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A Systematic Review of Treatment Strategies for the Prevention of Junctional Complications After Long-Segment Fusions in the Osteoporotic Spine

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Abstract

Study Design: Systematic review

Objectives: Proximal junctional kyphosis (PJK) and proximal junctional failure (PJF) are well-known complications after long-segment fusions in the thoracolumbar spine of osteoporotic patients. Recent advances in anti-resorptive and anabolic medications, instrumentation, surgical technique, and cement augmentation have all aided in the avoidance of junctional kyphosis. In this article, current literature on the prevention of PJK and PJF in the osteoporotic spine is reviewed.

Methods: A systematic literature review was conducted using the PubMed/MEDLINE and Embase databases in order to search for the current preventive treatment methods for PJK and PJF published in the literature (1985 to present). Inclusion criteria included (1) published in English, (2) at least 1-year mean and median follow-up, (3) preoperative diagnosis of osteoporosis, (4) at least 3 levels instrumented, and (5) studies of medical treatment or surgical techniques for prevention of junctional kyphosis.

Results: The review of the literature yielded 7 studies with low levels of evidence ranging from level II to IV. Treatment strategies reviewed addressed prophylaxis against ligamentous failure, adjacent vertebral compression fracture, and/or bone-implant interface failure. This includes studies on the effect of osteoporosis medication, cement augmentation, multi-rod constructs, and posterior-tension band supplementation. The role of perioperative teriparatide therapy maintains the highest level of evidence.

Conclusions: Perioperative teriparatide therapy represents the strongest evidence for preventive treatment, and further clinical trials are warranted. Use of cement augmentation, sublaminar tethers, and multi-rod constructs have low or insufficient evidence for recommendations. Future guidelines for adult spinal deformity correction may consider bone mineral density–adjusted alignment goals.

Keywords

junctional kyphosis, junctional failure, osteoporosis, long-segment fusions, adult spinal deformity

Introduction

Proximal junction complications, proximal junctional kyphosis (PJK) and proximal junctional failure (PJF), continue to be significant challenges in adult spinal deformity (ASD), particularly in the osteoporotic patient.[1] The reported incidence of PJK ranges from 20% to 40%.[2] Need for revision ranges from 13% to 55%, with many modifiable and nonmodifiable risk factors characterized, including a nearly 2-fold increase in risk in the presence of osteopenia or osteoporosis.[3,4] The occurrence of this phenomenon leads to worse outcomes, even after revision surgery that often involves osteotomies and extension of pedicle screw fixation for sagittal balance restoration.[5-7] In addition to increased disability, revision operations are associated with exorbitant costs with an average direct expense of over

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$50 000 per case.[8] Thus, there is significant value to investigate strategies to reduce junctional complications for the osteoporotic patient.

Pathogenesis is related to disruption of the posterior tension band, adjacent vertebral compression fracture, and/or instrumentation failure.[9] Thus, the significance of bone density loss is directly related to the etiology and serve as a prime target for treatment.[10-12] However, interventions to prevent PJK/PJF in patients with poor bone stock lack a standardized approach to effectively minimize these complications after long-segment fusions. Strategies for reducing incidence of pseudarthrosis in osteoporotic patients undergoing degenerative lumbar spine fusion were systematically reviewed but excluded ASD.[13] Multiple expert opinions have reviewed the methods to prevent adjacent segment failure in ASD in osteoporosis with mixed discussions of the literature.[14-16] The advances in antiresorptive and anabolic medications, instrumentation and surgical technique, and cement augmentation are well described but have yet to undergo a full appraisal.[17] Here, the current literature on preventive treatment options for PJK and PJF in the osteoporotic spine is systematically reviewed.

Methods

Inclusion and Exclusion Criteria

We searched PubMed/Medline and the Embase database to identify eligible studies of medical treatment or surgical techniques for prevention of junctional kyphosis in the osteoporotic spine. The following terms were used in our search: “Proximal Junctional Kyphosis” OR “PJK” OR “Junctional Kyphosis” OR “Proximal Junctional Failure” OR “PJF” AND “osteoporosis.” Inclusion criteria included (1) published in English, (2) at least 1-year mean and median follow-up, (3) preoperative diagnosis of osteoporosis, (4) at least 3 levels instrumented, and (5) studies of medical treatment or surgical techniques for prevention of junctional kyphosis. Screening was performed by 2 authors according to the inclusion and exclusion criteria to collect the data of prevention or curative management. Secondary searches for additional sources were conducted by searching the reference lists of the selected studies, reviews, or comments.

