European Spine Journal (2022) 31:364–379
https://doi.org/10.1007/s00586-021-07052-3

REVIEW ARTICLE

The predictive value of preoperative paraspinal muscle morphometry on complications after lumbar surgery: a systematic review

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Received: 28 January 2021 / Revised: 18 July 2021 / Accepted: 1 November 2021 / Published online: 12 November 2021

Abstract

Purpose The effect of paraspinal muscles atrophy and fat infiltration (FI) on the complications of spinal surgery has not been established.

Methods A review of the literature was conducted from a search of the PubMed, EMBASE, and Web of Science databases from inception through January 2021. The literature was searched and assessed by independent reviewers based on criteria that included an assessment of preoperative paraspinal muscle morphology in addition to measuring its relationship to surgical complications. All relevant papers were assessed for risk of bias according to the modified Newcastle Ottawa Scale and the Joanna Briggs Institute Critical Appraisal Tools. A narrative synthesis was conducted.

Results The initial search yielded 5632 studies, of which 16 studies were included in the analysis. All included studies were at a low risk of bias. There existed strong evidence that the atrophy and FI of paraspinal muscles had an association with the development of bone nonunion (two high quality studies), pedicle screw loosening (two high quality studies), adjacent segment degeneration (three high quality studies) and proximal junctional kyphosis (five high quality studies) after lumbar surgery. Besides, there is also limited evidence for association between atrophy and FI of paraspinal extensor muscles and less local and global curve improvement.

Conclusions Strong evidence was found for an association between preoperative paraspinal muscle degeneration and multiple postoperative complications after lumbar surgery. However, the findings should be interpreted with caution due to the small quantity of the available literature and high heterogeneity among studies.

Keywords Atrophy · Complication · Fat infiltration · Lumbar surgery · Paraspinal muscle

Introduction

Spine surgery, a common therapeutic adjunct in degenerative spinal diseases, has noticeably increased over the years [1]. However, this is associated with a growth in the frequency of postoperative complications after spinal surgery [2, 3], even more than 30% patients have underwent revision surgery for complications in degenerative lumbar diseases [4]. Studies have revealed that the paraspinal muscle degeneration, a universal phenomenon among old people, is implicated in multiple degenerative lumbar pathologies [5–7]. Thus, the atrophy and fat infiltration (FI) of multifidus (MF), erector spinae (ES) and psoas major (PS) serving as primary extensor and flexor muscles may be closely related to patients' clinical outcomes.

Currently, the value of preoperative paraspinal muscle morphometry on image examination is being unearthed, which has been assessed as a prognostic factor for several surgical disciplines [8–10]. Paraspinal muscle morphometry can be visibly characterized by a decreased cross-sectional area (muscle atrophy) and an increase in fat content (fat infiltration). With manual definition of region of interest and several threshold methods, the cross-sectional area and FI

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can be measured on magnetic resonance imaging. Although substantial work has been carried out to identify potential factors for spine surgery prognosis [11, 12], few unequivocal predictive factors related with paraspinal muscle have come to light. Some reviews previously concluded the degree of preoperative paraspinal muscle degeneration in relation to disability and persistent pain after surgery [13, 14], whereas no review has focused on the predictive value of paraspinal muscles on complications.

Objectives

The objective of this review is to investigate the association between preoperative paraspinal muscle morphology on MRI and common complications after surgery, inclusive of bone nonunion, pedicle screw loosening, adjacent segment degeneration, proximal junctional kyphosis and sagittal imbalance, in adults with degenerative lumbar spine diseases.

Methods

Literature search strategy

The Preferred Reporting Items for Systematic Reviews and Meta—Analyses (PRISMA) statement was used to structure this systematic review. To retrieve interrelated articles, we conducted a search in the following three databases: PubMed, EMBASE, and Web of Science databases from inception through January 2021. All fields were searched for these terms: "paraspinal muscle", "paravertebral muscle", "multifidus", "erector spinae" or "psoas major"; and "surgery", "operative", "complication", "clinical outcome" or "functional status"; and "lumbar" or "lumbosacral".

Eligibility criteria

Two authors assessed all abstracts and titles to rate adherence to review criteria. Inclusion criteria consisted of the following: (1) articles including adult with degenerative lumbar diseases; (2) assessment of any lumbar paraspinal muscle characteristic on magnetic resonance imaging (MRI) preoperatively; (3) assessment of any complications after lumbar surgery; (4) analyzed the relationship between preoperative imaging data and postoperative outcomes; and (5) articles were published in English. Studies were excluded if they included subjects < 18 years of age; assessed lumbar muscles through nonconventional MRI (such as functional MRI, MR spectroscopy and chemical-shift MRI); included only postsurgical data. Studies included randomized controlled trials, case–control studies, case series and cohort studies.

Study selection

We screened titles and abstracts for relevant articles from the electronic search based on the eligibility criteria. Relevant full-text articles were obtained and then assessed in the same manner. The study selection process is illustrated in Fig. 1.

Assessment of risk of bias

We used the modified Newcastle Ottawa Scale (NOS) [15] for case–control studies and cohort studies and the Joanna Briggs Institute (JBI) Critical Appraisal Tools for case series [16] to evaluate potential bias on account of no one-fold, widely accepted tool for evaluating the risk of bias in prognostic studies. All articles meeting review criteria were evaluated independently for risk of bias by two authors, with any differences in assessment resolved by discussions until consensus was reached. For case–control studies and cohort studies, we regarded studies achieving six or more points as high quality. For case series, we regarded studies achieving eight or more points as high quality.

Data extraction

Two authors independently extracted the following information from included studies: study design, participant characteristics, details of MRI assessments of preoperative lumbar muscle characteristics, and clinical outcomes that were relevant to our research question.

Clinical outcome variables

Clinical outcome measures included were bone nonunion (measured using dynamic lumbar X-rays or computed tomography), pedicle screw loosening (measured using spine radiographs or computed tomography), adjacent segment degeneration (diagnosed based on the flexion and extension lateral radiography or on MRI), proximal junctional kyphosis (measured using full spine radiographs) and sagittal imbalance (defined as the deterioration of local alignment or global alignment on full spine radiographs).

