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Evaluating Paraspinal Back Muscles Using Computed Tomography (CT) and Magnetic Resonance Imaging (MRI): Reliability Analysis and Correlation with Intervertebral Disc Pathology

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Original Article

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Purpose: To investigate the reliability of CT and MRI for quantitative and qualitative analyses of lumbar paraspinal muscle fatty infiltration (PSFI) and correlation of PSFI with intervertebral disc pathology.

Materials and Methods: Lumbar spine CT and MRI of 36 subjects were reviewed retrospectively. Two observers independently outlined lumbar paraspinal muscles at each mid-intervertebral disc level. Paraspinal muscles on CT and MRI were graded according to the Goutallier grading system (GGS). The area, mean value, and standard deviation (SD) of the Hounsfield unit (HU) were obtained. Intervertebral discs were assessed on axial image of T2WI at each level. Correlations between qualitative and quantitative data and intervertebral disc pathology, age, and sex were evaluated.

Results: Inter- and intra-observer agreements for results of GGS on MRI were substantial (κ = 0.79) and moderate (κ = 0.59), respectively. Inter- and intra-observer agreements for results of GGS on CT were almost perfect (κ = 0.88) and substantial (κ = 0.66), respectively. Quantitative measurements of HU showed almost perfect inter- and intra-observer reliabilities (κ = 0.82 and κ = 0.99, respectively). There were statistically significant correlations between intervertebral disc pathology and PSFI at L1-2, L2-3, and L4-5 levels on MRI and at L1-2 and L3-4 levels on CT. Age showed significant correlation with results of GGS at all levels on CT and MRI.

Conclusion: This study showed that GGS results and HU measurements could be useful for evaluating PSFI because they showed correlations with intervertebral disc pathology results at certain levels.

Keywords: Muscle; Spine; Magnetic resonance imaging; Computed tomography; Goutallier grades

INTRODUCTION

Lumbar paraspinal muscles are dynamic stabilizers of the spine. They assist in three

plane rotation of the trunk and facilitate side-to-side intersegmental rotation in the transverse plane, thereby minimizing wear and tear of the articular cartilage (1, 2). Lumbar paraspinal muscle fatty infiltration (PSFI) increases slowly with age independent of body mass index (BMI) (3). It is also correlated with chronic low back pain (CLBP) (4), lumbar spondylosis, lumbar stenosis (5), and the severity of leg pain in those who have CLBP (6). It is more pronounced in the lumbar multifidus muscle (7). Moreover, older subjects have a steeper decrease in CT muscle density of the erector spinae muscle compared to multifidus at L4 and L5 levels. A decrease in cross-sectional area of the multifidus muscle and the erector spinae muscle in elderly subjects has been reported (8).

Recent studies have also shown that significant loss of muscle, known as sarcopenia, in the elderly and those who are chronically ill is an independent predictor of negative outcome in developing poor physical function, osteoporosis, hip fractures, and major postoperative complication (9). CT measure of sarcopenia defined as paraspinal muscle density has also been proven to be a significant negative prognostic indicator of overall survival and progression-free survival in patients with colorectal cancer (10). Therefore, there is a strong need for establishing uniform methods for evaluating normal parameters and degenerative changes of paraspinal muscles as CT muscle assessment might act as a biomarker for many medical and surgical conditions.

A previous MRI study by Battaglia et al. (11) has evaluated the cross-sectional area and fat content within lumbar paraspinal muscles, reporting substantial intra- and inter-observer reliabilities when using the Goutallier grading system (GGS) for quantifying lumbar PSFI. Keller et al. (12) have conducted a study in 2003 and determined intra-observer and machine reliabilities for measuring cross-sectional area and CT density of paraspinal muscles of 31 patients at T12-L1, L3-4 and L4-5 levels, showing acceptable results. However, they did not look at inter-observer reliability. To the best of our knowledge, there have been few studies assessing qualitative and quantitative data from both CT and MR images of paraspinal muscles. Thus, the objectives of this study were to: 1) measure qualitative and quantitative properties of paraspinal muscles on CT and MR images, 2) evaluate intra- or interobserver reliabilities of these measurements, and 3) compare these results with intervertebral disc pathology at each corresponding level according to participant's age and sex.

MATERIALS AND METHODS

Subjects

This was a retrospective study on subjects from the neurosurgery outpatient clinic who had pre-operative CT and MRI images due to low back pain from July 2014 to October 2016. Patients who had acute traumatic fracture, previous vertebral body surgery, or malignancy were excluded from this study. A total of 36 individuals were included in this study. There were 20 male and 16 female patients with an average age of 48.55 years (range, 14 to 84 years; mean: 37.45 years for males and 56.13 years for females). Two radiologists with 3 and 4 years of experience in interpreting MR images independently analyzed all lumbar disc levels (n = 358).

