THE EUROPEAN SOCIETY OF MEDICINE
Medical Research Archives, Volume 13 Issue 1

RESEARCH ARTICLE

Osteoporosis is a Risk Factor for Proximal Junctional Failure Following Long Spinal Fusion for Adult Spinal Deformity

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OPEN ACCESS

PUBLISHED
31 January 2025

CITATION
Mohanty, S., et al., 2025. Osteoporosis is a Risk Factor for Proximal Junctional Failure Following Long Spinal Fusion for Adult Spinal Deformity. Medical Research Archives, [online] 13(1). https://doi.org/10.18103/mra.v13i1.6199

DOI
https://doi.org/10.18103/mra.v13i1.6199

ISSN
2375-1924

ABSTRACT

Background: Bone health has emerged as a critical modifiable risk factor for complications following adult spinal deformity correction. Among these complications, mechanical issues and proximal junctional kyphosis/failure remain particularly challenging, affecting up to 61% and 44% of patients, respectively. We hypothesized that osteoporotic patients undergoing deformity correction experience higher rates of instrumentation failure and proximal junctional kyphosis/failure.

Purpose: To evaluate and compare the complication profiles of osteoporotic and non-osteoporotic patients undergoing long thoracolumbar fusion for adult spinal deformity.

Study Design: Retrospective comparative study

Patient Sample: adult spinal deformity patients who underwent long thoracolumbar spinal fusion (>7 levels) at two large academic medical centers between 2010 and 2019.

Outcome Measures: The primary outcome was all-cause revision surgery. Secondary outcomes included pseudarthrosis with or without implant failure, proximal junctional kyphosis/failure rates, infection rates, and time to complication occurrence.

Methods: This retrospective, multicenter study analyzed deformity patients undergoing long-segment instrumentation (≥7 levels) with a minimum two-year follow-up. Exclusion criteria included spinal deformity secondary to tumor, infection, trauma, or neuromuscular disorders. Preoperative osteoporosis status was determined using dual-energy X-ray absorptiometry (DXA) T-scores at the hip and femoral neck. The complication profiles of osteoporotic and non-osteoporotic deformity patients were compared using Chi-squared or Fisher's exact tests for categorical variables and two-tailed t-tests for continuous variables.

Results: Among 399 adult spinal deformity patients, 131 (32.8%) were osteoporotic. Osteoporotic patients were significantly older than their non-osteoporotic counterparts [66.43 (SD: 8.9) vs. 63.51 (SD: 8.9), P = 0.0018]. The overall complication rate was significantly higher in osteoporotic patients compared to non-osteoporotic patients [40.5% (n = 53) vs. 28.0% (n = 75), P = 0.0122]. Incidences of PJK [35.1% (n = 46) vs. 21.6% (n = 58), P = 0.0040] and PJF [19.8% (n = 26) vs. 6.7% (n = 18), P = 0.0001] were also higher in the osteoporotic group, while rates of construct failure/pseudarthrosis [11.5% vs. 15.7%, P = 0.2578] and infection [4.6% vs. 3.7%, P = 0.6849] showed no significant differences. Time to pseudarthrosis (8.1 vs. 8.3 months, P = 0.4582), infection (4.7 vs. 1.5 months, P = 0.0773), PJF (9.3 vs. 10.1 months, P = 0.7300), and overall time to first complication (8.4 vs. 7.6 months, P = 0.5119) were similar between the groups.

Conclusions: Osteoporotic patients have increased risk of proximal junctional kyphosis and failure compared to non-osteoporotic patients, highlighting the need for preoperative osteoporosis surveillance, optimization, and postoperative monitoring to mitigate complications.

Keywords: adult spinal deformity; scoliosis; osteoporosis; surgical complications; fusions; kyphosis; construct failure; revision

Introduction

With a globally aging population, the prevalence of adult spinal deformity (ASD) is rising. Since 2005, rates as high as 68% have been reported in geriatric patients, affecting quality of life of over 28 million elderly individuals[1,2]. The rate of corrective surgery for ASD, aimed at preventing progressive deformity, relieving pain, improving self-image, addressing cardiopulmonary comorbidities, and decompressing neurologic elements[3–5], increased by 141% since the early 2000s. This rise was predominantly driven by a 460% rise in the incidence of long-segment deformity correction in the elderly subsegment[6]. Despite advancements in the safety of deformity correction, the complication rate remains formidable with large multicenter studies reporting reoperation rates of 26% to 30%[7]. Of these, mechanical complications and proximal junctional kyphosis(PJK) remain among the most challenging issues, affecting up to 61% and 44% of patients, respectively[8,9].