Levels of evidence

We performed a qualitative summary of the evidence for lumbar muscle characteristics as predictors of complications, using definitions for levels of evidence applied in previous systematic reviews [17, 18]: "strong" evidence was

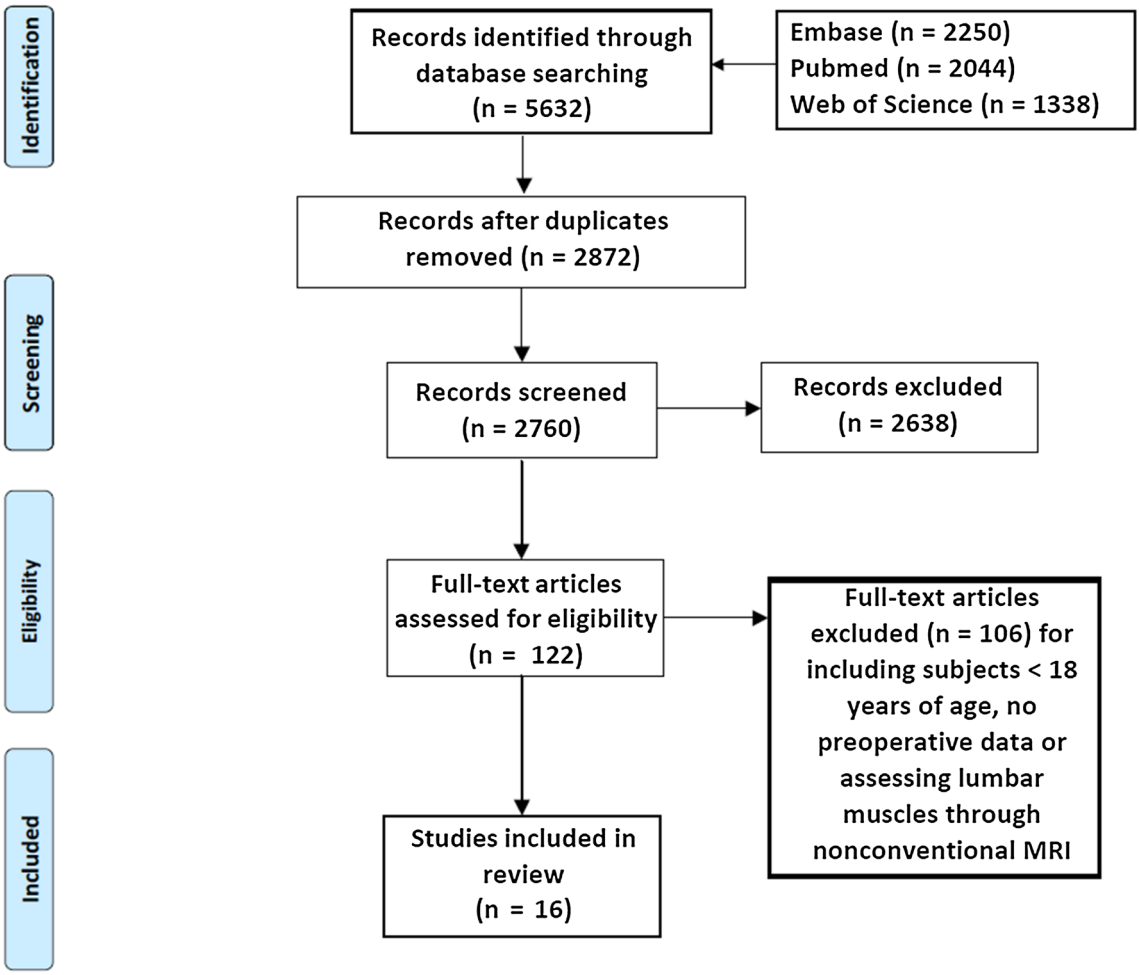

Fig. 1 PRISMA diagram showing the flow of studies through phases of the review

defined as consistent findings (≥ 80%) in at least two high-quality studies; "moderate" evidence was defined as one high-quality study and consistent findings (≥ 80%) in one or more low-quality studies; "limited" evidence was defined as findings in one high-quality study or consistent findings (≥ 80%) in one or more low-quality studies; "conflicting" evidence was defined as inconsistent findings irrespective of study quality.

Synthesis of results

For evaluating the level of evidence, we decided in advance not to require the consistency of diseases, surgeries and follow-up duration between studies due to high heterogeneity. For abating the effect of heterogeneity, we conducted subgroup analyses in each complication according to measured paraspinal muscles and its method of morphology measure. Similar subgroup analyses were performed by previous studies [14, 19]. We defined the paraspinal extensor muscle (PSE) group as the integrity of MF and ES. The parameters of muscle atrophy included the cross-sectional area of total and lean paraspinal muscles declined; and the parameters of FI covered the percentage of fat content increased and signal intensity of muscles increased. Considering the data obtained from the included literatures was clinically heterogeneous, meta-analysis analysis was precluded. Instead, a narrative synthesis was conducted.

Results

Study selection

We identified 5632 studies through database searching. Of these articles, 122 were deemed to be eligible for full-text review. A total of 16 articles were included. All included studies investigated the correlation between a measure of preoperative paraspinal muscles (e.g. greater tCSA and/

or low FI) and at least one complication at follow-up. The search flow diagram is shown in Fig. 1.

Study characteristics and results of assessment of risk of bias

The characteristics of the included studies are summarized in Table 1. Of the 16 included studies, three studies investigated participants with lumbar spinal stenosis (LSS) [20–22], three studies investigated degenerative lumbar scoliosis (DLS) [21, 23, 24], one study investigated degenerative flat back [25], one study investigated spondylolisthesis [26] and 9 investigated multiple degenerative lumbar diseases [27–35]. Three studies examined the effect of preoperative paraspinal muscles on bone nonunion [20, 27, 28], two studies examined screw loosening [23, 29], four studies examined ASD [26, 30, 32, 35], five studies examined PJK [21, 24, 31, 33, 34], and two studies examined studies examined sagittal imbalance [22, 25]. For paraspinal muscle morphometry, 6 investigated muscle CSA only [20, 27, 29, 30, 33, 34], 2 investigated FI only [26, 28] and 8 investigated both [21–25, 31, 32, 35]. All included studies examined paraspinal muscle morphology on MRI. There were 12 case–control studies [20, 23, 24, 26–29, 31–35], 1 cohort studies [21] and 3 case series studies [22, 25, 30]. In line with assessment of risk of bias, all studies were rated as high quality (Table 2).