Review Procedure

Abstracts were screened by 2 reviewers using the inclusion and exclusion criteria stated above. In cases of disagreement, a third reviewer was involved to make the final decision. Full-text versions of articles meeting the criteria were gathered and reviewed in full to determine eligibility for inclusion in the final analysis. The inclusion and exclusion of studies was performed according to the latest version of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (www.prisma-statement.org). The bias of each study was evaluated with the criteria recommended by the Cochrane Back Review Group, and studies were considered to have an overall low risk of bias when at least 6 of the individual criteria were determined to have a low risk of bias.[18]

Data Extraction and Qualitative Assessment

Studies information, type of intervention, number of patients, average age of patients, follow-up duration, and average or minimum *t*-scores were recorded. Clinical and radiographic outcomes were collected and divided into comparative groups if provided. When included in the article, the statistical significance of the outcomes between groups were noted in the table. Number of levels instrumented and degree of correction, specifically change in lumbar lordosis (LL) or sagittal vertical axis (SVA) from preoperative to immediate postoperative radiographs, were documented if available. Rate of PJK was defined by a kyphotic change of 10° or more measured between the upper instrumented vertebrae (UIV) and the vertebrae 2 levels supra-adjacent (UIV+2),[2,19] and rate of PJF was defined as proximal junction fracture or fixation failure with substantial kyphosis requiring revision or extension of the fusion.[20] Clinical outcomes were also recorded including patient-reported measures if available. Due to the low number of studies, heterogeneity in methodology, and variable clinical outcomes measures reported, it was not possible to perform a meta-analysis of the results.

Results

Search Strategy

The results of our search are summarized in the PRISMA flow diagram shown in Figure 1. In brief, our search returned 102 results from the searched databases, and an additional 8 records were identified through review of the bibliographies of the examined articles. After removing duplicates, 76 records were screened. After screening based on title and abstract, 36 full-text versions of the remaining studies were collected and screened for further eligibility. Of these 36 studies, 7 were found to meet inclusion criteria for qualitative analysis. Reasons for exclusion of the 29 articles are listed.

Baseline Characteristics and Quality Assessment

Table 1 lists the study information and patient demographics, including type of intervention, number of patients, average age of patients, follow-up duration, and average or minimum *t* scores. Overall, studies analyzed an elderly population with a minimum mean age of 62 years. Table 2 details the radiographic and clinical outcomes, including number of levels instrumented, amount of correction, rate of PJK and/or PJF, and reported clinical outcome measures. Number of levels instrumented were a minimum mean of 5, and in general were associated with substantial deformity correction. In some series, no events of junctional kyphosis were reported but others ranged as high as 38%. Levels of evidence were low, and ranged from II to IV.