The clinical and economic burden of PJK and its more severe form, proximal junctional failure (PJF), is profound, with up to a 50% worsening in SRS self-image and pain scores, frequent severe neurological injuries[10–13], and direct costs ranging from $20,000 to $120,000[14,15]. Consequently, significant research has been directed toward understanding etiology, diagnosis, identifying vulnerable populations, and developing prevention strategies and optimal management approaches for PJK/PJF[16,17].

Among modifiable patient traits, bone health has emerged as a pivotal risk factor for PJK. For example, Shen et al. reported significantly higher PJK rates in osteoporotic patients (35.4% vs. 17.5%, P = 0.01)[18], while Yao et al. found a negative correlation between mean Hounsfield units (HU) and PJK angle progression (r = -0.475). In fact, HU values below 120 were associated with nearly sixfold higher PJK risk[19]. Highlighting the causal nature of this relationship, patients treated with osteo-anabolic agents exhibited significantly lower PJK rates compared to untreated osteoporotic patients (4.6% vs. 15.2%)[20]. Beyond PJK and PJF, multiple studies have identified poor bone health as a key driver of adverse perioperative outcomes following ASD surgery. Compared to patients with normal bone density, osteoporotic patients have a twofold higher likelihood of all-cause reoperation[21,22]. Osteopenic and untreated osteoporotic patients exhibit nearly three times the rate of pseudarthrosis with or without implant failure[23,24], a 3.20-fold higher likelihood of discharge to rehabilitation facilities[25], and fragile postoperative functional patient-reported outcome scores. For example, osteoporotic patients are significantly overrepresented among those experiencing postoperative functional decline and persistent debilitating low back pain [26,27].

Evidently preoperative optimization, risk profiles, and outcomes are markedly distinct for osteoporotic patients undergoing ASD correction. While studies such as Varshneya et al. (2022)[28] have highlighted the detrimental effects of osteoporosis on the perioperative course and 90-day healthcare utilization, comprehensive characterization of its long-term impact on ASD complications remains limited. This analysis aimed to characterize the two-year complication profiles of patients with osteoporosis compared to those with normal bone mineral density undergoing ASD correction.

Methods

This retrospective study analyzed patients treated for adult spinal deformity (ASD) at two large academic medical centers between 2010 and 2019. Inclusion criteria included adults over 40 years undergoing long-segment spinal fusion involving more than seven instrumented levels, with at least two years of follow-up. A combination of ICD-10 codes—M41.3X (thoracogenic scoliosis), M41.5X (other secondary scoliosis), M41.8X (other forms of scoliosis), and M41.9X (unspecified scoliosis)—and CPT codes 22843 (posterior segmental instrumentation, 7–12 vertebral segments) and 22844 (posterior segmental instrumentation, 13 or more vertebral segments) was deployed to identify eligible patients.

The analysis comprised patients diagnosed with adult degenerative, idiopathic, or iatrogenic spinal

deformity (ASD) with the primary deformity apex located in the cervicothoracic or thoracolumbar region. Eligible participants met at least one of the following radiographic and/or procedural criteria: pelvic incidence minus lumbar lordosis (PI-LL) ≥20°, T1 Pelvic Angle(TPA) ≥20°, Sagittal Vertical Axis(SVA) ≥4 cm, scoliosis ≥50°, global coronal malalignment ≥4 cm, undergoing a three-column osteotomy, or spinal fusion involving ≥7 levels. Exclusion criteria included those with active spine tumors or infections, spinal deformities secondary to trauma, neuromuscular conditions, syndromic scoliosis, inflammatory or autoimmune diseases, incarceration, pregnancy. All patients underwent posterior spinal fusion (PSF), with the use of 1-2 level (L3-S1) transforaminal lumbar interbody fusions (TLIFs), 24 mg of BMP, and supplemental rods determined at the surgeon's discretion.

DATA COLLECTION

We collected data on demographic and patient characteristics, bone health, aggregate preoperative health measures, baseline spinal alignment, and surgical characteristics. Preoperative bone health evaluations were performed for patients over 40 years, with osteoporosis status determined by T-scores at the hip and femoral neck. Radiographic assessments were conducted preoperatively and at two years postoperatively using the EOS 2D/3D Imaging System.

