

Sarcopenia Is an Independent Risk Factor for Proximal Junctional Disease Following Adult Spinal Deformity Surgery

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Abstract

Study Design: Retrospective cohort study.

Objectives: Sarcopenia is a risk factor for medical complications following spine surgery. However, the role of sarcopenia as a risk factor for proximal junctional disease (PJD) remains undefined. This study evaluates whether sarcopenia is an independent predictor of proximal junctional kyphosis (PJK) and proximal junctional failure (PJF) following adult spinal deformity (ASD) surgery.

Methods: ASD patients who underwent thoracic spine to pelvis fusion with 2-year clinical and radiographic follow-up were reviewed for development of PJK and PJF. Average psoas cross-sectional area on preoperative axial computed tomography or magnetic resonance imaging at L4 was recorded. Previously described PJD risk factors were assessed for each patient, and multivariate linear regression was performed to identify independent risk factors for PJK and PJF. Disease-specific thresholds were calculated for sarcopenia based on psoas cross-sectional area.

Results: Of 32 patients, PJK and PJF occurred in 20 (62.5%) and 12 (37.5%), respectively. Multivariate analysis demonstrated psoas cross-sectional area to be the most powerful independent predictor of PJK ($P = .02$) and PJF ($P = .009$). Setting ASD disease-specific psoas cross-sectional area thresholds of $<12 \text{ cm}^2$ in men and $<8 \text{ cm}^2$ in women resulted in a PJF rate of 69.2% for patients below these thresholds, relative to 15.8% for those above the thresholds.

Conclusions: Sarcopenia is an independent, modifiable predictor of PJK and PJF, and is easily assessed on standard preoperative computed tomography or magnetic resonance imaging. Surgeons should include sarcopenia in preoperative risk assessment and consider added measures to avoid PJF in sarcopenic patients.

Keywords

sarcopenia, adult spinal deformity, proximal junctional kyphosis, proximal junctional failure, revision, degenerative

Introduction

Adult spinal deformity (ASD) is associated with significant pain and disability, particularly in patients with positive sagittal imbalance.¹ Surgical restoration of sagittal balance is associated with dramatic improvements in health-related quality of life²; however, correction of large sagittal plane deformity places patients at high risk for postoperative development of proximal junctional disease (PJD).³

PJD following ASD surgery ranges from asymptomatic proximal junctional kyphosis (PJK) to catastrophic proximal junctional failure (PJF; Figure 1) associated with severe pain

and disability, neurologic injury, loss of sagittal correction, and the need for revision surgery.^{3,4} A variety of preventive techniques have been proposed, yet PJD remains a persistent

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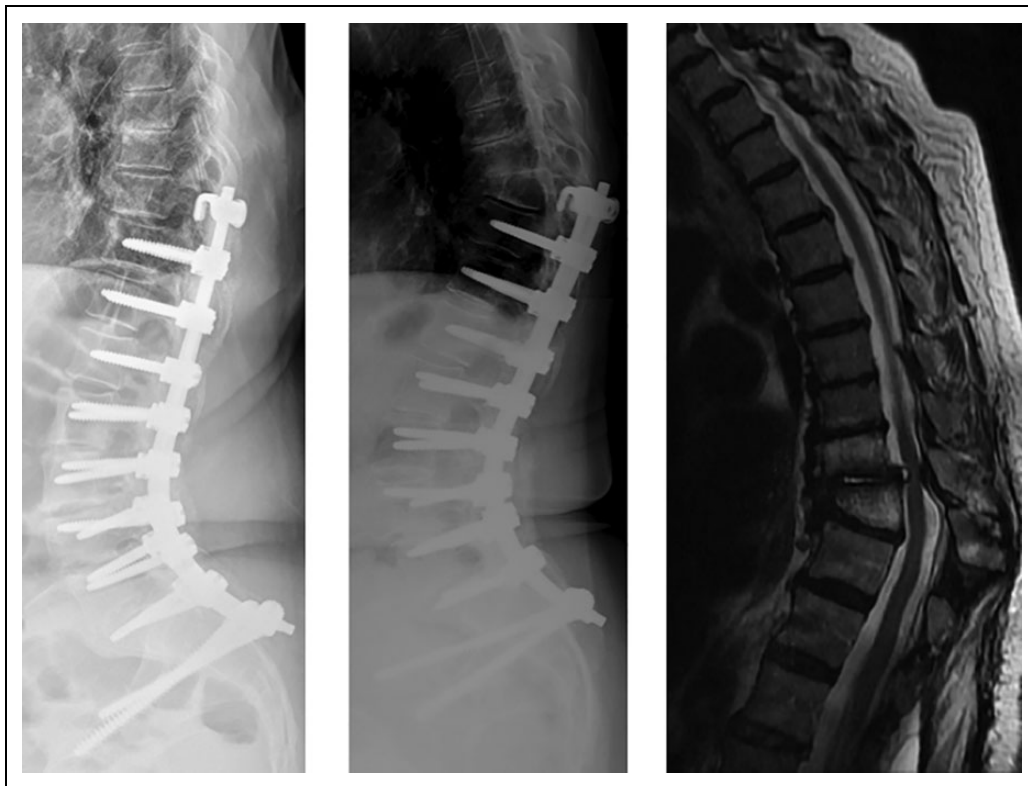