Magnetic Resonance Imaging

We used a 3T MR scanner (Skyra, Verio: Siemens, Erlangen, Germany) and obtained selected sequences from T12 to sacrum with the following standardized protocol: (a) T2-weighted sagittal images were obtained with the following parameters: repetition time (TR)/echo time (TE), 3040/91 ms; matrix, 410 × 512; sequence time, 1m 54s; field of view (FOV), 320 mm; number of excitation (NEX), 2; slice thickness, 3 mm; and slice gap interval, 0.6 mm; (b) T2W axial images were obtained with the following parameters: TR/TE, 2830/100 ms; matrix, 230 × 384; sequence time, 1 m 48 s; FOV, 160 mm; NEX, 2; slice thickness, 4 mm; and slice gap interval, 0.4 mm; (c) T1W axial images were obtained with the following parameters: TR/TE, 425/15 ms; matrix, 230 × 384; sequence time, 2 m 1 s; FOV, 160 mm; NEX, 2; slice thickness, 4 mm; and slice gap interval, 0.4 mm.

Computed Tomography

Axial and reconstructed sagittal images were obtained using a MD scannier (SOMATOM Definition Flash, Siemens, Forchheim, Germany) from T12 to sacrum with tube voltage of 100-120 kV, exposure of 40-200 mAs, slice thickness of 2 mm, and soft tissue kernel reconstruction. CT images were acquired within one week after obtaining MR images.

Image Analysis

Paraspinal muscles on each side (left and right) were analyzed at each mid- intervertebral disc level from L1-L2 to

L5-S1 (Fig. 1). The first and the second set of measurements by each observer were made one month apart. Both observers were blinded to each other's measurement results and previous results. Analysis of MR images was made two weeks apart from CT analysis. Observers were blinded to results of each interpretation.

GGS has been commonly used as the standard of qualitative measurement for rotator cuff muscles of the shoulder. Thus, we used GGS in the present study. Areas of high signal intensity within the paraspinal muscle on both axial T1 and T2 images were considered as fatty infiltration. This visual grading system has a scale 0 to 4 to categorize fatty infiltration, with grade 0 corresponding to 'no fatty infiltration' (Fig. 2a), grade 1 corresponding to 'fatty streaks' (Fig. 2b), grade 2 corresponding to 'less fat than muscle' (Fig. 2c), grade 3 corresponding to 'equal fat and muscle' (Fig. 2d), and grade 4 corresponding to 'more fat than muscle' (Fig. 2e).

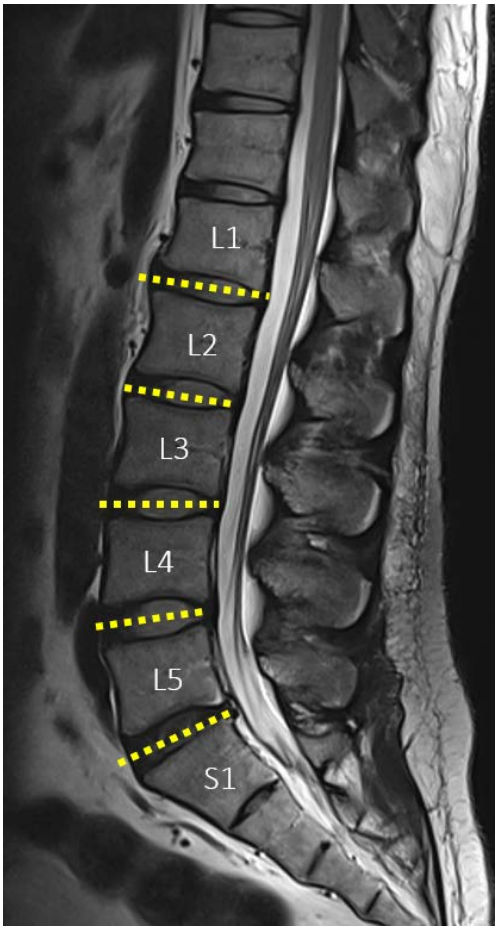

Fig. 1. Analysis of lumbar paraspinal muscles at each mid-intervertebral disc level from the L1-L2 to L5-S1 level parallel to each center of the disc.

For quantitative measurement, observers manually drew along the contour around the mutifidus and erector spinae muscles, including the fat between investing fascia muscle and fat infiltrating muscles using a freehand drawing tool on the PACS (picture archiving and communication system). The area, mean value, and standard deviation (SD) of Hounsfield units (HU) were obtained (Fig. 3).

Disc Pathology Assessment

Intervertebral discs were assessed on axial images of T2WI from L1-2 to L5-S1 by consensus of the two reviewers and classified as follows: grade 0, no significant or mild disc bulging; grade 1, diffuse disc bulging; and grade 2, disc protrusion, extrusion, or sequestration.