OUTCOME MEASURES

The primary outcome was the two-year overall complication rate. Recorded surgical complications included hardware-related failures, pseudarthrosis, hematoma, proximal junctional kyphosis/failure (PJK/F), wound dehiscence, and both superficial and deep infections.

Secondary outcomes included pseudarthrosis with or without implant failure—defined as rod breakage, screw loosening, breakage, pullout, or interbody graft dislodgement—determined through consensus between a radiologist and surgeon using thin-section CT scans. All pseudarthrosis cases were confirmed intraoperatively. Additional secondary outcomes included the PJK rate, defined as a ≥10° increase in kyphosis between the upper instrumented vertebra (UIV) and UIV+2 on follow-up radiographs. The time to reoperation was recorded and stratified into four categories: 0–30 days, 30–90 days, 90 days–2 years, and greater than 2 years postoperatively, with quantitative values ranging from seven to 882 days post-surgery.

STATISTICAL ANALYSIS

The impact of osteoporosis status on clinical outcomes was evaluated by comparing patients with osteoporosis to those with normal bone mineral density (BMD). Categorical variables were analyzed using Chi-Squared or Fisher's exact tests, while continuous outcomes were assessed with two-tailed t-tests. Statistical significance was defined as $P \leq 0.05$. Analyses were conducted using SAS (SAS 9.4, SAS Institute Inc., Cary, NC, USA) and GraphPad Prism (v8.4.2, GraphPad Software, La Jolla, CA, USA).

Results

The cohort comprised of 399 patients, of whom 131 (32.8%) were classified as osteoporotic and 268 (67.2%) as those with normal bone mineral density. The mean age of the cohort was 64.47 years (SD: 8.8), with osteoporotic patients being significantly older than their non-osteoporotic counterparts [66.43 (SD: 8.9) vs. 63.51 (SD: 8.9), P = 0.0018].

Females comprised 66.2% (n = 264) of the cohort, with a higher prevalence among osteoporotic patients compared to non-osteoporotic patients (74.8% vs. 61.9%, P = 0.0107). The racial distribution was predominantly Caucasian (95%, n = 379), with no significant differences in the distribution of ethnicities between groups (P = 0.4772).

Complication incidence was significantly higher in the osteoporotic group compared to the non-osteoporotic group [40.5% (n=53) vs. 28.0% (n=75), *P*=0.0122]. The prevalence of patients suffering two or more complications was comparable between groups (8.4% vs. 8.6%, *P*=0.9504).

Among complications the incidence of PJK was notably higher in the osteoporotic group [35.1%

(n=46) vs. 21.6% (n=58), *P*=0.0040] with 26.1% (n=104) of all ASD patients experiencing PJK.

Similarly, osteoporotic patients exhibited higher rates of proximal junctional failure (PJF) [19.8% (n=26) vs. 6.7% (n=18), *P*=0.0001]. However, the incidence of construct failure/pseudarthrosis and infection did not differ significantly between groups [11.5% vs. 15.7%, *P*=0.2578; 4.6% vs. 3.7%, *P*=0.6849, respectively]. Complications attributed to other causes were rare in both groups, accounting for 4.6% in osteoporotic and 1.9% in non-osteoporotic patients.

Finally, complications were stratified by time to occurrence and compared within cohorts. Early complications predominantly consisted of infections, occurring on average within the first three months postoperatively. In contrast, pseudarthrosis and related implant failure (mean: 8.3 months) and proximal junctional failure (PJF) (mean: 9.7 months) typically occurred between 8–12 months postoperatively. There were no significant differences in time to pseudarthrosis (8.1 vs. 8.3 months, P = 0.4582), infection (4.7 vs. 1.5 months, P = 0.0773), PJF (9.3 vs. 10.1 months, P = 0.7300), or the overall mean time to the first complication (8.4 vs. 7.6 months, P = 0.5119) between osteoporotic and non-osteoporotic patients.

Discussion

There are three key findings of the present analysis: (1) 26.0% of ASD patients older than 40 years suffered PJK, nearly half of which progressed to PJF requiring reoperation (2) Osteoporotic patients had a significantly higher PJK rate, with a threefold increase in PJF incidence compared to patients without osteoporosis (3) there was no significant difference in the rate of pseudarthrosis or implant failure among patients with osteoporosis.

