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Original Article

Correlation between multifidus muscle and proximal junctional kyphosis after long-segment instrumentation for lumbar degenerative disease

Wenyi Zhu*, Lei Zang*, Jian Li, Li Guan, Yong Hai

*Department of Orthopedic, Beijing Chaoyang Hospital, Capital Medical University, Beijing, China. *Equal contributors.*

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Abstract: Background: The purpose of this study was to use magnetic resonance imaging (MRI)-based assessments of multifidus muscle to predict development of proximal junctional kyphosis (PJK). Methods: We retrospectively reviewed 62 patients with lumbar degenerative disease (LDD) who underwent fusion of L5 and all the upper instrumented vertebrae (UIVs) in the thoracolumbar spine (T9-L2), with ≥2 years' follow-up, at a single center between 2008 and 2014. All patients underwent standing radiographic imaging preoperatively, immediately postoperatively, and at final follow-up, as well as preoperative supine MRI. The patients were divided into PJK and non-PJK groups and subdivided into four groups by the UIVs (T9-T12 vs L1-L2). The demographic data included age, sex and body mass index. The MRI-based multifidus assessment was performed using ImageJ version 1.46. Subsequently, the relative functional cross-sectional area (rFCSA) was calculated. Sagittal parameters were measured within the whole spine, using Surgimap version 2.0. Results: PJK was observed in 22 of 62 patients (35%). Average follow-up was 34 months. There was a significant difference in rFCSA between the PJK and non-PJK groups (P=0.026). Patients who developed PJK comprised 37.5% of the L1-L2 group and 31.8% of the T9-T12 group, but there was no significant difference in the incidence of PJK. The L1-L2 group showed significant differences in age, rFCSA, lumbar lordosis, and global sagittal alignment (P=0.047, 0.001, 0.041, 0.016, respectively), between the PJK and non-PJK groups. However, there was no difference in the T9-T12 group. Conclusions: rFCSA measured using MRI at the level of L4-L5 is an effective tool in predicting PJK after long-segment fusion for LDD, especially UIVs in the lumbar spine.

Keywords: Multifidus, proximal junctional kyphosis, magnetic resonance imaging, lumbar degenerative disease

Introduction

Lumbar degenerative disease (LDD) is common in middle-aged and elderly people (age >50 years). The most significant imaging features include disc herniation, degenerative disc disease, degenerative spondylolisthesis, and loss of lordosis in the lumbar spine. Pain and disability are the most relevant findings when deciding upon surgical treatment [1].

Surgical treatment for patients with LDD often includes multiple decompressions of neural elements with long instrumented fusion due to long-standing degenerative changes and weakened paraspinal muscles [2]. However, rigid fixation alters the normal spinal biomechanics and may result in a series of complications. One particular problem is proximal junctional kyphosis (PJK), which has been reported in up to 39% of cases [3].

Several studies have documented risk factors of PJK including age, sagittal imbalance, high pelvic incidence (PI), and combined anterior/posterior surgery. Some researchers have suggested decreased muscle strength as a result of surgical damage as a risk factor for PJK, although this opinion has not been proven by current research [4]. However, we consider that muscle atrophy rather than injury is a risk factor for PJK.

We investigated the multifidus muscle because current studies have reported that it is one of the most important paraspinal muscles controlling intervertebral activity [5, 6]. The multifidus muscle is located deep in the back extensor