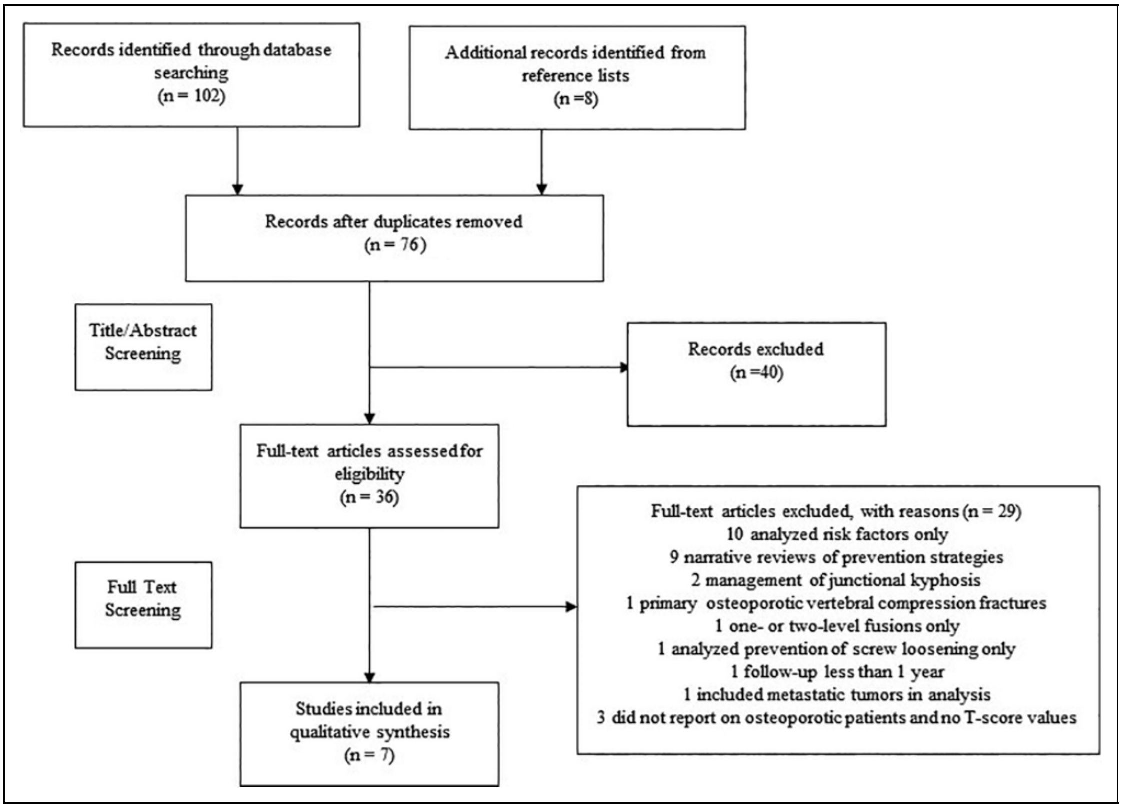

Figure 1. PRISMA flow diagram.

The Effect of Cement Augmentation

Three studies were identified that employed cement augmentation for the prevention of junctional complications after long-segment posterior spinal fusion in an osteoporotic patient population. Aydogan et al reported in a retrospective case series results of pedicle screw fixation augmented with polymethylmethacrylate (PMMC).[21] Cases were solely in severely osteoporotic patients with a neurologic deficit that could not be delayed for proper preoperative optimization. Their strategy involved cement augmentation at every instrumented level, as well as at the UIV + 1 for prophylaxis against PJK. Only one complication related to cement pulmonary embolism occurred. One patient developed pseudarthrosis at L5-S1. No junctional complications, proximal or distal, were appreciated during follow-up.

Martin et al and Erdem et al reported on a more strategic use of cement augmentation by limiting injections to the UIV and the UIV + 1.[22,23] Martin et al employed this 2-level prophylactic vertebroplasty on 41 prospective patients, and found rates of PJK and PJF to have reduced to 8% and 5%, respectively.[23] Patients with PJK did not have significantly different patient-reported outcome measures than non-PJK/PJF patients. However, PJF was associated with a decreased treatment effect, although was still improved from baseline. Erdem et al compared a similar strategic use of cement augmentation at the upper levels, for example, T10-T12 in a T10-pelvis posterior fusion, as well as prophylactic vertebroplasty at the UIV + 1 versus cement augmented pedicle screws at all segments. They found no difference in rates of PJK/PJF (no events reported in either group). However, there were significantly more cement-related pulmonary complications in the group that received cement augmentation at all segments, 41.2% versus 7.1%, $P = .038$.

The Effect of Multirod Constructs

Banno et al[24] compared multirod constructs versus standard 2-rod constructs in an elderly, osteopenic population undergoing ASD surgery. Patients with multirod constructs did have a higher incidence of iliac and UIV screw loosening, but a significantly lower incidence of rod fracture. No significant difference was found in rates of PJK/PJF or in clinical outcomes.

The Effect of Posterior-Tension Band Supplementation

Rodriguez-Fontan et al evaluated the success of Mersilene tape at the UIV and UIV + 1 with results stratified by diagnosis of osteoporosis.[25] Compared to patients without use of this augmented stabilization, the group of patients with Mersilene tape demonstrated decreased risk of PJK when stratified by presence of osteoporosis, odds ratio = 0.13 (95% confidence interval 0.01; 1.2), $P = .06$. Despite the increased incidence of PJK in the control group, there was no increased need for revision surgery. Risk of infection was similar in both groups (0.0% vs 3.3%, $P = .56$).

Table 1. Study Information and Patient Demographics.