Figure 1. Radiograph of a patient who initially underwent T10-pelvis posterior spinal fusion for adult degenerative scoliosis (left panel). At 2-year follow-up (middle panel), the patient had developed proximal junctional failure at T9 with magnetic resonance imaging demonstrating severe stenosis (right panel) and neurologic deficits necessitating revision surgery.

problem following ASD surgery.⁴ There are several modes of failure leading to PJD, including vertebral compression fracture and posterior ligamentous disruption. A significant challenge in preventing PJD is that its etiology is not fully understood and is likely multifactorial.⁴ Previously reported PJD risk factors include older age, osteopenia, obesity, and a large magnitude of both preoperative sagittal imbalance and intraoperative correction.^{5,6} It is not clear that each risk factor contributes equally to each mode of failure. Certainly, a better understanding of PJD etiology will allow for more effective and individualized prevention strategies.

Sarcopenia, defined as deficient skeletal muscle mass relative to total body mass, is a risk factor for poor outcomes and increased mortality in a diverse range of medical and surgical populations.⁷⁻¹⁰ For example, sarcopenia has been associated with dropped head syndrome,¹¹ degenerative scoliosis,¹² and has been correlated with cervical spine malalignment after laminoplasty,¹³ indicating that muscle mass plays an important role in the maintenance of normal sagittal balance. Importantly, sarcopenia is a modifiable risk factor, with treatment, including resistance exercise and diet modification.^{14,15} Despite being a known risk factor for poor surgical outcomes,⁷⁻¹⁰ limited data exists on the relationship between sarcopenia and PJD.¹⁶ As a better understanding of modifiable PJD risk factors may lead to improved surgical outcomes, the aim of this study was to

determine whether sarcopenia is an independent risk factor for PJD in patients undergoing ASD surgery.

Materials and Methods

Patient Population

We hypothesized that sarcopenia (Figure 2) would be a significant, independent risk factor for development of PJD. Institutional review board approval was obtained, and this study was conducted following STROBE (Strengthening the Reporting of Observational studies in Epidemiology) guidelines. Retrospective review was performed of prospectively collected data from a single-institution clinical registry of thoracolumbar ASD patients. All patients included in the registry had an underlying diagnosis of adult degenerative scoliosis, and all patients provided consent for registry inclusion. Criteria for registry inclusion were age >18 years and at least one of the following preoperative measures of thoracolumbar deformity: sagittal vertical axis (SVA) >5 cm, coronal Cobb angle >20°, pelvic incidence–lumbar lordosis (PI-LL) mismatch >20°, or pelvic tilt (PT) >20°. All ASD patients who underwent posterolateral fusion from the thoracic spine to the pelvis, with or without anterior fusion and with a minimum of 2-year clinical and radiographic follow-up were included.