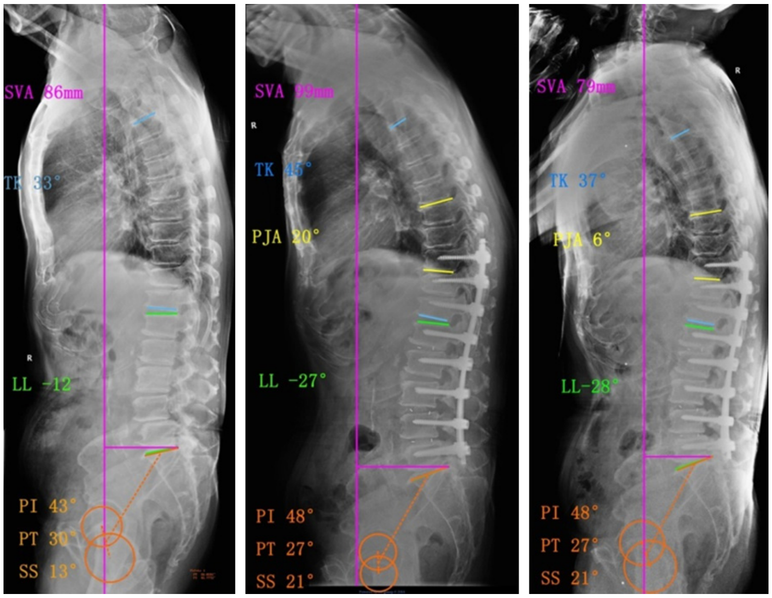

Figure 1. Lateral radiographs obtained at different times (preoperatively, immediately postoperatively, and at final follow-up). SVA (pink), PJA (yellow), pelvic parameters (PI, PT and SS, orange), regional curvature (TK, blue; LL, green), alignment matching included GSA=TK+LL+PI and PI-LL. Measurements were performed using Surgimap version 1.4. It shows that postoperative muscle weakness may lead to immediate PJK (PJA=20°), but PJA recovers at final follow-up with a higher rFCSA (90%).

muscles, remains in a state of isometric contraction, and maintains spinal balance. The change due to gradual age-related trunk muscle atrophy is most significant in the multifidus [7]. Atrophy of the extensor muscles in the lumbar spine has been described as a risk factor for global kyphosis [8]. The relationship between acute and chronic low back pain, disc herniation, stenosis, and strength of the multifidus has also been confirmed [9-11]. In addition, it has been reported that multifidus muscle strength is linearly correlated with C7 plumb line (C7PL) and sacral slope (SS) angle in a study of spinal sagittal balance [12].

Muscle morphology is a quantifiable measure that contributes to muscle performance. It is often measured using magnetic resonance imaging (MRI), which is a high-resolution, non-radioactive and reproducible technique, with an ability to distinguish soft tissues [13]. Previous measurements using the physiological cross-sectional area (CSA) have demonstrated a relationship with lumbar multifidus muscle function [14]. However, muscle strength is affected by quantity as well as quality of muscle fiber [15]. Many studies have reported fatty infiltration of the lumbar multifidus muscle tissue in older individuals, (age >50 years). The same CSA of muscle is not always of the same quality. As a result, Kang et al. [16] have developed software to exclude fatty tissue, and have defined the remaining tissue as the functional cross-sectional area (FCSA) [17]. Chen et al. [18] and Lee et al. [19] have found that FCSA is not solely responsible for muscle function, because function is still influenced by race, sex, weight and height.

Given the above background, we calculated the relative FCSA (rFCSA), that is, the ratio of the FCSA to the CSA of the disc at the same level, which eliminates the differences between individuals and fatty infiltration. We hypothesized that preoperative smaller rFCSA of the multifidus may be a risk factor for postoperative PJK.

Materials and methods

Patient selection

We included 62 patients with a diagnosis of LDD, seen at Beijing Chao-Yang Hospital between 2008 and 2014. The study was approved by the Institutional Review Board. Each patient had to meet the following inclusion criteria: (1) age >50 years; (2) posterior approach surgery with pedicle screw-only construction; (3) end-constructs fused to L5 and all the upper instrumented vertebrae (UIVs) in the thoracolumbar spine (T9-L2) [20]; and (4) complete radiographic follow-up for at least 2 years. Exclusion criteria included: (1) spinal tumor, postoperative infection, congenital spinal deformity, adolescent idiopathic scoliosis (AIS), or ankylosing spondylitis; (2) connective tissue disorder, fracture, or neuromuscular disease; and (3) no integrity imaging data.

Operative procedure

The surgical procedure used a standard posterior midline approach with a multiple segmental

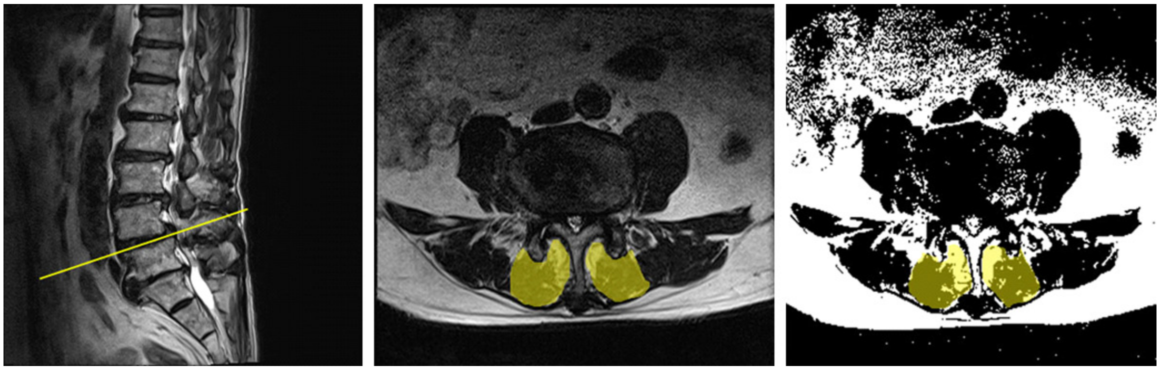

Figure 2. Shape of the multifidus at the level of L4-L5 (yellow line) as seen using ImageJ version 1.46 software. Functional multifidus area=13221 mm^2, mean=48.036, min=5, max=76, disc area=14690 mm^2, rFCSA=90%).