Author and year	Study type	Intervention	Patients (n)	Average age (years)	Follow-up (months)	*t* score
Aydogan 2009	Retrospective case series	Universal pedicle screw and UIV + 1 cement augmentation	49	66 (range 59-78)	37 (range 24-48)	−2.5 and below
Banno 2018	Retrospective comparative review	Comparison of 2-rod vs multirod construct	106	68.2 ± 9.5	42 (range 13-83)	−1.5 ± 1.1
Erdem 2016	Retrospective comparative review	Comparison of cemented pedicle screws at all segments (Group A) vs strategic cement augmentation at proximal and distal vertebrae plus UIV + 1 (Group B)	31	Group A: 68.1 ± 4.7 Group B: 67.2 ± 6.5	Group A: 51.9 ± 16 Group B: 41.2 ± 10.4	−2.5 and below
Martin 2013	Prospective cohort study	UIV and UIV + 1 cement augmentation	38	64.4 (range 41-80)	32.3 (range 24-48)	−1 and below
Rodriguez-Fontan 2020	Retrospective comparative review	Comparison of UIV and UIV + 1 Mersilene Tape stabilization (Group A) vs without Mersilene Tape (Group B)	80	Group A: 63.2 ± 10.9 Group B: 62.1 ± 11.2	24	NR; osteoporosis was reported binarily
Viswanathan 2018	Prospective cohort study	UIV + 1 sublaminar band placement	40	64.0 (range 57.7-70.0)	12 (range 6-15)	Osteopenia: −1.0 to −2.5 Osteoporosis: −2.5 and below
Yagi 2016	Prospective comparative study	Comparison of immediate postoperative Teriparatide therapy (Group A) vs no postoperative Teriparatide therapy (Group B)	Group A: 43 Group B: 33	Group A: 68.6 ± 6.9 Group B: 66.7 ± 6.9 *P* = .39	Group A: 27.9 ± 3.9 Group B: 43.6 ± 4.9 *P* = .02	Group A: −1.1 ± 0.4 Group B: −0.9 ± 1.2 *P* = .69

Abbreviations: UIV, upper instrumented vertebrae; UIV + 1, one vertebrae above the UIV.

Table 2. Radiographic and Clinical Outcomes.

Author and year	Number of levels instrumented	Change in LL or SVA	Junctional complication rates	Clinical outcomes
Aydogan 2009	5 (3 to 8)	NR	0	Reported complete relief of neurologic symptoms
Banno 2018	2-rod construct: 8.6 ± 0.9 Multirod construct: 8.5 ± 0.9 P = .378	2-rod construct ΔSVA: 93 mm ΔPI-LL: 33.6° Multirod construct ΔSVA: 87 mm ΔPI-LL: 37° P = .752 and P = .151, respectively	2-rod construct PJK: 29% Multirod construct PJK: 22% P = .374	2-rod construct 1-year ΔODI: 15.7 point improvement Multirod construct 1-year ΔODI: 13.4 point improvement P = .634
Erdem 2016	Group A: 5.5 ± 2.0 Group B: 5.7 ± 1.8 P = .79 Mean cemented segments: Group A: 6.5 ± 2.7 Group B: 2.7 ± 0.8 P = .01	NR	0 in both groups	Symptomatic cement embolism: Group A: 41.2% Group B: 7.1% P = .038
Martin 2013	9 ± 1	NR	PJK 8% PJF 5%	Non-PJK/PJF group: ΔODI at final follow-up: 59.3 point improvement PJK group: ΔODI at final follow-up: 53.4 point improvement PJF group: ΔODI at final follow-up: 40.0 point improvement
Rodriguez-Fontan 2020	Group A: 6.7 ± 3.8 Group B: 7.5 ± 3.3	ΔLL *immediate postoperative vs preoperative* Group A: −13.4 ± 2.8° Group B: −9.9 ± 2.1° P = .79	PJK/PJF Group A: 15% PJK/PJF Group B: 38% P = .045	Infection: Group A, 0.0%; Group B, 3.3%; P = .56 Reoperation: Group A, 20%; Group B, 25%; P = .45
Viswanathan 2018	11.8 ± 3.5	ΔSVA immediate postoperative vs preoperative: −3.6 cm P = .20 ΔSVA final follow-up vs preoperative: −4.3 cm P < .001	PJK 6.5% PJF 0%	Difference of median values at 1 year postoperative VAS Back: −6.0; P = .001 VAS Leg: −5.5; P = .197 ODI: −10.0; P < .001 SF-36 Physical Function: +12.5; P = .003 SF-36 Social Function: +18.8; P = .007 SF-36 Pain: +32.5; P < .001
Yagi 2016	Group A: 9.1 ± 1.1 Group B: 9.1 ± 1.3 P = .88	ΔLL 24 months postoperative vs preoperative Group A: −22.8° Group B: −16.6°	Group A PJK: 9.3% Group B PJK: 18.2% P = .23 Group A PJF: 4.6% Group B PJF: 15.2% P = .01	Difference of median values preoperative vs 2 years postoperative ODI: Group A −30.6%; Group B −30.0% SRS22r function: Group A +0.93; Group B +0.78 SRS22r pain: Group A +1.37; Group B +1.15 SRS22r total: Group A +1.08; Group B +1.00