Results of individual studies

Bone nonunion

The strong evidence from two high quality studies showed that the atrophy of both PSE and PS was related to the bone nonunion at follow-up (Table 3). Two studies by Choi et al. [20, 27] included patients with degenerative lumbar diseases who were performed posterior lumbar interbody fusion (PLIF) using stand-alone cages. They found that nonunion group had a smaller tCSA of MF, ES and PS at lower lumbar segments than union group. Besides, Choi et al. [20] furtherly demonstrated that the PSE CSA and PS CSA were negatively correlated with time to fusion. Moreover, limited evidence from one high quality study indicated that the FI of PSE was associated with bone nonunion rate (Table 3). In Lee et al.'s study [28], they reported that the union rate decreased as the fat content of extensor muscles increased at L3-S1 in patients with degenerative lumbar diseases after instrumented fusion. Furtherly, they found that paraspinal muscle FI of ≥ grade 2 evaluated by Goutallier scale could be a cut-off value.

Pedicle screw loosening

Strong evidence from 2 high quality studies found that the atrophy of PSE was associated with screw loosening at follow-up. However, there was conflicting evidence from 2 high quality studies that the FI of PSE was associated with screw loosening. As for PS, limited evidence from 1 high quality study showed that the FI of PS, not the atrophy, was associated with screw loosening (Table 3). A case–control study by Kim et al. investigated the patients who underwent lumbosacral interbody fusion and pedicle screw fixation including L5–S1 [29]. The results figured that smaller CSAs and higher T2 signal intensity in both MF and ES at L5–S1 were related with screw loosening, while PS did not show any difference between S1 screw loosening group and non-loosening group at 1-year follow-up. Another case–control study by Leng et al. [23] included DLS patients underwent corrective surgery and divided them into two groups: group A had six or more fused levels and group B had four or five fused levels. They found that only in group A, patients with lower instrumented vertebra (LIV) screw loosening had a significantly higher muscle-fat index (MFI) of PS and a lower relative functional CSA (FCSA) and relative tCSA of ES at L4-5 and L5-S1.

Adjacent segment degeneration

Strong evidence from 3 high quality studies showed that both atrophy and FI of PSE were associated with the development of ASD at follow-up (Table 3). Kim et al. [31] divided patients who underwent PLIF for degenerative lumbar disease into ASD group and non-ASD group. They found that a smaller relative CSA and a higher FI of PSE at L4-5 were significant factors for ASD. In Chang's study, patients were included if they had undergone additional surgery for symptomatic ASD after lumbar fusion and were matched to control group [32]. Similarly, they found that the mean FCSA, the ratio of the FCSA to the tCSA, and the skeletal muscle index of the FCSA of the paraspinal muscles group were significantly smaller in patients with ASD compared to the control group. Duan et al. reported that MF FI was most significant at L3 in patients undergoing single-level transforaminal lumbar interbody fusion for spondylolisthesis with ASD than in those without ASD [26]. In addition, limited evidence from 1 high quality study showed that the atrophy of PS was associated with ASD (Table 3). Verla et al. [30] demonstrated that decreased PS thickness at L4-5 was associated with ASD among patients undergoing lumbar fusion.

Proximal junctional kyphosis

There was strong evidence from 5 high quality studies that both atrophy and FI of PSE were associated with proximal

Table 1 Study characteristic

Authors	Year	Study design	Participants characteristic	Mean age (years)	Follow-up	Disease	Surgery	Muscle morphology	Imaging characteristic	Complication
Choi [27]	2016	Retrospective case–control	68, female 32.4% (union group) 21, female 47.6% (nonunion group)	51.7 (union group) 58.4 (nonunion group)	20.4 ± 6.9 months (union group) 23.1 ± 7.8 months (nonunion group)	Degenerative lumbar diseases	Stand-alone cages PLIF at L4-5	FCSA of PS, ES and MF at level L3-4, L4-5, L5-S1	Axial T2-weighted MRI images	Bone nonunion
Lee [28]	2010	Retrospective case–control	280, female 80.71% (Union) 47, female 78.72% (Non-union)	Age < 55 years: 24.29% (Union) 12.77% (Non-union)	4.7 years; Range, 1–12.7 years	Degenerative lumbar diseases	Instrumented fusion including lumbosacral junction without additional iliac or S2 fixation	FI of lumbar paraspinal muscles at L3-4, L4-5, L5-S1	Axial T2-weighted MRI images	Bone nonunion
Choi [20]	2017	Retrospective case–control	L3-4: 48, female 43.75% (fusion group) 7, female 42.86% (non-fusion group) L4-5: 118, female 42.37% (fusion group) 19, female 52.63% (non-fusion group)	L3-4: 52.9 (fusion group); 60.1 years (non-fusion group) L4-5: 57.4 (fusion group); 59.2 (non-fusion group)	L3-4: 81.4 ± 22.4 weeks (fusion group); 89.5 ± 27.8 weeks (non-fusion group) L4-5: 83.1 ± 20.5 weeks (fusion group); 91.4 ± 28.1 weeks (non-fusion group)	Symptomatic LSS	PLIF (L3-4 and L4-5)	FCSA of PS, PSE from L2-3 to L5-S1	Axial T2-weighted MRI images	Bone nonunion
Kim JB[29]	2015	Retrospective case–control	38, female 52.6% (S1 screw loosening group) 118, female 57.6% (non-loosening group)	62.6 ± 7.1 (loosening group) 56.7 ± 13.6 (non-loosening group)		Degenerative lumbar diseases	Lumbosacral interbody fusion and pedicle screw fixation surgery	CSA and mean signal intensity of MF, ES (longissimus muscle and iliocostalis muscles) and PS at level L5-S1	Axial T2-weighted MRI images	S1 screw loosening

Table 1 (continued)