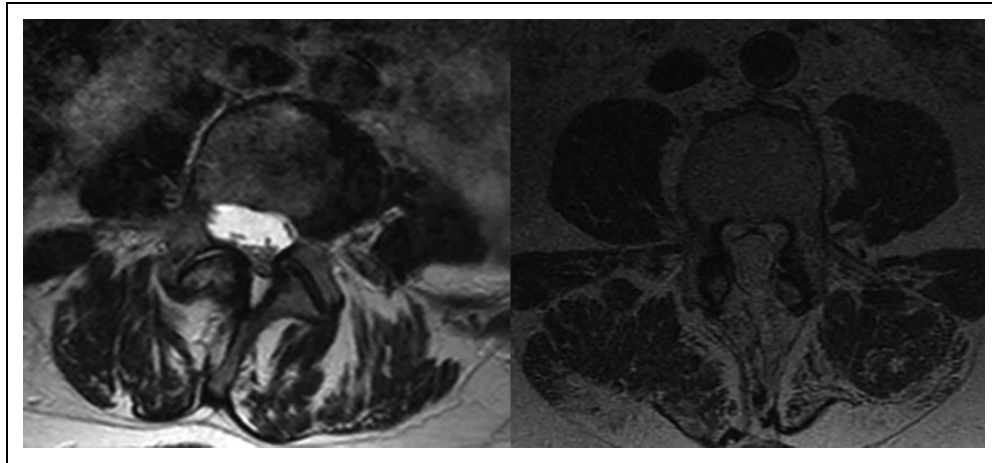


Figure 2. Example images of patients with and without sarcopenia. Left panel shows axial T2 magnetic resonance imaging (MRI) at the level of L4 pedicles in a 63-year-old woman with psoas cross-sectional area of 682 mm². She went on to develop hardware failure and proximal junctional disease (PJD), necessitating revision surgery. Right panel shows axial T2 MRI in a 69-year-old man with psoas cross-sectional area of 1996 mm²; he did not develop PJD at final follow-up.

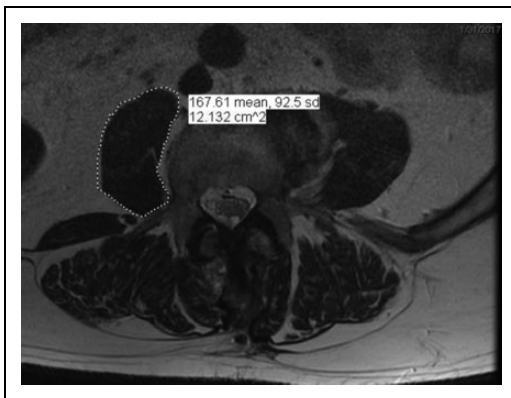


Figure 3. Measurement of psoas cross-sectional area on axial magnetic resonance imaging using region of interest tool.

Data Collection

PJK was defined as proximal junctional angle (PJA) or sagittal Cobb angle between the inferior endplate of the upper instrumented vertebra (UIV) and superior endplate of UIV + 2 of at least 10°, and an increase from preoperative PJA of greater than 10°. PJK was defined as the maximum increase in the PJA between the preoperative lateral x-ray and any postoperative lateral x-ray during the first 2 years following surgery.

Muscle mass measurement for identification of sarcopenia was performed by obtaining the average cross-sectional area of the 2 psoas muscles at the level of the L4 pedicle, as previously described.⁸ Measurements were obtained from preoperative computed tomography (CT) or magnetic resonance imaging (MRI) scan using the freehand region of interest tool (Figure 3)

in our PACS (picture archiving and communication system) system (Intellispace PACS Enterprise, Philips). A total of 21 patients had undergone preoperative CT scans of the lumbar spine or abdomen/pelvis. In these patients, axial CT Hounsfield units of trabecular bone at the L4 level were measured as an index of bone density, as previously described.^{17,18} However, bone density was not included in the final multivariable model given insufficient number of patients.

Covariates previously described as risk factors for PJD, including age, gender, body mass index (BMI), UIV in the upper versus lower thoracic spine, combined anterior/posterior fusion, 3-column osteotomy, revision surgery, preoperative SVA, and change in SVA were collected.

Statistical Analysis

Primary outcome measures included degrees of PJK and the rate of PJF. Categorical variables were compared using 2-tailed Fisher's exact test. Multivariate linear regression was performed to identify independent risk factors for PJK, and a separate multivariate linear regression was performed to identify independent risk factors for PJF. To determine whether psoas cross-sectional area should be indexed to patient size or height, multivariate regression analyses were repeated using psoas cross-sectional area corrected for patient height and for L4 vertebral body area ratios. Results of the repeated analyses were then compared using goodness of fit to the analyses performed using unadjusted psoas cross-sectional areas. Odds ratios for developing PJK and PJF were calculated based on psoas cross-sectional areas for both men and women, and subsequently used to determine disease specific thresholds for sarcopenia. Microsoft Excel (Microsoft Corp) and Wizard (version 1.9.42) were used for statistical calculations with level of significance defined as $P = .05$.

Table 1. Baseline Patient Characteristics and Surgical Variables.