These benchmarking data are crucial in the context of current clinical practice guidelines, which remain equivocal regarding the preoperative optimization of osteoporotic patients. While Wright et al. reported that 10.3% of Americans over age 50 are osteoporotic[29], our findings indicate that the ASD population is disproportionately enriched with osteoporotic patients (33.0%). Kuprys et al. recently reported that preoperative bone health was documented in only 25% of patients undergoing ASD surgery (an increase from 12% in 2012–2014), with fewer than 10% referred to bone health specialists[30]. DiPaola and Gupta analogously highlight significant gaps in osteoporosis assessment among ASD patients, with only 44% of spine surgeons routinely obtaining DEXA scans, 12% evaluating additional bone health markers, and frequent underdiagnosis due to the limitations of DEXA alone[31,32]. Similarly, a 2023 clinical practice guideline review concluded that there is *fair* evidence supporting osteoporosis as a risk factor for perioperative complications in ASD surgery without a recommendation for routine preoperative assessment[33].

The findings presented here highlight that osteoporotic patients face a markedly increased risk of PJK and PJF. A growing body of retrospective cohort studies, all published within the last seven years and limited by small sample sizes, corroborates these findings, consistently demonstrating higher PJK rates among osteoporotic patients[34–41]. Similarly, Kim et al.'s 2019 review was the first aggregate study to identify lower BMD as a significant risk factor for PJK (OR: 1.99; 95% CI 1.36–2.92; I^2 = 0%; P < 0.001), though this conclusion was based on only four studies)[42]. More recently, a 2023 meta-analysis reported an aggregate PJK incidence of 24.6% (n = 537), with significantly lower BMD T-scores observed in patients who developed PJK (mean difference: −0.69; 95% CI −0.88 to −0.50; I^2 = 63.9%; P < 0.001) [41]. Additionally, Hounsfield units (HU) at the upper instrumented vertebra (UIV) were significantly lower in the PJK group compared to the non-PJK group [41].

Interestingly, we observed a higher rate of PJF among osteoporotic patients, independent of PJK incidence, with 26/46 (56.5%) osteoporotic patients versus 18/58 (31.0%) non-osteoporotic patients progressing from PJK to PJF, suggesting a potential vulnerability of osteoporotic patients to this

progression. Few studies have explored radiographic progression following PJF development. In 2023, Park et al. identified overcorrection relative to age-adjusted alignment, proximal junctional angle (PJA) at PJF diagnosis, and fractures at the upper instrumented vertebra (UIV) as significant risk factors for PJK-to-PJF progression, though not osteoporosis (33% of progressors had osteoporosis vs. 38% of non-progressors)[43]. However, the limited number of osteoporotic patients and disparities in post-surgical osteoporosis treatment may have confounded their findings. Conversely, Lee et al., studying risk factors for both PJK and PJF in the same cohort, reported osteoporosis as a risk factor for PJF but not PJK, though their small cohort of 160 patients limits generalizability[44]. Collectively, it remains unclear whether osteoporotic patients are inherently more likely to develop PJK, thereby becoming overrepresented in PJF cohorts, or if PJK patients generally face an elevated risk of progressing to PJF.

Our study counterintuitively found no difference in the prevalence of pseudarthrosis or micromotion-related implant failure between osteoporotic and non-osteoporotic patients[24]. This finding is surprising given that BMD is known to influence pseudarthrosis risk; osteoporotic spines exhibit 61.1% to 78.9% of the axial pullout force of pedicle screws compared to those with normal BMD[45,46]. Consistently, multiple studies have demonstrated an increased risk of pseudarthrosis and revision surgery in osteoporotic patients following spinal fusion[24]. Evidence of this, Puvanesarajah et al. reported a twofold increase in the odds of reoperation among osteoporotic patients compared to those with normal BMD[21,28,47].

Taken together, our findings suggest that osteoporotic patients are overrepresented among those undergoing ASD correction and face an increased risk of mechanical complications and progressive postoperative sagittal alignment loss, highlighting the critical importance of preoperative BMD optimization[48,49] or pharmacologic intervention with osteo-anabolic agents [24,50].

Limitations

This study has several limitations. Its retrospective design may introduce indication bias, and the inclusion of only osteoporotic patients with sufficient bone quality for surgery likely introduces selection bias, limiting generalizability. The primarily Caucasian female cohort further restricts applicability to broader populations. Diagnosing pseudarthroses posed challenges, as only symptomatic patients underwent postoperative CT scans, with diagnosis requiring a combination of CT, MRI, and intraoperative validation; thus, the true rate of radiographic non-union may be underreported. Additionally, we did not account for surgeon experience, concomitant medical conditions, the chosen surgical approach, or the relative complexity of the procedures, all of which could unduly influence outcomes. Finally, osteoporosis was analyzed as a categorical variable rather than a continuous one, without accounting for the varying severity of bone density loss within the osteoporotic group.