Authors	Year	Study design	Participants characteristic	Mean age (years)	Follow-up	Disease	Surgery	Muscle morphology	Imaging characteristic	Complication
Leng [23]	2020	Retrospective case–control	Group A (≥6 fused levels): 40, female 90.0% (LIV screw loosening) 28, female 85.7% (unloosening) Group B (4 or 5 fused levels): 37, female 62.2% (LIV screw loosening) 32, female 90.6% (unloosening)	Group A: 60.9 ± 7.0 (LIV screw loosening) 61.6 ± 6.1 (unloosening) Group B: 65.1 ± 5.6 (LIV screw loosening) 62.8 ± 5.5 (unloosening)	≥1 years	DLS	Corrective surgery	RCSA and MFI of PS, ES and MF at middle slices of L4-5 and L5-S1 intervertebral discs	Axial T2-weighted MRI images	LIV screw loosening
Verla [30]	2016	Retrospective case series	257 female 45.3%	58.15 ± 14.96	15.7 months	Multiple (≥1 levels) degenerative lumbar diseases	PLIF	Thickness of PS at level L1-5	Axial T1-weighted MRI images	ASD
Kim [35]	2016	Retrospective case–control	50, female 70% (ASD group) 50, female 70% (control group)	60.80 ± 6.61 (ASD) 60.82 ± 6.43 (control)	42.98 months (ASD) 40.83 months (control)	Degenerative lumbar diseases	Posterior lumbar fusion surgery	RCSA and FI of paraspinal muscles (MF, ES) and PS at level L4-5	Axial T2-weighted MRI images	ASD
Chang [32]	2019	Retrospective case–control	50, female 74% (ASD group) 50, female 68% (control group)	61.4 ± 9.1 (ASD) 61.3 ± 9.3 (control)	59.1 ± 34.2 (ASD) 56.9 ± 45.9 (control)	Symptomatic ASD	Additional surgery after lumbar fusion	TCSA, fCSA and SMI of paraspinal muscles (MF, ES) and PS at level L4-5	Axial T2-weighted MRI images	ASD
Duan [26]	2020	Retrospective case–control	178	\	>2 years	Spondylolisthesis	Single-level L4-5 TLIF	FI of the MF at L3, L4, L5	Axial T2-weighted MRI images	ASD

Table 1 (continued)

Authors	Year	Study design	Participants characteristic	Mean age (years)	Follow-up	Disease	Surgery	Muscle morphology	Imaging characteristic	Complication
Hyun [31]	2016	Retrospective case–control	17, female 94.1% (PJK group) 27, female 85.2% (non-PJK group)	64.7 ± 7.3 (PJK) 63.4 ± 7.3 (non-PJK)	At least 2 years follow-up	Adult spinal deformity	Multilevel spinal instrumented fusion surgery (stopping at thoracolumbar junction: T9-L2)	CSA of muscle-vertebral body ratio and FI of ES and MF at each level (inferior endplate of T10, T11, T12, L1, and L2)	Axial T2-weighted MRI images	PJK
Yagi [21]	2016	Retrospective, matched cohort	120, female 100%	68.0 ± 6.8 (DLS) 67.1 ± 8.9 (LSS)	4.3 ± 1.4 years (DLS)2.9 ± 1.9 (LSS)	DLS and LSS	Posterior correction and fusion surgery	avCSA and FI of MF and PS at level L5-S1	Axial T2-weighted MRI images	PJK
Zhu [33]	2018	Retrospective case–control	female 71.9% (all participants)	67.9 ± 15 (PJK) 65.0 ± 9.5 (non-PJK)	34 months (all participants)	Degenerative lumbar diseases	Fusion of L5 and all the upper instrumented vertebrae in the thoracolumbar spine (T9-L2)	rfCSA (the ratio of the FCSA to the total area of the disc) of MF at level L4-5	Axial T2-weighted MRI images	PJK
Pennington [34]	2019	Retrospective case–control	169, female 65.7%	66.1 (PJK) 62.6 (non-PJK)	At least 6 months follow-up	Degenerative lumbar diseases	Thoracolumbosacral fusion (> 2 levels)	RCSA of the paraspinal muscles at the upper instrumented vertebrae	Axial T2-weighted MRI images	PJK
Lee [25]	2017	Retrospective case series	45, female 91.1%	69.9 ± 6.01	6 months	Degenerative flat back	Corrective surgery	the ratio of CSA between PSE and disc at the same level and FI of MF and ES from level L1-2 to L4-5	Axial T2-weighted MRI images	Thoracic/lumbar angle improvement

Table 1 (continued)

Authors	Year	Study design	Participants characteristic	Mean age (years)	Follow-up	Disease	Surgery	Muscle morphology	Imaging characteristic	Complication
Dohzono [22]	2016	Retrospective case series	61, female 50.8%	69.4	29.9 ± 14.8 months	LSS	Microendoscopic laminotomy surgery	TCSA and FI of MF and ES at level L2–3, L3–4, and L4–5 The percentage of FI was assessed using threshold technique	Axial T2-weighted MRI images	SVA improvement
Yuan [24]	2020	Retrospective case–control	17, female 88.23% (PJK) 67, female 83.58% (non-PJK)	63.53 ± 7.33 years (PJK) 62.69 ± 6.40 (non-PJK)	22.0–58.0 months (PJK) 28.0–44.5 months (non-PJK)	DLS	Posterior multilevel spinal fusion (stopping at thoracolumbar junction: T9-L2)	RCSA, TCSA, FCSA, lean MFI and total MFI of PS, QL, PSE (MF and ES) from level L1-2 to L5-S1	Axial T2-weighted MRI images	PJK

ASD adjacent segment degeneration, *LBP* low back pain, *LSS* lumbar spinal stenosis, *LDH* lumbar disc herniation, *DLS* degenerative lumbar scoliosis, *LIV* lower instrumented vertebra, *PLIF* posterior lumbar interbody fusion, *MRI* magnetic resonance imaging, *CT* Computed tomography, *MF* multifidus, *ES* erector spinae, *PS* psoas major, *PT* psoas major muscle, *PSE* paraspinal extensor muscle, *SMI* skeletal muscle index, *CSA* cross section area, *TCSA* total cross section area, *f/FCSA* functional cross section area, *rfCSA* relative functional cross-sectional area, *avCSA* average cross section area, *NTPA* normalized total psoas area, *rCSA* relative cross-sectional area, *MFI* muscle-fat index, *FI* fat infiltration, *SI* signal intensity, *PE* pulmonary embolism, *ASD* adjacent segment degeneration, *PJK* proximal junctional kyphosis, *SVA* sagittal vertical axis, |*PI-LL*| absolute value of the pelvic incidence minus lumbar lordosis mismatch, *TLJ* thoracolumbar junctional angle, *TK* thoracic kyphosis;