Covariate	No PJK/PJF	PJK	PJF	Overall	P
Number	8 (25.0%)	20 (62.5%)	12 (37.5%)	32	n/a
Age (years)	64.3	65.6	68.8	65.7	.331
BMI (kg/m ²)	27.3	26.9	27.0	27.5	.982
Male gender	5 (62.5%)	5 (25.0%)	4 (33.3%)	12 (37.5%)	.169
Anterior fusion	2 (25.0%)	12 (60.0%)	4 (33.3%)	14 (43.8%)	.152
Revision surgery	4 (50.0%)	12 (60.0%)	4 (33.3%)	17 (53.1%)	.344
Preoperative SVA (mm)	80	65	52	72	.440
Postoperative SVA (mm)	36	37	42	37	.570
Δ SVA (mm)	43	28	10	35	.392
Preoperative PT (deg)	25	22	22	24	.710
Pelvic incidence (deg)	52	54	54	54	.964
Preoperative LL (deg)	30	39	41	36	.275
Postoperative LL (deg)	45	53	54	51	.145
Postoperative PI-LL (deg)	7	1	-1	4	.434
ΔLL (deg)	15	14	13	15	.940
Preoperative TK (deg)	35	39	41	38	.708
Postoperative TK (deg)	45	52	56	49	.265
ΔTK (deg)	11	13	14	12	.887
Psoas area (mm ²)	1552	943	917	1130	<.001

Abbreviations: PJK, proximal junctional kyphosis; PJF, proximal junctional failure; BMI, body mass index; SVA, sagittal vertical axis; PT, pelvic tilt; LL, lumbar lordosis; TK, thoracic kyphosis; n/a, not applicable.

Results

Patients and Baseline Demographics

Of 52 patients in the ASD registry, 39 underwent instrumented posterolateral spinal fusion from the thoracic spine to the pelvis. Of the 39 patients, 7 were excluded for insufficient clinical or radiographic follow-up. The remaining 32 patients were included in our study. Patient demographics, baseline radiographic characteristics, and surgical variables are summarized in Table 1; with the exception of psoas cross-sectional area, no significant difference was observed between cohorts with regard to baseline characteristics, radiographic parameters, or surgical variables. All patients in the cohort without PJD, as well as all patients in the cohort with PJF, had undergone proximal augmentation with hooks at their UIV. Three patients in the PJK cohort did not have proximal augmentation constructs; all other patients in the PJK cohort had hook augmentation at their UIV.

Table 2 lists descriptions of the index procedures performed and associated junctional complications. Among all patients, mean preoperative SVA was 72 mm, and mean postoperative SVA was 37 mm. Lumbar lordosis increased from a mean of 36° preoperatively to 51° postoperatively. Of the 32 patients, PJK and PJF occurred in 20 (62.5%) and 12 (37.5%), respectively. The mean magnitude of PJK was 16°. The rate of PJF was 33.3% in men and 40% in women ($P = .73$). The mode of PJF was construct failure in 7 patients, vertebral body fracture in 12 patients, and posterior osseo-ligamentous failure in 5 patients, with many patients having multiple simultaneous modes of failure. The mean cross-sectional psoas area was 1130 mm² (range: 518-1996 mm²), with mean of 1545 mm² in men and 880 mm² in women.

Multivariable Analysis, Disease-Specific Sarcopenia Thresholds, and Bone Density

Table 3 lists results of multivariable analysis for PJK risk factors. Of risk factors included in the analysis, only psoas cross-sectional area was significantly associated with development of PJK. Results of multivariable analysis for PJF risk factors are shown in Table 4; of the included risk factors, only revision surgery ($P = .04$) and psoas cross-sectional area ($P = .009$) were significantly associated with development of PJF. Each 1 cm² decrease in psoas cross-sectional area was associated with an increase of 2.8° of PJK (95% CI 0.7°-4.9°) and a 1.1% increase in the risk of PJF (95% CI 0.3%-1.9%). The R^2 value for the PJF regression using psoas area alone was 0.49, as compared with 0.44 after adjusting psoas cross-sectional area for patient height; R^2 was 0.41 after adjusting psoas cross-sectional area for L4 vertebral body area. Thus, we concluded that correcting psoas area for patient size did not contribute significant additional predictive capacity to the model.