Conclusion

Osteoporotic patients are enriched among patients undergoing ASD corrective surgery. Patients have increased risk of PJK and PJF compared to non-osteoporotic patients, highlighting the need for preoperative osteoporosis surveillance, optimization, and postoperative monitoring to mitigate complications.

Table 1. Demographic data comparing osteoporotic and non-osteoporotic patients.

Parameter	Osteoporotic Patients	Non-Osteoporotic Patients	All Patients	p Value
Number of Patients	131	268	399	-
Age (Mean ± SD)	66.43 ± 8.9	63.51 ± 8.9	64.47 ± 8.8	0.0018
Sex				0.0107
Male	33 (25.2%)	102 (38.1%)	135 (33.8%)	
Female	98 (74.8%)	166 (61.9%)	264 (66.2%)	
Race				0.4772
Caucasian	121 (92.4%)	258 (96.3%)	379 (95.0%)	
Black	2 (1.5%)	4 (1.5%)	6 (1.5%)	
Asian/Middle Eastern	3 (2.3%)	3 (1.1%)	6 (1.5%)	
Other	3 (2.3%)	0 (0.0%)	3 (0.8%)	
Unknown	2 (1.5%)	3 (1.1%)	5 (1.3%)	

Comparison of demographic and clinical parameters between osteoporotic, non-osteoporotic, and all patients. Data are presented as counts with percentages in parentheses for categorical variables and as means with standard deviations (SD) for continuous variables. Statistical significance was assessed using appropriate statistical tests, with p-values reported for comparisons between osteoporotic and non-osteoporotic patients. $p < 0.05$ was considered statistically significant.

Table 2: Overview of revision surgeries among osteoporotic and non-osteoporotic patients.

Parameter	Osteoporotic (n=131)	Non-Osteoporotic (n=268)	Total (n=399)	p Value
Complication Incidence	53 (40.5%)	75 (28.0%)	128 (32.1%)	0.0122
Multiple Complications	11 (8.4%)	23 (8.6%)	34 (8.5%)	0.9504
Complication Type				
Construct Failure/Pseudoarthrosis	15 (11.5%)	42 (15.7%)	57 (14.3%)	0.2578
Infection	6 (4.6%)	10 (3.7%)	16 (4.0%)	0.6849
PJF	26 (19.8%)	18 (6.7%)	44 (11.0%)	0.0001
Other Causes	6 (4.6%)	5 (1.9%)	11 (2.8%)	-
Total Complications	53 (40.5%)	75 (28.0%)	128 (32.1%)	0.0122
PJK Incidence	46 (35.1%)	58 (21.6%)	104 (26.1%)	0.004

Comparison of complication incidence, multiple complications, and specific complication types between osteoporotic and non-osteoporotic patients. Data are presented as counts with percentages in parentheses. P-values represent statistical significance for comparisons between osteoporotic and non-osteoporotic groups. $P < 0.05$ was considered statistically significant.

Table 3: Timing of Revision Surgeries Following Index Surgery.

Complication Type	Osteoporotic (n=131)		Non-Osteoporotic (n=268)		Total (n=399)		P-Value
	Incidents	Time (Months)	Incidents	Time (Months)	Incidents	Time (Months)	
Construct Failure/ Pseudoarthrosis	15	8.1	42	8.3	57	8.3	0.4582
Infection	6	4.7	10	1.5	16	2.7	0.0773
PJF	26	9.3	18	10.1	44	9.7	0.73
Other Causes	6	9.1	5	4.4	11	6.9	-
TOTAL	53	8.4	75	7.6	128	7.9	0.5119

Timing and incidence of revision surgeries following index surgery in osteoporotic and non-osteoporotic patients, including total cohort data. Data are presented as the number of incidents and the average time in months after index surgery when revision procedures occurred. P-values represent statistical significance for comparisons between osteoporotic and non-osteoporotic groups. $P < 0.05$ was considered statistically significant.

The manuscript submitted does not contain information about medical device(s)/drug(s). No funds were received in support of this work. No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

Conflict of Interest:

None

Acknowledgements:

None

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