Table 2 Study results and quality of studies

Authors	Results	Quality of studies
Bone nonunion		
Choi [20]	Univariate analyses (Mann–Whitney U test): PLIF at L3-4 segment The CSA at segments (L3-4, L4-5) in bone fusion groups and bone non-fusion group were significantly different ($p=0.047$, 0.031) for the PS muscle, those at L2-3 and L4-5 segments between groups were significantly different ($p=0.039$, 0.015) for the ES and MF PLIF at L4-5 segment The CSA at all segments (L3-5, L5-S1) in bone fusion groups and bone non-fusion group were significantly different ($p<0.05$) for the PS, those at L4-5 and L5-S1 segments between groups were significantly different ($p=0.011$, 0.039) for the ES and MF Multivariate analysis (Logistic regression test): the PS CSA at L4–L5 was an independent factor for decreased possibility of non-fusion status in both segments (OR = 0.812, $p=0.028$, 95% CI 0.402–1.222) Pearson correlation coefficient: PLIF at L3-4 segment PS CSA at L3-4 ($p=0.048$) and L4-5 ($p=0.014$) were negatively correlated with time to fusion ($p<0.05$) ES and MF CSA at L4-5 ($p=0.042$) were negatively correlated with time to fusion PLIF at L4-5 segment PS CSA at all segments ($p<0.05$) were negatively correlated with time to fusion ES and MF CSA at L3-4 ($p=0.025$) and L4-5 ($p=0.048$) were negatively correlated with time to fusion	High quality
Choi [27]	Univariate analyses (Mann–Whitney U test): The CSA at all segments (L3-5, L5-S1) in bone union groups and bone nonunion group were significantly different for the PS muscle ($p<0.05$), those at L3-4 and L4-5 segments between groups were significantly different for the ES and MF ($p=0.048$, 0.021) Multivariate analysis (Logistic regression test): Differences in the PS CSA at the L4-5 and L5-S1 segments remained significant ($p=0.048$, 0.043; OR = 1.098, 1.169; 95%CI 0.998–1.198, 1.002–1.335)	High quality
Lee [28]	Univariate analysis: The grade of fat content of paraspinal muscle was significantly higher in the nonunion group than the union group ($p<0.0001$) Multiple logistic regression analysis: Fat content of paraspinal muscles remained significantly related to union ($p<0.05$)	High quality
Pedicle Screw Loosening		
Kim JB[29]	Student t-test: Smaller CSA and high T2 signal intensity in both MF and ES were in the S1 screw loosening group at 1 year follow-up after surgery ($p<0.05$) PS didn't show any difference in both CSA and signal intensity between the two groups at 1 year follow-up ($p>0.05$)	High quality
Leng [23]	Group A Student t test: Patients with LIV screw loosening at final follow-up (≥ 1 year) had significantly higher founctional MFI of PS and lower rtCSA and rfCSA of ES (all $p<0.05$) There were no significant difference between loosening and unloosening groups at final follow-up (≥ 1 year) for MF (all $p>0.1$) Mean muscle ratio of ES was significantly lower in patients with clinical screw loosening at final follow-up (≥ 1 year) compared with radiological screw loosening ($p=0.029$) Binary logistic regression: Mean rfCSA of ES < 0.71 was an independent risk factor of LIV screw loosening at final follow-up (≥ 1 year) (OR 5.0, 95%CI 1.5–16.4, $p=0.008$) Group B All muscular parameters showed no significant difference (all $p>0.1$)	High quality

junctional kyphosis (PJK) at follow-up (Table 3). Hyun et al. [31] reviewed 44 cases of patients having multilevel spinal instrumented fusion stopping at thoracolumbar junction for adult spinal deformity. They found that a smaller relative CSA of ES and higher MFI of both MF and ES at T10 to L2 preoperatively were identified risk factors for PJK. However, lower muscularity of MF was not corelated to PJK. Another study by Yagi et al. included surgically treated 60 DLS patients and followed for at least 2 years [21]. They found that the preoperative MF average CSA at L5–S1 was

Table 2 (continued)

Authors	Results	Quality of studies
Adjacent Segment Degeneration		
Kim [35]	Student t tests: Mean CSA and rCSA of the paraspinal muscles were significantly smaller in the ASD group than in the control group (both $p < 0.01$) Mean CSA and rCSA of the PT (psoas major muscle) were not significantly different between the two groups (CSA, $p = 0.96$; rCSA, $p = 0.72$) The degree of FI in the paraspinal muscles was significantly greater in the ASD group than in the control group ($p < 0.01$) Multivariate logistic regression analysis: Smaller rCSA and more FI of the paraspinal muscles preoperatively was a significant factor for predicting the development of ASD (OR = 0.083, $p = 0.003$; OR = 1.080, $p = 0.044$) Neither the CSA ($p = 0.585$) nor the FI of PS did not have the predictive value	High quality
Chang [32]	Independent-sample t test (matched for sex, age, BMI, the fusion level and the number of fusion segments): Mean fCSA (2178.6 mm^2 vs 2594.0 mm^2; $p = 0.004$), the fCSA/tCSA (45.4% vs 52.2%; $p = 0.001$), and the SMI of the fCSA (8.8 vs 10.6; $p = 0.001$) of the paraspinal muscles were significantly smaller in patients with ASD compared to the control group When the paraspinal muscles and PS groups were combined, the mean fCSA (3680.8 mm^2 vs 4268.2 mm^2; $p = 0.013$), fCSA/CSA (53.3% vs 58.6%; $p = 0.004$), the SMI of the tCSA (27.7 vs 29.3; $p = 0.049$), and the SMI of the fCSA (14.9 vs 17.3; $p = 0.002$) were significantly lower in patients with ASD than in control patients	High quality
Duan [26]	Univariate analysis: FI of the MF was significantly greater in the ASD group than the non-ASD group ($p = 0.029$) FI of the MF at L3 ($p = 0.017$) but not L4 or L5 ($p = 0.354$ for L4 and $p = 0.077$ for L5) was significantly greater in the ASD group than the non-ASD group	High quality
Verla [30]	Chi-squared test: Patients with postoperative DVT/PE had smaller PS thickness (L3-4, $p = 0.032$; L4-5, $p = 0.021$) Patients with postoperative (< 2 years) ASD had smaller PS thickness (L4-5, $p = 0.045$)	High quality
Proximal Junctional Kyphosis		
Yagi [21]	Correlation coefficient tests: The MF avCSA at the L5–S1 level was correlated with the postoperative progression of the proximal junctional angle at the final follow-up (> 2 years) in the DLS group (R = 0.22), not the PS avCSA The MF CSA at the L5–S1 level was correlated with the postoperative progression of kyphosis at the unfused thoracic vertebrae (R = 0.34) in the DLS group at the final follow-up (> 2 years), not the PS CSA	High quality
Zhu [33]	Student t tests: For all patients, there was a significant difference in rfCSA between the PJK and non-PJK groups at the final (mean 34 months) follow-up ($p = 0.026$) For the L1-2 group, there was a significant difference of rfCSA between the PJK and non-PJK groups at the final (mean 34 months) follow-up ($p = 0.001$) For the T9-T12 group, there were not significant difference of any muscular parameters measured between the PJK and non-PJK groups at the final (mean 34 months) follow-up ($p = 0.852$)	High quality
Pennington [34]	Univariate analysis: PJK was associated with smaller paraspinal muscles at the upper instrumented vertebrae at the final follow-up (≥ 6 months) ($p < 0.001$) Multivariate logistic regression: Higher postoperative SVA (OR 1.1 per cm), smaller paraspinal muscles at the upper instrumented vertebrae (OR = 2.11), and more aggressive reduction in |PI-LL| (OR = 1.03) were independent predictors of radiographic PJK at the final follow-up (≥ 6 months)	High quality