Thresholds of 12 cm² in men and 8 cm² in women were found to maximize odds ratios of developing PJK. The rate of PJF was 69% in patients with psoas cross-sectional area below these thresholds and 16% in patients above these thresholds. Subanalysis of the 21 patients with preoperative CT scan demonstrated a low correlation ($R^2 = 0.02$) between psoas cross-sectional area and bone density as measured by L4 Hounsfield units.

Discussion

In this 2-year follow-up study of 32 patients who underwent surgery for ASD, decreased psoas cross-sectional area was found to be significantly associated with development of both

Table 2. Procedure Type and Junctional Complications.

Age (years) /gender	Procedure	Junctional complication
62/M	T4–pelvis PSF with anterior release	
75/M	Revision T10–pelvis PSF	T9 vertebral body fracture
67/F	T10–pelvis PSF	Revision to T3–pelvis PSF for PJK
71/M	L3 PSO, T10–pelvis PSF	
58/F	T10–pelvis PSF	
63/F	Revision T4–pelvis PSF	
75/M	L1-4 ALIF, T11–pelvis PSF	
58/F	T10–pelvis PSF	
67/F	L1-5 ALIF, T10–pelvis PSF	
63/F	T4–pelvis PSF	T3 vertebral body fracture, dislodgement of proximal hook
64/F	T8 PCO, L3 PSO, T4–pelvis PSF	
72/M	L3 PSO, T10–pelvis PSF	Removal of prominent proximal instrumentation due to PJK
63/M	T10–pelvis PSF	
73/F	T10–pelvis PSF	Revision to T4–pelvis PSF and then C2–pelvis PSF due to PJK
61/M	T10–pelvis PSF	
59/F	T10–pelvis PSF	Revision to T4–pelvis PSF due to PJK
75/F	T4–pelvis PSF	
67/F	L1-5 ALIF, T10–pelvis PSF	Revision to T4–pelvis PSF due to PJK
67/F	T4–pelvis PSF	T3 vertebral body fracture
67/F	L3 PSO, T4–pelvis PSF	
79/M	L3 PSO, T10–pelvis PSF	T10 vertebral body fracture
80/F	T10–pelvis PSF	Revision to T4–pelvis PSF due to PJK
67/F	Revision T3–pelvis PSF	
65/F	ALIF L1-5, T10–pelvis PSF	
63/F	T2–pelvis PSF	T2 vertebral body fracture requiring revision to C5–pelvis PSF with T2 VCR
51/F	T12–L5 ALIF, T5–S1 PSF	
61/M	T10–pelvis PSF	T9 vertebral body fracture
69/M	L3-5 ALIF, T10–pelvis PSF	
70/M	L1-4 ALIF, T10–pelvis PSF	
51/F	L5/S1 ALIF, L3 PSO, T3–pelvis PSF	
55/F	L2 PSO, T10–pelvis PSF	
63/M	L2 PSO, T4–pelvis PSF	

Abbreviations: F, female; M, male; PJK, proximal junctional kyphosis; PSF, posterior spinal fusion; ALIF, anterior lumbar interbody fusion; PSO, pedicle subtraction osteotomy; VCR, vertebral column resection.

Table 3. Multivariate Linear Regression of Proximal Junctional Kyphosis Risk Factors.

Risk factor	Coefficient	P
Psoas area (mm ²)	−0.03	.02
Preoperative SVA (mm)	−0.11	.29
Body mass index	0.91	.13
Change in SVA (mm)	0.11	.18
Revision surgery	6.8	.31
Postoperative PI-LL	−0.21	.33
Male gender	7.1	.43
Anterior/posterior fusion	2.6	.57
3-column osteotomy	1.04	.88
Age	0.02	.96
Upper thoracic fusion	−0.05	.99

Abbreviations: SVA, sagittal vertical axis; PI-LL, pelvic incidence – lumbar lordosis mismatch

Table 4. Multivariate Linear Regression of Proximal Junctional Failure Risk Factors.

Risk factor	Coefficient	P
Psoas area (mm ²)	−0.001	.009
Revision surgery	−0.54	.04
Male gender	0.58	.10
3-column osteotomy	0.36	.19
Change in SVA (mm)	−0.003	.28
Preoperative SVA (mm)	0.003	.44
Anterior/posterior fusion	−0.09	.61
Age	−0.007	.69
Upper thoracic fusion	−0.08	.69
Body mass index	−0.005	.81
Postoperative PI-LL	0.001	.94

Abbreviations: SVA, sagittal vertical axis; PI-LL, pelvic incidence – lumbar lordosis mismatch.