spinal pedicle screws system. Bilateral instrumentation was used throughout. We performed regional lamina decompression if spinal canal stenosis was found and transforaminal lumbar interbody fusion if there was disc herniation or spondylolisthesis.

Data collection

Imaging included lateral standing radiography and supine lumbar MRI. The radiographs were obtained preoperatively, immediately postoperatively, and at final follow-up. MRI was only performed preoperatively. Measurements were made on lateral radiographs of the spine identifying pelvic parameters [PI, pelvic tilt (PT) and SS], regional curvature [lumbar lordosis (LL) and thoracic kyphosis (TK)], global alignment [sagittal vertical axis (SVA)], and alignment matching [global sagittal alignment (GSA) and PI-LL], which were responsible for explaining most of the variance. The results were calculated using measurements provided by Surgimap version 2.0 (**Figure 1**).

The detailed methods were as follows. PI was measured as the angle subtended by the perpendicular to the midpoint of the S1 cephalad end plate and the line from the S1 midpoint to the middle of both femoral heads. PT was defined as the angle from the midpoint of the S1 cephalad endplate to the center of the femoral heads and vertical line. SS was the angle formed by the S1 cephalad endplate and the horizon. TK was measured as the angle from the upper endplate of T4 to the lower endplate of T12. LL was measured from the upper endplate of L1 to the upper endplate of S1. The SVA was measured as the distance from the C7PL to the perpendicular line drawn from the superior posterior endplate of the S1 vertebral body. GSA was the sum of TK, LL and PI. GSA >45° was considered sagittally imbalanced. PI-LL represented the congruence between lumbar lordosis and pelvic shape. Values >10° were considered incongruous. The proximal joint angle (PJA) was defined as the angle between the caudal endplate of the UIV to the cephalad endplate of two superjacent vertebrae. Abnormal PJK was defined [4] by two criteria as described in a previous study: (1) proximal junctional sagittal Cobb angle ≥10°; and (2) proximal junctional sagittal Cobb angle at least 10° greater than the preoperative measurement. The presence of both criteria was necessary to be considered abnormal. Follow-up lasted 2 years, and at the final follow-up, it was determined whether the PJA represented PJK.

Axial T2-weighted MRI of all patients was taken at the level of L4-l5 [1, 19], which has previously been confirmed as best presenting the strength of the multifidus muscles. These scans were all obtained during a single data collection session, using a General Electric 1.5T MR scanner using a fast spin echo sequence of TR=2800 ms, TEef=100 ms, 4-mm slice thickness, and a 384 × 256 matrix. The field of view for the scans (30 cm × 30 cm) was set so that all paraspinal muscles of interest were visible. Images were saved as 16-bit DICOM files for later analysis.

ImageJ version 1.46 (National Institutes of Health, Bethesda, MD, USA) software installed on a notebook computer was used to examine MR images. The FCSA of the multifidus muscle was measured in such a manner that the fat

Table 1. Intergroup comparison of demographic and radiographic parameters

	PJK group	Non-PJK group	*P* value
Age (yr)	67.9±15	65±9.5	0.416
BMI (kg/m^2)	22.1±9.4	20±11.3	0.494
TK (°)	28.6±13.9	23.8±13.9	0.211
LL (°)	24.4±16.7	28.4±15.4	0.361
PI (°)	45.3±11	47.6±12.8	0.674
PT (°)	28.6±13	23.7±13	0.628
SS (°)	22.9±9.7	23.9±10.6	0.718
SVA (mm)	45.5±60	30.8±46	0.314
PI-LL (°)	20.9±16	19.7±16	0.78
GSA (°)	47.5±2.5	43.5±2.29	0.233
rFCSA	0.4±0.2	0.5±0.2	0.026*

Values are given as mean ± SD. $P<0.05$ was considered to indicate statistical significance. *Statistically significant.