Abbreviations: LL, lumbar lordosis; SVA, sagittal vertical axis; PI, pelvic incidence; Δ, change; PJK, proximal junctional kyphosis; PJF, proximal junctional failure; ODI, Oswestry Disability Index; VAS, visual analogue scale; SF-36, Short-Form 36; SRS22r, Scoliosis Research Society Health-Related Quality of Life Questionnaire.

Viswanathan et al described their experience with sublaminar band placement at the UIV + 1 in a prospective cohort of 40 osteopenic and osteoporotic patients.[26] At final follow-up, rate of PJK was only 6.5% without any reported PJF. Significant improvements were seen in patient-reported outcome measures. Three complications were noted to be directly related to sublaminar banding placement, including 2 durotomies and a case of transient unilateral hip-flexion weakness related to presence of stenosis at the level of the UIV + 1. Of note, follow-up was limited to 3 months for 2 patients: one developed discitis treated with intravenous antibiotics and hardware and sublaminar band removal at 4 months postoperatively, whereas another patient died due to unrelated causes at 3.5 months postoperatively. Eleven of the patients only had 6-month follow-up, although their mean and median follow-up was still 12 months for the cohort.

The Effect of Osteoporosis Medication

Yagi et al compared immediate postoperative Teriparatide (TP) therapy, a recombinant human parathyroid hormone, versus no postoperative TP therapy in a nonrandomized prospective study of ASD patients.[27] Patients were osteopenic at baseline with dual-energy X-ray absorptiometry (DEXA) scans performed preoperatively and at 6 months after surgery. Changes in mean bone mineral density (BMD) and rates of PJK over long-term follow-up were analyzed. After 6 months of treatment postoperatively, the TP therapy group demonstrated increased BMD at the UIV + 1 had increased 14%, $P = .0038$. At 2-year follow-up, the TP therapy group had a 6.7 $\pm$ 4.9% increase in hip BMD from baseline compared to a decrease of 1.4 $\pm$ 4.2% in the control group, $P = .05$. Rates of PJK were not significantly decreased in the TP therapy versus control group, 9.3% versus 18.2% ($P = .23$), respectively. However, rates of PJF were significantly decreased in the interventional arm, 4.6% versus 15.2% ($P = .01$). Despite this, there were no significant differences in the 2-year postoperative clinical outcomes with both groups showing significant improvement. Need for revision surgery was not recorded. Three patients (7%) had to discontinue TP therapy due to adverse effects, including two with nausea and headaches and one with nonspecific C-reactive protein elevation.

Discussion

As the number of older and elderly patients with ASD increases so does the prevalence of osteoporosis in long-segment spinal fusion surgery.[28] Fischer et al performed a systematic review on treatment strategies to prevent pseudoarthrosis in osteoporotic patients, but excluded deformity surgery.[13] Likewise, a multitude of studies have been performed on the risk factors for PJK/PJF but do not review proactive treatment strategies.[1,29,30] This systematic review is the first to appraise studies on the medical and surgical technique options for PJK/PJF prevention in patient with low BMD undergoing long-segment thoracolumbar fusion. Overall, the included studies are sparse, do not reach high level of evidence, and emphasizes the need for a standardized approach in osteoporotic patients.