Table 2 (continued)

Authors	Results	Quality of studies
Yuan [24]	Univariate analysis: PSE The FCSA (all $p<0.05$), but not the tCSA (all $p>0.05$) of PSE from L1-2 to L5-S1 was significantly smaller in the PJK group than the non-PJK group The lean MFI and total MFI of PSE from L1-2 to L5-S1 was significantly higher in the PJK group than the non-PJK group (all $p<0.05$) PS and QL There were no significant difference between the PJK and non-PJK groups for CSA, lean-MFI or totalMFI of PS and QL from L1-2 to L5-S1 (all $p>0.05$) Multivariate logistic regression: Smaller FCSA (OR = 22.56, $p=0.021$) and higher totalMFI (OR = 16.44, $p=0.029$) of PSE from L1-2 to L5-S1 were independent predictors of radiographic PJK	High quality
Hyun [31]	Mann–Whitney U test: The CSA of ES at each level was significant smaller in the PJK group at the final follow-up ($p<0.05$) There were no significant differences for CSA of MF at each level between the two groups at the final follow-up ($p>0.05$) The FI of ES and MF at each level was significant higher in the PJK group at the final follow-up ($p<0.05$) Multivariate regression analysis (Cox proportional hazards model): ES muscularity < 120 (HR = 2.24, 95% CI = 1.21–3.82, $p=0.007$) and ES fatty degeneration > 60 at all levels (HR = 3.03, 95% CI = 1.61–5.59, $p<0.001$) were identified risk factors for PJK at the final follow-up Smaller muscularity and Higher fatty degeneration of MF and ES (131.8 vs 159.0, $p<0.01$; 59.0 vs. 44.0, $p<0.001$, respectively) were identified risk factors for PJK at the final follow-up	High quality
Sagittal Imbalance		
Lee [25]	Pearson correlation coefficient: In static parameters Thoracolumbar junctional angle (TLJ) at 6 months follow-up was correlated with L1–2, L2-3 PSE/disc CSA (r = -0.427, -0.382; $p=0.004$, 0.010) and L1–2 SI (r = -0.318, $p=0.035$) TK at 6 months follow-up was correlated with L1–L2 SI (r = -0.385, $p=0.010$), L3–L4 PSE/disc CSA (r = 0.326, $p=0.031$), and L4–L5 SI (r = -0.350, $p=0.020$) The improvement of TK was correlated with L1–2 (r = 0.399, $p=0.023$) and L2–3 (r = 0.344, $p=0.021$) PSE/disc CSA In dynamic parameters Maximal thoracic angle at 6 months follow-up was correlated with L1–2, L2-3 PSE/disc CSA(r = 0.384, 0.363; $p=0.010$, 0.015), and L1–L2 SI (r = -0.197, $p=0.200$) Maximal lumbar angle at 6 months follow-up was correlated with L3–4 PSE/disc CSA (r = -0.345, $p=0.022$) and L4–5 PSE/disc CSA (r = -0.352, $p=0.019$) Minimal thoracic angle at 6 months follow-up was correlated with L1–2 PSE/disc CSA (r = 0.323, $p=0.032$) Minimal lumbar angle at 6 months follow-up was correlated with L2–3 SI (r = 0.355, $p=0.018$), L3–4 PSE/disc CSA (r = -0.344, $p=0.022$), L3–4 SI (r = 0.357, $p=0.018$), and L4–5 PSE/disc CSA (r = -0.359, $p=0.017$) The improvement of maximal thoracic angle was correlated with L1–2 (r = 0.329, $p=0.029$) and L2–3 (r = 0.335, $p=0.026$) PSE/disc CSA The improvement of maximal lumbar angle was correlated with L1–2, L2–3, L3–4, and L4–5 PSE/disc CSA (r = 0.342, 0.345, 0.423, 0.467; all $p<0.05$) The improvement of minimal thoracic angle was correlated with L1–2 (r = 0.356, $p=0.018$) and L2–3 (r = 0.369, $p=0.014$) PSE/disc CSA The improvement of minimal lumbar angle was correlated with L1–2, L2–3, L3–4, and L4–5 PSE/disc CSA (r = 0.327,0.365, 0.425,0.467; all $p<0.05$)	High quality

Table 2 (continued)

Authors	Results	Quality of studies
Dohzono [22]	Pearson product moment correlation coefficient: The TCSA and percentage of FI of MF and ES at L4–5 were not associated with SVA improvement at the final follow-up (> 1 year) in patients with preoperative SVA ≥ 40 mm ($p = 0.28$, $p = 0.60$) Multiple regression analysis: The TCSA and percentage of FI of MF and ES at L4–5 were not associated with SVA improvement at the final follow-up (> 1 year) in patients with preoperative SVA ≥ 40 mm ($p > 0.05$)	High quality

ASD adjacent segment degeneration, *LBP* low back pain, *LSS* lumbar spinal stenosis, *LDH* lumbar disc herniation, *DLS* degenerative lumbar scoliosis, *LIV* lower instrumented vertebra, *PLIF* posterior lumbar interbody fusion, *MRI* magnetic resonance imaging, *CT* Computed tomography, *MF* multifidus, *ES* erector spinae, *PS* psoas major, *PT* psoas major muscle, *PSE* paraspinal extensor muscle, *SMI* skeletal muscle index, *CSA* cross section area, *TCSA* total cross section area, *f/FCSA* functional cross section area, *rfCSA* relative functional cross-sectional area, *avCSA* average cross section area, *NTPA* normalized total psoas area, *rCSA* relative cross-sectional area, *MFI* muscle-fat index, *FI* fat infiltration, *SI* signal intensity, *PE* pulmonary embolism, *ASD* adjacent segment degeneration, *PJK* proximal junctional kyphosis, *SVA* sagittal vertical axis, *|PI-LL|* absolute value of the pelvic incidence minus lumbar lordosis mismatch, *TLJ* thoracolumbar junctional angle, *TK* thoracic kyphosis, *OR* odds ratio, *CI* confidence interval, *p* p value

correlated with PJK, not the PS CSA. This finding was in accordance with a case–control study by Zhu et al. [33]. They included patients with lumbar degenerative diseases who underwent fusion of L5 and performed a relative FCSA of MF assessment at L4-5. Zhu et al. showed that there was a significant difference in the preoperative relative FCSA of MF between the PJK and non-PJK groups [33]. They also found that the predicting value of MF only emerged in the L1–L2 group, not the T9–T12 group. Pennington et al. found a smaller size of paraspinal muscles at the upper instrumented vertebrae was an independent factor of PJK in patients undergoing thoracolumbosacral fusion greater than 2 levels [34]. Yuan et al. reviewed 84 DLS patients undergoing long instrumented fusion surgery and found that the FCSA of PSE was statistically smaller and MFI of PSE was higher at all levels in the PJK group than in the non-PJK group [24].