PJK and PJF after adjusting for previously described PJD risk factors. The association between psoas cross-sectional area and PJD was stronger than the association between PJD and other previously described PJD risk factors. Further analysis

demonstrated that threshold psoas cross-sectional areas of 12 cm² in men and 8 cm² in women could predict development of PJD and may serve as reference values for defining sarcopenia in ASD patients.

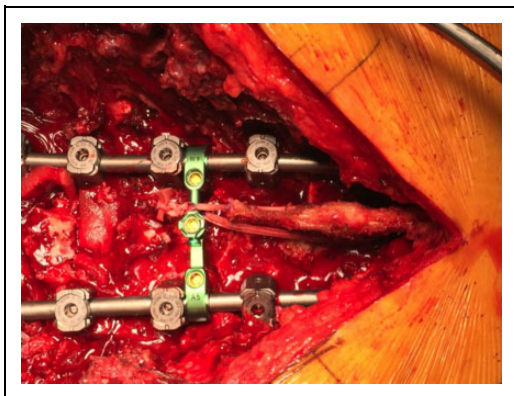


Figure 4. Intraoperative photo showing ligament augmentation with polyester fiber tape as a prophylaxis measure against proximal junctional kyphosis (PJK). The tape is passed through the spinous process of the upper instrumented vertebra and tensioned through a crosslink, tethering the junctional zone against flexion deformity forces.

To our knowledge, no studies have attempted to establish thresholds for defining sarcopenia in ASD, and only one other study has evaluated the relationship between sarcopenia and PJD. In their study of 49 ASD patients, Kim et al¹⁶ found sarcopenia to be significantly associated with PJK but did not adjust for other known PJD risk factors, such as BMI. In addition to Kim et al,¹⁶ there is evidence that skeletal muscle plays an important role as a dynamic stabilizer of spinal alignment. For example, dropped head syndrome is associated with sarcopenia as well as a variety of myopathies.^{11,19,20} PJK has also been linked to neuromuscular diseases such as diabetic neuropathy, prior stroke, and metabolic encephalopathy.²¹ These previous studies, when combined with our findings, suggest that a complete risk assessment and prevention strategy for PJD needs to account for muscle strength and control.

Our study has important clinical implications. First, as psoas cross-sectional area is easily measured on standard preoperative imaging, surgeons should consider integrating psoas cross-sectional measurements into their preoperative workup. Patients identified as higher risk for PJK based on psoas cross-sectional area may subsequently be referred to physical therapy for preoperative strengthening, dieticians for nutritional optimization, or other specialists for appropriate management of comorbidities contributing to sarcopenia. In addition, preoperative identification of sarcopenia can help with preoperative planning, as these patients may benefit from augments such as tethers (Figure 4) to reduce their risk of PJD.²²

Strengths of our study include multivariable analyses, 2-year follow-up data, and use of well-defined and easily adopted radiographic parameters, which increase generalizability of our results. For example, we chose to use psoas cross-sectional area as an index of sarcopenia, as it is the most commonly used index of skeletal muscle mass in previous studies of the relationship between sarcopenia and clinical outcomes.^{8,9,23} Psoas cross-sectional area has been closely correlated with other assessments of sarcopenia, including measurement of muscle

mass on dual-energy x-ray absorptiometry (DEXA),²⁴ bioimpedance analysis,²⁴ grip strength,²⁵ and serum markers of muscle atrophy.²⁶

This study has several limitations. Generalizability is limited by small sample size and single-institution data. However, while the study was limited by its sample size, the strong correlation of sarcopenia with PJD suggests that sarcopenia may be among the strongest predictors of PJD. Further studies with larger patient populations will be necessary to objectively compare effect sizes of various PJD risk factors. The small sample size may also explain the decrease in R^2 value when adjusted psoas cross-sectional area was included in the regression model. We specifically used the R^2 value to determine whether adjustment of psoas cross-sectional area measurements would allow the model to more precisely fit patients' risk for developing PJD. With the finding that utilizing unadjusted versus adjusted psoas cross-sectional area had minimal impact on the model's fit of the data points, we decided to not include adjusted psoas cross-sectional area in the final model. The rationale for not including adjusted cross-sectional area is that this would introduce extra variables and potential bias into the model. Interestingly, the R^2 value decreased when the adjusted, rather than nonadjusted psoas cross-sectional area was included in the model; however, this may be due to addition of more data points in the model. These specific data points included L4 vertebral body cross-sectional area and patient height, which were used separately to adjust psoas cross-sectional area, and which themselves were susceptible to additional measurement errors and outliers. The effect of such measurement errors and outliers may be compounded by the relatively small sample size of the study population. Given the small sample size, it is unlikely that any meaningful conclusion can be drawn from the decrease in R^2 when adjusted psoas cross-sectional area is included in the model.