Here, treatment strategies reviewed addressed all 3 facets in the etiology of PJK/PJF—ligamentous failure, adjacent vertebral compression fracture, and/or bone-implant interface failure.[9] Maruo et al determined that fracture at the UIV and adjacent level are the most common mechanism in their series.[31] Thus, loss of BMD is directly related to the development of PJK/PJF. Cement augmentation and TP therapy both target the underlying pathophysiology as a treatment strategy. While use of PMMC has advantages for prophylaxis against adjacent compression fracture and increased pull-out strength, life-threatening complications did occur in all 3 studies. This may be minimized with limited or strategic injections to the UIV and UIV + 1 as demonstrated by Erdem et al.[22] To determine the need for cement augmentation, additional preoperative planning may involve measuring the Hounsfield Units at the planned UIV on computed tomography.[32]

TP therapy has been shown to have a significant effect on improving BMD, and Yagi et al demonstrated its success in preventing PJF.[27] Since this was studied in a prospective comparative study, this represents the strongest evidence for preventive treatment of PJK/PJF in patients with osteoporosis undergoing ASD correction. Two prospective trials evaluating TP therapy compared to risedronate and control groups also show a significantly higher rate of fusion in patients treated with TP.[33,34] Based on these studies, it advisable for spine surgeons to refer patients with osteoporosis undergoing long-segment fusion to start treatment with TP in the perioperative period. Wanderman et al provides an algorithm for its use in spine fusion patients.[35]

In general, the approach to preventing PJK/PJF is similar in osteoporotic and non-osteoporotic patients. This includes the interventions reviewed here as well as goals in sagittal balance correction. A survey of spinal deformity surgeons determined that the most common techniques to prevent PJK are to contour the terminal rod into kyphosis (80%), starting treatment if the BMD is found to be low (77%), use of transverse process hooks at the UIV(56%), and vertebroplasty at the UIV, UIV + 1, or both (42%).[36] Such sentiment is likely the result of several studies that lend support to these strategies, although the patient populations were not specifically examined for the presence of osteoporosis or osteopenia. In a retrospective review of women aged 60 and older, Hart et al demonstrated the efficacy of vertebroplasty at the UIV and UIV + 1 levels in decreasing PJK/PJF.[37] Patients were suspected of having low BMD; however, the majority of patients did not undergo DEXA scan prior to surgery. Despite a confirmed diagnosis, in this high-risk population prophylactic vertebroplasty decreased the incidence of PJF by 15.3%. Posterior tethers have also recently gained traction as way to allow for a gradual return to physiologic range of motion between instrumented and noninstrumented vertebral levels. Finite element analysis by Bess et al demonstrated that the utilization of posterior polyethylene tethers are superior to pedicle screws and transverse process hooks in generating a gradual transition to normal range of motion between UIV − 1

