables are presented as mean (standard deviation)

Bold values denote statistical significance at the $p < 0.05$ level

SS sacral slope, *PT* pelvic tilt, *PI* pelvic incidence, *CL* cervical lordosis, *TK* thoracic kyphosis, *TL* thoracolumbar lordosis, *LL* lumbar lordosis, *PI-LL* pelvic incidence minus lumbar lordosis, *SVA* sagittal vertical axis, *T1SPi* T1 spinopelvic inclination, *NRS* numerical rating scale, *ODI* oswestry disability index, *VR*-12 veterans RAND 12-item, *PCS* physical component score, *MCS* mental component score, *SRS*-22 scoliosis research society 22-item

matched at LL, L1–L4, and L4–S1, respectively, regardless of the construct length (Table 4). Of note, 90.9% patients with L1-S1/ilium spanning constructs, 90.5% patients with L1–L4 spanning constructs, and 59.8% patients with L4–S1 spanning constructs were undercorrected within the span of the construct, and only 9.1%, 4.8%, 26.1% were matched to lordosis targets, respectively. Variables are presented as count (frequency)

Table 3 Segmental and global lordosis by srs-schwab type in SHORT fusion

	T Type (*N* = 2)	L Type (*N* = 30)	D Type (*N* = 9)	N Type (*N* = 130)
LL				
Undercorrected	2 (100.0)	28 (93.3)	7 (77.8)	121 (93.1)
Matched	0 (0.0)	0 (0.0)	1 (11.1)	5 (3.8)
Overcorrected	0 (0.0)	2 (6.7)	1 (11.1)	4 (3.1)
L1–L4				
Undercorrected	2 (100.0)	28 (93.3)	8 (88.9)	111 (85.4)
Matched	0 (0.0)	0 (0.0)	0 (0.0)	7 (5.4)
Overcorrected	0 (0.0)	2 (6.7)	1 (11.1)	12 (9.2)
L4–S1				
Undercorrected	1 (50.0)	19 (63.3)	5 (55.6)	84 (64.6)
Matched	0 (0.0)	6 (20.0)	2 (22.2)	26 (20.0)
Overcorrected	1 (50.0)	5 (16.7)	2 (22.2)	20 (15.4)

Variables are presented as count (frequency)

LL lumbar lordosis

Table 4 Segmental and global lordosis by construct span in SHORT fusion

	L1-S1/Ilium (*N* = 11)	L1-L4 (*N* = 21)	L4-S1 (*N* = 92)
LL			
Undercorrected	10 (90.9)	19 (90.5)	86 (93.5)
Matched	1 (9.1)	1 (4.8)	3 (3.3)
Overcorrected	0 (0.0)	1 (4.8)	3 (3.3)
L1–L4			
Undercorrected	9 (81.8)	19 (90.5)	83 (90.2)
Matched	1 (9.1)	1 (4.8)	2 (2.2)
Overcorrected	1 (9.1)	1 (4.8)	7 (7.6)
L4–S1			
Undercorrected	5 (45.5)	13 (61.9)	55 (59.8)
Matched	3 (27.3)	4 (19.0)	24 (26.1)
Overcorrected	3 (27.3)	4 (19.0)	13 (14.1)

Procedural details

SHORT patients had higher rates of 3-COs (30.2% vs. 12.3%, $p < 0.001$), decompressions (62.0% vs. 50.3%, $p = 0.021$), and implant removals (85.3% vs. 0.0%, $p < 0.001$) (Table 5). SHORT patients also had a higher Surgical Invasiveness Score (87.81 vs. 78.28, $p = 0.006$). Stratification by SHORT modes of failure revealed that procedural details were comparable across groups ($p > 0.05$), with the

Table 5 Breakdown of procedures performed

Procedure	PRIMARY ($N=368$)[a]	SHORT ($N=129$)[a]	P-value
Osteotomy	286 (77.7)	104 (80.6)	0.490
3-CO	45 (12.3)	39 (30.2)	**<0.001**
Decompression	185 (50.3)	80 (62.0)	**0.021**
Anterior	4 (1.1)	1 (0.8)	0.743
Posterior	158 (44.4)	69 (53.5)	0.064
Interbody fusion	259 (70.4)	69 (53.5)	**<0.001**
Type			
Anterior	78 (21.2)	20 (15.5)	0.162
Posterior	161 (43.8)	38 (29.5)	**0.004**
Lateral	41 (11.1)	15 (11.6)	0.880
Levels Fused	12.13 (4.29)	3.95 (3.86)	**<0.001**
Postoperative UIV			
Average	T6-T7	T8-T9	**<0.001**
Most common	T10	T10	-
Postoperative LIV			
Average	S2	Ilium	**<0.001**
Most Common	Ilium	Ilium	-
Implant Removal	0 (0.0)	110 (85.3)	**<0.001**