Table 2. Distribution of PJK in different UIV groups

UIV	PJK	Non-PJK	Total
L1-L2 group	7 (31.8)	15 (68.2)	22
T9-T12 group	15 (37.5)	25 (62.5)	40
Total	22 (35.5)	40 (64.5)	62

$\chi^2=0.2$, $P=0.65$, $P<0.05$ was considered to indicate statistical significance.

component was eliminated from the muscle within the region of interest, using a threshold technique based on visual differences in pixel signal intensities [17, 19, 21]. This technique measured the FCSA of the multifidus by first outlining the multifidus muscles bilaterally and then using the threshold function of the software to obtain image-specific signal intensity ranges for muscle tissue. The disc CSA was also measured using the total area of the disc outline. rFCSA was calculated as the ratio of the FCSA of the multifidus to the total area of the disc (**Figure 2**). All parameters were measured by two senior authors who were independent of the operating team. Inter-observer agreement was high (κ=0.88; 95% confidence interval 0.75-0.99).

Data analysis

Patients were divided into two groups, cases (PJK) and controls (non-PJK), dependent on the final follow-up result. We compared age, body mass index (BMI), sagittal alignment, pelvic parameters, regional curvature, alignment matching, and rFCSA of the multifidus between the two groups. We calculated descriptive statistics, including means and standard deviations, to characterize the patients and muscle measurements, and the *t*-test was used to determine the statistical significance of differences between the groups. Patients were also divided into different groups based on the UIVs. The T9-T12 group ($n=22$) and L1-L2 group ($n=40$). On this basis, we had four groups after dividing by PJK and UIV status, and the observed differences in categorical data were tested using the χ^2 test and the significance of differences in continuous variables was again checked using the *t*-test. All analyses were performed using SPSS version 19.0 (SPSS, Chicago, IL, USA).

Results

Patient demographic characteristics

Sixty-two patients from Beijing Chaoyang Hospital were investigated from 2008 to 2014, with a mean follow-up of 34 months. Patients were aged >50 years, with a mean age of 67 years. There were 45 (71.9%) women and 17 (28.1%) men. Patients were divided into the PJK group and non-PJK group. The PJK group included 22 patients (35.4%) with a mean (± SD) age of 67.9±15 years and a mean BMI of 22.1±9.4 kg/m^2. The non-PJK group included 40 patients with a mean age of 65.0±9.5 years and a mean BMI of 20.0±11.3 kg/m^2. There were no significant differences between the two groups in terms of age or BMI (**Table 1**).

Radiographic parameters

The radiographic parameters of the patients are shown in **Table 1**. Statistically significant differences were observed between groups with respect to rFCSA (PJK group 0.4±0.2, non-PJK group 0.5±0.2; $P<0.05$). No other parameters differed significantly between the groups.

The patients were also divided into the T9-T12 group and L1-L2 group, according to the UIVs, and subdivided into four groups when considering their PJK status; 15 (37.5%) of the L1-L2 group and 7 (31.8%) of the T9-T12 group had PJK. Using the χ^2 test to compare both subgroups, we found that $\chi^2=0.2$, $P=0.65$. No significant differences were found between the groups (**Table 2**).

Table 3. Comparison of parameters between PJK and non-PJK group with different UIVs

		PJK	Non-PJK	
L1-L2 group	rFCSA	0.36±0.14	0.54±0.15	0.001*
	Age (yr)	72±5.7	65±12	0.047*
	BMI (kg/m^2)	21.8±9.47	20.6±11	0.713
	SVA (mm)	51.4 75.6	23.3±43.9	0.14
	LL (°)	-22±16	-32±12	0.041*
	TK (°)	27±11.6	26±13.9	0.825
	PI (°)	46±10	49±12	0.967
	PT (°)	23±7.5	19.3±9	0.162
	SS (°)	22.3±10.4	26.3±9.4	0.226
	PI-LL	23.7±16.3	14.3±12.3	0.05
	GSA (°)	51±15	41±10	0.016*
T9-T12 group	rFCSA	0.54±0.27	0.52±0.2	0.852
	Age (yr)	68±5	64±4	0.106
	BMI (kg/m^2)	21.3±9.8	25.7±4.46	0.274
	SVA (mm)	33.7±31.3	49.4±9.1	0.471
	LL (°)	-28±17	-21±16	0.372
	TK (°)	31±18	18.2±13.9	0.097
	PI (°)	43.7±13.4	48.2±14.4	0.509
	PT (°)	18.3±13.8	28.2±8	0.055
	SS (°)	24.3±8.7	19.8±11.9	0.4
	PI-LL	15.1±16.5	28.2±13.7	0.088
	GSA (°)	46±13	47±14	0.834

$P<0.05$ was considered to indicate statistical significance. *Statistically significant.