In addition to sample size, additional limitations include the study's retrospective design, which precluded our ability to demonstrate a causative link between sarcopenia and PJD. Furthermore, while sarcopenia may be treated through exercise and nutrition,^{14,15} it is unknown whether such interventions would decrease surgical complication rates. Our study is also limited by the lack of bone mineral density data on all patients, as osteopenia may contribute to PJK.¹⁶ We attempted to use CT Hounsfield units of trabecular bone as a substitute for DEXA data, as this has been correlated with DEXA assessment of bone density and fracture risk.^{17,18} With CT data, we did not find a correlation between osteopenia and sarcopenia. However, prior studies have reported a link between the conditions.²⁷ While osteopenia and sarcopenia may both result from and be signs of overall frailty, there is evidence that the relationship is site specific; leg muscle strength has been shown to be more predictive of proximal femoral bone density than total body skeletal muscle mass.²⁸ This implies that the 2 conditions may have a direct relationship due to local mechano-transductive effects, and as such, addressing sarcopenia may reduce the risk of PJK attributed to reduced bone mineral density.

In conclusion, we found that decreased psoas cross-sectional area is significantly associated with risk of developing PJD and were able to define disease-specific thresholds for sarcopenia in ASD. This is significant, as sarcopenia is a potentially modifiable PJD risk factor. As such, preoperative identification of sarcopenia may inform both preoperative patient optimization, as well as use of adjuncts when preoperative planning. Future studies should assess disease specific sarcopenia thresholds in ASD, as well as outcomes following interventions for sarcopenia.


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: Dr Klineberg has worked as a consultant for DePuy Synthes Spine, Stryker, and Medtronic, and Drs Klineberg and Javidan have received honoraria and a fellowship grant for University of California, Davis from AOSpine. Dr Javidan has worked as a consultant for NuVasive, Alphatec, and Stryker, holds stocks in Alphatec, and has served as a consultant for Medtronic.