Categorical variables are presented as count (frequency) and continuous variables are presented as mean (standard deviation)

Bold values denote statistical significance at the $p<0.05$ level

Abbreviations: 3-CO 3-column osteotomy, *UIV* uppermost instrumented vertebrae, *LIV* lowermost instrumented vertebrae

[a]$N=62$ PRIMARY and $N=45$ SHORT patients did not undergo any procedure during the study period

exception of higher rates of 3-CO (Implant = 29.8%, Junctional = 15.8%, Malalignment = 37.2%, Neurologic = 22.2%, $p=0.029$) in the malalignment group compared to the junctional group (Table S5). Categorical variables are presented as count (frequency) and continuous variables are presented as mean (standard deviation)

Baseline patient reported outcome measures

SHORT patients had worse NRS back (7.61 vs. 6.88, $p<0.001$) and leg (4.86 vs. 4.16, $p=0.023$) pain, ODI (50.45 vs. 41.03, $p<0.001$), VR-12 PCS (25.16 vs. 30.07, $p<0.001$) and MCS (46.49 vs. 49.20, $p=0.021$), and SRS-22 activity (2.55 vs. 3.04, $p<0.001$), pain (2.22 vs. 2.60, $p<0.001$), appearance (2.33 vs. 2.49, $p=0.017$), mental (3.47 vs. 3.63, $p=0.046$) and total (2.66 vs. 2.94, $p<0.001$) scores (Table 2). Stratification by SHORT modes of failure revealed that PROMs were comparable across groups ($p>0.05$) (Table S4).

Discussion

In this cohort of patients with severe sagittal plane deformity, nearly half (45.3%) were revision spinal fusions. Of those, 23.1% were iatrogenic LONG and 22.2% were iatrogenic SHORT corrections. SHORT revisions were predominantly associated with sagittal malalignment (65.5%), with 92.5% being undercorrected to lordosis goals regardless of the SRS-Schwab type or construct length. SHORT revision patients had worse baseline spinopelvic alignment and PROMs, and frequently underwent more invasive procedures such as 3-column osteotomies.

Revision surgery is frequently performed in the elderly and frail ASD patients undergoing lumbar spine deformity correction.[3] Most revisions occur within a year of initial surgery and resulted from surgical complications, such as adjacent segment disease (56.3%), implant failure (32.2–43.1%), proximal junctional kyphosis (24.4%), pseudoarthrosis (17.2–32.2%), infection (11.8–11.9%), and neurologic sequelae (10.2–26.6%) [5, 14, 15, 18, 19]. In the present study, revisions comprised nearly half of the cases (45.3%) and were frequently associated with in-construct sagittal malalignment (65.5%), though proximal junctional kyphosis (33.3%), radicular pain (24.7%), and pseudoarthrosis (19.0%) were also common.

Although risk factors for subsequent need for revision were not explored, age and frailty did surface on demographic analyses. Prior studies have shown that older age, male sex, higher frailty, comorbidities, and specific surgical parameters, such as surgical approach and implant material, can increase the risk of revision [20–23]. Any number of these factors may have played a role in the maintenance or development of sagittal malignment following initial surgery.