When comparing the demographic and radiographic parameters by subgroup, in the L1-L2 group, we found significant differences in age (72±5.7 years in PJK group vs 65±12 years in non-PJK group; $P=0.047$), LL (-22±16° in PJK group vs -32±12° in non-PJK group; $P=0.041$), GSA (51±15° in PJK group vs 41±10° in non-PJK group; $P=0.016$), and rFCSA (0.36±0.14° in PJK group vs 0.54±0.15° in non-PJK group; $P=0.001$). However, there were no significant differences in the T9-T12 group. The results are shown in **Table 3**.

Discussion

LDD is common among middle-aged and elderly individuals and is usually caused by spinal degeneration that primarily affects the lumbar spine and involves intervertebral discs, facet joints, ligaments, and bone. The main symptoms include pain and dysfunction. Many LDD patients are usually treated surgically. Long-fusion surgery with a posterior approach is a common treatment strategy. However, recent studies on outcomes following long-fusion surgery have shown high rates of complications, and one of the most frustrating is PJK. The incidence of PJK is reported to be 39% [3], and it was 35.4% in the present study.

Many studies have described some potential risk factors for developing PJK, for example, preoperative SVA >5 cm, age >55 years, high PI, and GSA >45° [2, 22]. Recent reviews have also provided preventive measures for this complication. Intact soft tissues are reported to decrease local stress. Preservation of the posterior soft tissue envelope may help prevent PJK. However, the existing research has mainly paid attention to muscle damage during surgery, and few studies have reported the correlation between PJK and peroperative muscle atrophy. By considering the relationship between the strength of extensor muscles and degenerative spinal disease, we chose the multifidus muscle morphology as a key feature in PJK following long-segment fusion. We confirmed that the multifidus muscle plays an important role in maintaining spinal balance.

Current imaging techniques can obtain the multifidus muscle CSA and density in order to identify functional muscle fibers. We used rFCSA to analyze different groups of patients in an attempt to isolate the effect of individuals and fatty infiltration. We found that only rFCSA was significantly different between the PJK and non-PJK groups. Other indicators that have been reported as risk factors for PJK did not differ significantly in this study. This could have been because all patients recruited were older (>50 years old), and all other parameters were similar between the groups.

The current literature has documented that stress is most concentrated in proximal long fusion in the thoracolumbar segment, where there is a transition from the mobile lumbar to relatively fixed thoracic spine, especially with fusion of L1-L2 [23]. We divided patients into L1-L2 and T9-T12 groups according to UIVs. We found no significant difference in the incidence of PJK between the two groups. This may have resulted from the small sample size. However, in comparison of all parameters between the PJK and non-PJK groups with different UIVs, we found that age, LL, rFCSA and GSA were significantly different in the L1-L2 group, but there were no significant differences in the T9-T12 group. This may have been because the regional stress concentration was greater in the L1-L2 than T9-T12 group. Consequently, it is more effective to predict PJK by using the rFCSA of the multifidus in the L1-L2 group.

rFCSA represents the degree of muscle atrophy and fatty infiltration as a protective factor. As rFCSA increases, the incidence of PJK decreases. Conversely, if rFCSA decreases, the mean functional muscle area also decreases, and PJK can occur easily postoperatively. Age, LL, GSA were also risk factors for PJK in L1-L2 group. Rates of PJK following LDD surgery increased with age, LL decreased and GSA increased.

In this study, we also found that in some patients, PJK occurred immediately after operation, possibly due to muscle damage during operation, but PJA would recover to normal within 6 months as long as rFCSA is more than 50%. However, a clear conclusion needs to be confirmed by future studies.

The present study was limited by the small sample size. Also, all the patients were older (>50 years old). In addition, human spinal balance required mutual adjustment of nervous control, vertebrae, and muscles. Therefore, it could not be comprehensively analyzed using rFCSA, which represented only muscle strength.

In conclusion, we found that rFCSA could predict PJK by assessing the preoperative MRI axial view at the level of L4-L5 for the CSA of the multifidus muscle. We suggest that the decrease in the preoperative rFCSA of the multifidus muscle was a risk factor for PJK. We expect that this result will help with clinical decision making in spinal care.

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Disclosure of conflict of interest

None.

Address correspondence to: Dr. Yong Hai, Department of Orthopedic, Beijing Chaoyang Hospital, Capital Medical University, 8 Gongti South Road, Beijing 100016, China. Tel: 86-10-51718292; E-mail: yonghai_1@126.com

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