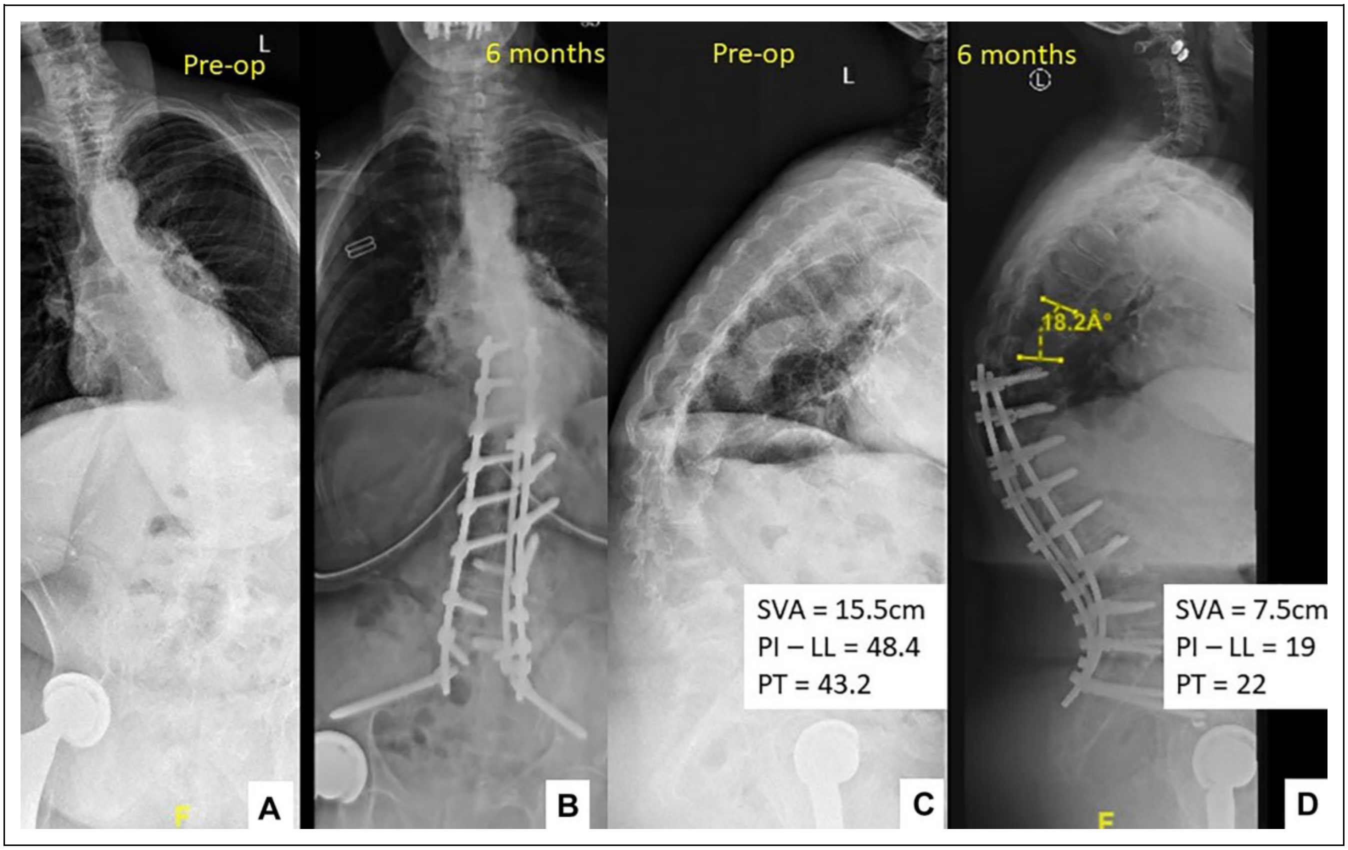

Figure 2. Pre- and postoperative anterior-posterior (AP) and sagittal radiographs of a 74-year-old woman, *t*-score of −2.0 preoperatively and placed on Teriparatide perioperatively, who underwent T10-pelvis posterior spinal fusion, L5-S1 transforaminal lumbar interbody fusion, and L4 pedicle subtraction osteotomy. Preoperative kyphoscoliosis seen on AP (a) and marked sagittal imbalance (c). Six-months postoperative AP (b) and sagittal X-rays (d) demonstrate appropriate age-adjusted alignment correction in coronal and sagittal alignment, however approximately 18° of proximal junctional kyphosis present. This finding has been stable and without any clinical symptoms.

and UIV + 2.[38] However, a separate biomechanical study Kim et al found that transection of the posterior ligamentous complex did not significantly change the degree of flexion at the proximal junctional segment, and augmentation with a polyester fiber loop did not attenuate flexion loads.[39] In a recent pilot study examining the use of polyethylene tethers for prevention of PJK in long instrumented fusions, Buell et al found a 10.9% reduction in the rates of PJK when a tether was placed through the spinous processes of UIV − 1 and UIV + 1.[40] They showed that utilizing a crosslink tethering technique, in which the tether is passed through the spinous process of UIV + 1 and tied to a crosslink between UIV − 1 and UIV − 2, was even more effective with a 27.4% reduction compared to nontether controls. However, these studies were not performed on patients with established low BMD, and a concern may be the ability of osteoporotic bone to withhold these tensile forces. The publications by Rodriguez-Fontan et al and Viswanathan et al analyzed above demonstrate that this procedure may be safe and effective in the osteopenic and osteoporotic population.[25,26]

In addition to supplemental procedures such as posterior tethers and cement augmentation, precise alignment goals are crucial for the prevention of junctional complications. Line et al demonstrated in a propensity score matched analysis of 625 ASD patients that using surgical implants and avoiding overcorrection were necessary to prevent PJF in a general population.[41] Thus, there may be a synergistic effect by employing both patient-specific correction goals as well as intraoperative augmentation procedures. Whether achieving age-adjusted sagittal alignment decreases risk for the development of PJK/PJF in addition to improving symptoms has not yet been established.[42] With this in mind, prior studies have also shown that excessive correction of lumbar lordosis is a risk factor for subsequent development of PJK/PJF and should be avoided, particularly in the osteoporotic and osteopenic populations.[31,43,44]