Sagittal imbalance

Limited evidence from 1 high quality study indicated that both atrophy and FI of PSE had an association with less LL improvement at follow-up (Table 3). A study by Lee et al. demonstrated that the severity of atrophy or FI of PSE group was correlation with LL improvement in patients with degenerative flat back after corrective surgery [25]. Besides, evidence for an association between PSE and SVA improvement at follow-up was limited. Sho Dohzono et al. uncovered that preoperative tCSA and FI of PSE group at L4–5 were not associated with SVA improvement in LSS patients with preoperative SVA ≥ 40 mm [22].

Discussion

This systematic review identified 16 studies providing evidence for relationships between various lumbar muscle characteristics and five main postoperative complications. First, the review found strong evidence for an association between the atrophy of all paraspinal muscles and bone nonunion. These could be interpreted by the fact that paraspinal muscle atrophy was correlated to poorer function and weakness [36, 37]. Paraspinal muscles with serious degeneration might have a weak effect on reducing the mechanical loading on bone, thus increasing the risk of bone nonunion. In addition, Lee et al. found that paraspinal muscle FI of ≥ grade 2 evaluated by Goutallier scale could be a cut-off value. They thought that in cases with a paraspinal muscle fat contents of ≥ grade 2, more rigid fixation, more graft bone, and meticulous fusion bed preparation should be necessary.

There was strong evidence that PSE atrophy was predictive of screw loosening. Notably, Leng et al. found that screw loosening group had a significantly smaller CSA of ES than non-loosening group in six or more level fusion for DLS, whereas no difference was found between two groups in four or five level fusion [23]. It is postulated that the role of paraspinal muscles to maintain stability was more important as the stress upon LIV was stronger in longer fused levels [23]. Once atrophy of paraspinal muscles appeared preoperatively, especially in patients with long-segment fusion, the screw would undertake stronger stress and was prone to loosening. Thus, we considered that more rigid fixation or more graft bone might be requisite in cases with PSE atrophy during preoperative evaluation.

There was strong evidence that both preoperative atrophy and FI of PSE could predict the development of ASD. Previous study has reported that extensive degeneration and weakness of PSE after operation were risk factors of

Table 3 Levels of evidence for paraspinal muscle characteristics as predictors of postoperative complications after lumbar surgery

Results	Level of evidence	Supporting studies	Quality of
Bone nonunion			
Atrophy of PSE can predict the bone nonunion	Strong		
Smaller tCSA of MF and ES at lower lumbar predicted higher bone nonunion in patients with multiple degenerative lumbar diseases after PLIF		Choi [20, 27]	High
FI of PSE can predict the bone nonunion	Limited		
Higher FI of PSE group at L3-S1 predicted higher bone nonunion in patients with multiple degenerative lumbar diseases after interbody fusion		Lee [28]	High
Atrophy of PS can predict the bone nonunion	Strong		
Smaller tCSA of PS at lower lumbar predicted higher bone nonunion in patients with multiple degenerative lumbar diseases after PLIF		Choi [20, 27]	High
Pedicle Screw Loosening			
Atrophy of PSE can predict the screw loosening	Strong		
Smaller tCSA of both MF and ES at L5–S1 predicted more S1 screw loosening in patients with multiple degenerative lumbar diseases after surgery		Kim [29]	High
Lower rfCSA and rtCSA of ES at L4-5 and L5-S1 predicted LIV screw loosening in patients with DLS after corrective surgery		Leng [23]	High
FI of PSE can predict the screw loosening	Conflicting		
Higher FI of both MF and ES at L5–S1 predicted more S1 screw loosening in patients with multiple degenerative lumbar diseases after surgery		Kim [29]	High
FI of both MF and ES at L4-5 and L5-S1 did not predict LIV screw loosening in patients with DLS after corrective surgery		Leng [23]	High
Atrophy of PS cannot predict the screw loosening	Limited		
Smaller rfCSA of PS at L4-5 and L5-S1 predicted LIV screw loosening in patients with DLS after corrective surgery		Leng [23]	High
FI of PS can predict the screw loosening	Limited		
Higher FI of PS at L4-5 and L5-S1 predicted LIV screw loosening in patients with DLS after corrective surgery		Leng [23]	High
Adjacent Segment Degeneration			
Atrophy of PSE can predict the development of ASD	Strong		
Smaller CSA of PSE group at L4-5 predicted the development of ASD in patients with multiple degenerative lumbar diseases after PLIF		Kim [35]	High
Smaller FCSA and tCSA of PSE group at L4-5 predicted the development of ASD in patients with symptomatic ASD after lumbar fusion		Chang [32]	High
FI of PSE can predict the development of ASD	Strong		
Higher FI of PSE group at L4-5 predicted the development of ASD in patients with multiple degenerative lumbar diseases after PLIF		Kim [35]	High
Higher FI of PSE group at L4-5 predicted the development of ASD in patients with symptomatic ASD after lumbar fusion		Chang [32]	High
Higher FI of MF at L3 predicted the development of ASD in patients with spondylolisthesis after transforaminal lumbar interbody fusion		Duan [26]	High
Atrophy of PS can predict the development of ASD	Limited		
Smaller PS thickness at L4-5 predicted the development of ASD in patients with multiple degenerative lumbar diseases after surgery		Verla [30]	High
Proximal Junctional Kyphosis			
Atrophy of PSE can predict the progression of PJK	Strong		
Smaller rCSA of MF at L5–S1 predicted the progression of PJK in patients with DLS after surgery		Yagi [21]	High
Smaller rfCSA of MF at L4-5 predicted the progression of PJK in patients with multiple degenerative lumbar diseases after fusion of L5		Zhu [33]	High
Smaller CSA of PSE group at UIV predicted the progression of PJK in patients with multiple degenerative lumbar diseases after thoracolumbosacral fusion		Pennington [34]	High
Smaller FCSA of PSE group at all levels predicted the progression of PJK in patients with DLS after posterior multilevel spinal fusion		Yuan [24]	High