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References

- Bess S, Line B, Fu KM, et al. The health impact of symptomatic adult spinal deformity: comparison of deformity types to United States Population Norms and chronic diseases. *Spine (Phila Pa 1976)*. 2016;41:224-233.
- Smith JS, Klineberg E, Schwab F, et al. Change in classification grade by the SRS-Schwab Adult Spinal Deformity Classification predicts impact on health-related quality of life measures: prospective analysis of operative and nonoperative treatment. *Spine (Phila Pa 1976)*. 2013;38:1663-1671.
- Kim HJ, Bridwell KH, Lenke LG, et al. Patients with proximal junctional kyphosis requiring revision surgery have higher postoperative lumbar lordosis and larger sagittal balance corrections. *Spine (Phila Pa 1976)*. 2014;39:E576-E580.
- Nguyen NL, Kong CY, Hart RA. Proximal junctional kyphosis and failure—diagnosis, prevention, and treatment. *Curr Rev Musculoskelet Med*. 2016;9:299-308.
- Kim YJ, Bridwell KH, Lenke LG, Glattes CR, Rhim S, Cheh G. Proximal junctional kyphosis in adult spinal deformity after segmental posterior spinal instrumentation and fusion: minimum five-year follow-up. *Spine (Phila Pa 1976)*. 2008;33:2179-2184.
- O'Leary PT, Bridwell KH, Lenke LG, et al. Risk factors and outcomes for catastrophic failures at the top of long pedicle screw constructs: a matched cohort analysis performed at a single center. *Spine (Phila Pa 1976)*. 2009;34:2134-2139.
- Nakanishi R, Oki E, Sasaki S, et al. Sarcopenia is an independent predictor of complications after colorectal cancer surgery. *Surg Today*. 2018;48:151-157.
- Bokshan SL, Han AL, DePasse JM, et al. Effect of sarcopenia on postoperative morbidity and mortality after thoracolumbar spine surgery. *Orthopedics*. 2016;39:e1159-e1164.
- Nakamura R, Inage Y, Tobita R, et al. Sarcopenia in Resected NSCLC: effect on postoperative outcomes. *J Thorac Oncol*. 2018;13:895-903.
- Matsuo Y, Mitsuyoshi T, Shintani T, Iizuka Y, Mizowaki T. Impact of low skeletal muscle mass on non-lung cancer mortality after stereotactic body radiotherapy for patients with stage I non-small cell lung cancer. *J Geriatr Oncol*. 2018;9:589-593.
- Eguchi Y, Toyoguchi T, Koda M, et al. The influence of sarcopenia in dropped head syndrome in older women. *Scoliosis Spinal Disord*. 2017;12:5.
- Eguchi Y, Suzuki M, Yamanaka H, et al. Associations between sarcopenia and degenerative lumbar scoliosis in older women. *Scoliosis Spinal Disord*. 2017;12:9.
- Koshimizu H, Sakai Y, Harada A, Ito S, Ito K, Hida T. The impact of sarcopenia on cervical spine sagittal alignment after cervical laminoplasty. *Clin Spine Surg*. 2018;31:E342-E346.
- Yoshimura Y, Wakabayashi H, Yamada M, Kim H, Harada A, Arai H. Interventions for treating sarcopenia: a systematic review and meta-analysis of randomized controlled studies. *J Am Med Dir Assoc*. 2017;18:553.e551-e553.e516.
- Pinto CL, Botelho PB, Carneiro JA, Mota JF. Impact of creatine supplementation in combination with resistance training on lean mass in the elderly. *J Cachexia Sarcopenia Muscle*. 2016;7:413-421.
- Kim DK, Kim JY, Kim DY, Rhim SC, Yoon SH. Risk factors of proximal junctional kyphosis after multilevel fusion surgery: more than 2 years follow-up data. *J Korean Neurosurg Soc*. 2017;60:174-180.
- Pickhardt PJ, Pooler BD, Lauder T, del Rio AM, Bruce RJ, Binkley N. Opportunistic screening for osteoporosis using abdominal computed tomography scans obtained for other indications. *Ann Intern Med*. 2013;158:588-595.
- Marinova M, Edon B, Wolter K, Katsimbari B, Schild HH, Strunk HM. Use of routine thoracic and abdominal computed tomography scans for assessing bone mineral density and detecting osteoporosis. *Curr Med Res Opin*. 2015;31:1871-1881.
- Karaoglu P, Quizon N, Pergande M, et al. Dropped head congenital muscular dystrophy caused by de novo mutations in LMNA. *Brain Dev*. 2017;39:361-364.
- Garibaldi M, Pennisi EM, Bruttini M, et al. Dropped-head in recessive oculopharyngeal muscular dystrophy. *Neuromuscul Disord*. 2015;25:869-872.
- Glassman SD, Coseo MP, Carreon LY. Sagittal balance is more than just alignment: why PJK remains an unresolved problem. *Scoliosis Spinal Disord*. 2016;11:1.
- Safae MM, Osorio JA, Verma K, et al. Proximal junctional kyphosis prevention strategies: a video technique guide. *Oper Neurosurg (Hagerstown)*. 2017;13:581-585.

23. Mitchell PM, Collinge CA, O'Neill DE, Bible JE, Mir HR. Sarcopenia is predictive of 1-year mortality after acetabular fractures in elderly patients. *J Orthop Trauma*. 2018;32:278-282.
24. Yanishi M, Kinoshita H, Tsukaguchi H, et al. Dual energy X-ray absorptiometry and bioimpedance analysis are clinically useful for measuring muscle mass in kidney transplant recipients with sarcopenia. *Transplant Proc*. 2018;50:150-154.
25. Reeve TET, Ur R, Craven TE, et al. Grip strength measurement for frailty assessment in patients with vascular disease and associations with comorbidity, cardiac risk, and sarcopenia. *J Vasc Surg*. 2018;67:1512-1520.
26. Okugawa Y, Yao L, Toiyama Y, et al. Prognostic impact of sarcopenia and its correlation with circulating miR-21 in colorectal cancer patients. *Oncol Rep*. 2018;39:1555-1564.
27. Hida T, Shimokata H, Sakai Y, et al. Sarcopenia and sarcopenic leg as potential risk factors for acute osteoporotic vertebral fracture among older women. *Eur Spine J*. 2016;25:3424-3431.
28. Sherk VD, Palmer IJ, Bemben MG, Bemben DA. Relationships between body composition, muscular strength, and bone mineral density in estrogen-deficient postmenopausal women. *J Clin Densitom*. 2009;12:292-298.