Thus, the nuances in dealing with the osteoporotic spine should not be underestimated. If at all possible, decompression alone or short-segment fusions may be the preferred option in selected sagittally balanced patients.[45-48] However, in certain cases a patient with poor BMD must have a long-segment fusion due to neurologic deficit, spinal instability, or severe deformity. In these situations, it is prudent to minimize modifiable risks as much as possible. The greatest risk factors for PJK/PJF, in addition to age and osteoporosis, are the presence of sagittal imbalance and magnitude of deformity correction.[3,49-51] Therefore, it behooves the deformity surgeon to achieve less than full correction of global sagittal alignment parameters and aim for patient-specific alignment thresholds.[14,52,53] However, there are no clear guidelines how to incorporate objective values of BMD into recommended correction parameters, contrary to age and pelvic incidence.[42,54-57] BMD-adjusted alignment goals require further study and will likely be impactful in optimizing patient outcomes.

Of note, among the above studies included for analysis, an increased rate of PJK rarely resulted in worse clinical outcomes. Martin et al noted in their prospective cohort that at final follow-up patients with PJK or PJF reported lower pain and satisfaction compared with the non-PJK/PJF group.[23] Yet there were no significant differences in health or function scores, and all 3 groups had significant improvement for Oswestry Disability Index and 12-item Short Form Survey scores. In a systematic review by Kim et al, the development of PJK did not necessarily have a significant effect on health-related quality of life outcomes.[58] Accordingly, it is important to keep in mind that PJK is a spectrum from simple radiologic findings that only require observation to high degrees of angulation leading to clinical symptoms with significant impact in function and quality of life.[9,59] Figure 2 demonstrates such a patient with stable 18° of PJK on 6-month postoperative X-ray without complaint or need for any pain medications.

The limitations of this article relate to the lack of prospective randomized trials on the topic of osteoporosis and ASD surgery. Publications included in our qualitative analysis contained methodological heterogeneity with diversity of study designs, which required each intervention to be presented separately rather than a pooled analysis. Conclusions on long-term outcome are limited by our decision to include of articles with less than 2 years follow-up; however, this strict criterion would have significantly constricted our yielded studies. As mentioned, the study included by Viswanathan included patients with less than 1-year follow-up; however, their mean and median follow-up was 12 months. Despite our search strategy maximized to identify relevant articles, there is some subjectivity in screening for so-called preventive treatment, and thus one cannot exclude the possibility that our search strategy missed eligible trials. However, systematic reviews of the current literature such as this emphasize the need for high-quality studies that can provide meaningful information and guidance on treatment decisions. The importance of developing preventive treatment strategies will only become greater as the aging population increases.

Future directions of this topic will involve clinical studies of osteoporosis medications, including analysis of large prospective databases to determine BMD cutoff values. There is a need to develop methods to reduce risk of cement embolisms other than limiting its use to the UIV and UIV + 1. Future guidelines for ASD correction should incorporate BMD-adjusted alignment goals, which may be defined by hip-DEXA scans and/or Hounsfield Units at the UIV and UIV + 1.

Conclusions

This systematic review of the current literature determined that there are 7 studies evaluating the effect of preventative treatments of PJK/PJF in patients with osteoporosis undergoing ASD correction, with low levels of evidence ranging from level II to IV. TP therapy represents the strongest evidence with statistically significant increased BMD and decreased rates of PJF compared to a control group in a nonrandomized prospective comparative study, and further clinical trials are warranted. Retrospective and prospective cohorts advocate cement augmentation; however, they were not compared to a control group. Life-threatening complications from cement embolism may occur and were avoided by strategical use at the UIV and UIV + 1. Augmentation of the posterior tension band to the UIV + 1 through sublaminar tethers may support the spine against increased flexion loads and reduce the incidence of PJK compared to a control group; however, the clinical significance is unclear as there was no increased need for revision surgery. Future guidelines for ASD correction would benefit from incorporation of BMD-adjusted alignment goals.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Samuel K. Cho receives consulting fees from Zimmmer Biomet, Globus, and CGBio. Reza Yassari receives consulting fees from Stryker. The rest of the authors have no conflicts of interest.

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