Table 3 (continued)

Results	Level of evidence	Supporting studies	Quality of
Smaller CSA of ES at T10-L2 predicted the progression of PJK in patients with spinal deformity after lumbar fusion		Hyun [31]	High
FI of PSE can predict the progression of PJK	Strong		
Higher FI of both MF and ES at T10-L2 predicted the progression of PJK in patients with spinal deformity after lumbar fusion		Hyun [31]	High
Higher FI of PSE group at all levels predicted the progression of PJK in patients with DLS after posterior multilevel spinal fusion		Yuan [24]	High
Both atrophy and FI of PS cannot predict the progression of PJK	Limited		
FCSA and FI of PS did not predict the progression of PJK in patients with DLS after posterior multilevel spinal fusion		Yuan [24]	High
Sagittal Imbalance			
Both atrophy and FI of PSE can predict the degree of angular deformity	Limited		
Smaller rCSA and FI of PSE group predicted the degree of angular deformity in patients with degenerative flat back after corrective surgery		Lee [25]	High
Both atrophy and FI of PSE cannot predict the SVA improvement	Limited		
TCSA and FI of PSE group at L4–5 did not predict the SVA improvement in LSS patients after microendoscopic laminotomy		Dohzono [22]	High

DVT deep vein thrombosis, *PE* pulmonary embolism, *SSI* surgical site infection, *ASD* adjacent segment degeneration, *PJK* proximal junctional kyphosis, *SVA* sagittal vertical axis, *LSS* lumbar spinal stenosis, *LDH* lumbar disc herniation, *DLS* degenerative lumbar scoliosis, *PLIF* Posterior Lumbar Interbody Fusion, *LIV* lower instrumented vertebra, *UIV* upper instrumented vertebra, *MF* multifidus, *ES* erector spinae, *PS* psoas major, *PSE* paraspinal extensor muscle, *TCSA* total cross section area, *FCSA* functional cross section area, *rCSA* relative cross-sectional area, *rfCSA* relative functional cross-sectional area, *FI* fat infiltration

ASD [38]. Our findings demonstrate a satisfactory predictive value of preoperative PSE degeneration on ASD. This might be because that the paraspinal muscle degeneration potentially adds more stress to the adjacent levels accelerating the degenerative pathway [31]. For reducing ASD, surgeons could use less traumatic techniques to protect paraspinal muscles in patients with preexisting PSE degeneration.

There was strong evidence that both atrophy and FI of PSE were predictive of PJK. It is suggested that surgeons should pay attention to preoperative paraspinal muscle evaluation and perform some methods to prevent PJK in cases with severe muscle degeneration. However, the effect of PSE at which level should be remarkable was still uncertain. Hyun et al. [31] reported that both MF and ES degeneration at T10 to L2 preoperatively were identified risk factors for PJK, whereas Zhu et al. [33] found that the predicting value of MF only emerged in the L1–L2 group, not the T9–T12 group. Yuan et al. found that the degeneration of PSE was severer in the PJK group than the non-PJK group at L1–S1 [24]. Therefore, our results suggested that surgeons should evaluate muscularity and fatty degeneration at both thoracolumbar and lower lumbar area. Whether patients need fusion up to the upper thoracic area when finding severe atrophy and fatty degeneration of PSE in the preoperative MRI evaluation should be furtherly examined. In addition, there was no relationship between both atrophy and FI of PS and PJK with limited evidence.

Two studies have revealed the association between PSE and LL and SVA improvement, while it was still indeterminate with limited evidence. We hypothesized that PSE could provide support for lumbar stability when standing upright, thus the stabilizing effect decreased and sagittal imbalance subsequently developed as the degeneration of muscles occurred [39]. Further studies should explore the prognostic value of paraspinal muscles on the development of spinal curve.

Limitations

Few limitations in this review require to be considered. First, on account of relatively new research on the predictive value of paraspinal muscle morphology, the possibility of publication bias could not be eliminated. Thus, we conducted an extensive search of the literature and screened up to 5,000 articles to minimize this bias. Second, included studies had a high heterogeneity of lumbar diseases, surgical procedures, follow-up duration, paraspinal muscle parameters and definitions for each complication resulting in the inapplicability of meta-analysis. To abate the effect of heterogeneity, subgroup analyses according to previous systematic reviews have been conducted in each complication. In addition, due to the small volume of published literature, one additional study could switch the level of evidence in specific complication. In consequence, there is a need for more high-quality prospective

research demonstrating the association for different complications to achieve clinical application.

In addition, another potential limitation in this review was the adaptability of the assessment tools used for the risk of bias. The NOS was designed for cohort and case–control studies, while it was lacking in items evaluating the prognosis research. Therefore, we employed the modified NOS which had been used to assess the risk of bias in prognosis studies [18]. Moreover, the non-response rate in all included case–control studies was not reported or matched, which need to be addressed in future studies to reduce the risk of bias.

Ideally, future research should incorporate a prospective design and control potential confounding factors so as to demonstrate the predictive value of paraspinal muscle morphology. More studies are also required to assess the result consistency through different methodologies of paraspinal muscle morphology [40]. Besides, reporting cut-off value of muscle atrophy and FI related to complications can help clinicians easily distinguish patients who are inclined to have unsatisfactory outcomes at follow-up.

Conclusions

For predicting the postoperative complications, we found strong evidence that preoperative paraspinal muscle degeneration was related to the development of bone nonunion, pedicle screw loosening, ASD and PJK. However, the predictive value of paraspinal muscles on the less improvement of sagittal parameters was indeterminate. In general, it is possible that the assessment of paraspinal muscle degeneration could be a viable method to stratify patients by risk of postoperative complications. On account of the small volume of published literature, there is a need for more high-quality prospective research demonstrating the association for different complications to achieve clinical application.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00586-021-07052-3.

Funding This work was supported by the Clinical Cohort Construction Program of Peking University Third Hospital, China National Key Research and Development Program (2018YFB1307700) and the Accurate Diagnosis and Treatment Technology of Bone and Joint Diseases Research Program.

Availability of data and material Not applicable.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval Not applicable.

Consent to participate Not applicable.

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