Undercorrection of lumbar lordosis to ideal segmental values may be the driving force behind poor sagittal alignment in revision patients. Targets for global and segmental lumbar lordosis have been recently published [24]. Optimal lordotic correction in the lumbar spine and adequate cranial-caudal distribution of lordosis can prevent loss of alignment and subsequent adjacent segment compensation and implant or junctional failure, thus resulting in lower rates of revisions [6, 11, 25, 26]. Inadequate correction, on the other hand, can predispose patients to poor longitudinal outcomes. In particular, undercorrection has been associated with implant failure, pain, and poor functional outcomes, especially in younger patients since they often have lower thresholds and require more aggressive deformity correction [24, 27–29]. Overcorrection, on the other hand, has been associated with proximal junctional failure and posterior inclination of the UIV [24, 27]. Segmental lordosis analyses in this study revealed that undercorrection of lumbar lordosis was, in fact, more common (92.5%) among revision patients across SRS-Schwab types, and, unfortunately, often found within the construct. Most importantly, very few patients were found to match the published segmental lordosis targets. This could potentially be due to poor selection of the levels of fusion or inadequate surgical reconstruction at the chosen levels, thus contributing to iatrogenic flatback syndrome. The findings in Table 4 are particularly important to discuss. For example: in L4–S1 constructs, 60% of patients were undercorrected compared to L4–S1 segmental lordosis targets while 93.5% had global undercorretion of LL. This could be due to proximal junctional kyphosis, adjacent segment disease, or indicative of short segments for a patient that meet the criteria for spinal deformity. This paper, however, does not advocate for fusing more levels to achieve sagittal realignment. Therefore, the focus of our results was on in-construct alignment.

These findings highlight the need for adequate alignment maintenance or restoration to published alignment targets in order to mitigate the need for revision. Multiple reasons could be behind the high prevalence of iatrogenic flatback in patients; segmental lordosis targets remain relatively new science and their scalability is still limited. In addition, the importance of sagittal alignment in degenerative spine is evolving but it remains in its infancy in comparison to the deformity literature.

Revision patients frequently require costly and invasive procedures to correct their spinal deformity. Zuckerman et al., for instance, estimated the index ASD surgery to cost approximately $60,000–80,000, with revision surgeries increasing it by nearly $50,000–$87,000 [30]. Kim et al. further revealed statistically non-significantly higher rates of invasive procedures like pedicle subtraction osteotomies in the revision group [31]. While a cost analysis was not performed in this investigation, the present study did similarly see higher rates of surgically-intensive procedures (e.g., 3-CO) in revision patients to improve sagittal malalignment and these procedures can be very costly and fraught with complications. Furthermore, despite offering adequate correction, prior studies have noted worse PI-LL mismatch correction and higher rates of functional decline six months postoperatively in revision patients [32, 33]. Lower improvements in ODI and SRS-22 satisfaction scores have also been noted.[33,34] In addition, higher rates of procedure-related complications, such as surgical site infection, and repeat revisions (nearly 21%) have been observed in this population [13–15, 35, 36]. These poor postoperative outcomes can be a direct result of poor preoperative outcomes and frailty associated with failing a spine surgery. Indeed, risk factors for revision point to higher preoperative coronal and sagittal alignment, including higher PI-LL mismatch and SVA, in addition to the demographic and surgical parameters described previously [37–39]. Likewise, the present study notes worse spinopelvic deformity (i.e., PT, PI–LL, SVA) and PROMs (i.e., NRS, ODI, VR-12, SRS-22) likely perpetuating their need for revision. These findings further highlight the importance of optimizing sagittal alignment and PROMs following index surgery.

The present study has several potential limitations. First, surgeons across the study centers may have had different thresholds for recommending revision. Second, patient cohorts were not matched according to the complexity of spinal deformity, which may be more pronounced in revision patients. Third, postoperative outcomes data was not assessed and could provide valuable insights into the effectiveness of deformity correction. Fourth, this database represents multiple tertiary care centers that specialize in treating complex spinal reconstruction and results might be challenging for external validation. Lastly, some patients had multiple modes of failure and the predominant mode was not able to be identified.

Conclusion

Iatrogenic spinal deformity comprised nearly half of the ASD surgeries in this study cohort. Revision short fusions were predominantly sagittal malalignment reconstruction following inadequate restoration of segmental lordosis during the index operation, thus leading to an iatrogenic flatback deformity. To correct their deformity, revision patients frequently underwent more invasive procedures, such as 3-CO. However, their worse preoperative spinopelvic alignment and PROMs compared to primary patients likely contributes to their worse observed postoperative outcomes, including higher complications and repeat revisions. Surgeons should prioritize optimizing alignment during primary lumbar spinal fusion operations to avoid costly and invasive revision deformity corrections.

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Declarations

Conflicts of interest The authors declare that they have no conflicts of interest related to this paper.

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