Statistical Analysis

SPSS software version 20.0 (SPSS IBM; Armonk, NY, USA) was used for all statistical analyses. We used weighted Kappa coefficient for intra-observer reliability analysis of qualitative data and intraclass correlation coefficient for intra-and inter-observer reliability analysis of quantitative data. Concordance between Goutallier grades and HIVD grades was assessed using Spearman's correlation analysis. Correlations of qualitative data (i.e., Goutallier grades) with age and sex were evaluated using simple and multiple linear regression analyses. For correlation coefficients, cutoff points were used as described previously (13): 0.00-0.10 as negligible, 0.10-0.39 as weak, 0.40-0.69 as moderate, 0.70-0.89 as strong, and 0.90-1.00 as very strong correlation. Weighted Kappa values were interpreted as follows: 0, no agreement; 0.01-0.20, none to slight agreement; 0.21-0.40, fair agreement; 0.41-0.60, moderate agreement; 0.61-0.80, substantial agreement; and 0.81-1.00, almost perfect agreement (14). P value less than 0.05 was considered significant.

RESULTS

On MRI, inter-observer and intra-observer agreements for qualitative data were substantial (kappa = 0.79) and moderate (kappa = 0.59), respectively. On CT, inter-observer and intra-observer agreements for qualitative data were almost perfect (kappa = 0.88) and substantial (kappa = 0.66), respectively. Quantitative measurements of HU on

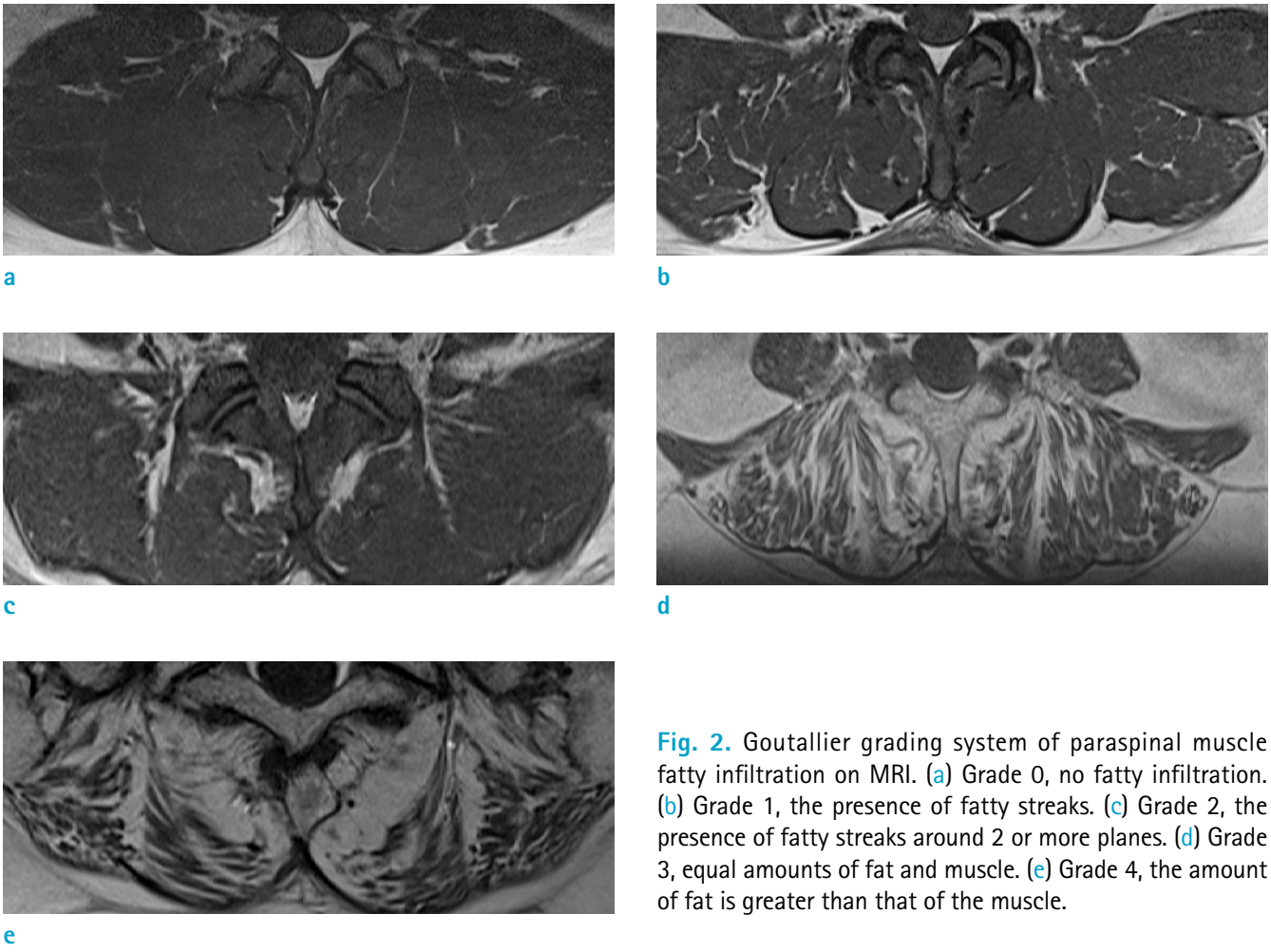

Fig. 2. Goutallier grading system of paraspinal muscle fatty infiltration on MRI. (a) Grade 0, no fatty infiltration. (b) Grade 1, the presence of fatty streaks. (c) Grade 2, the presence of fatty streaks around 2 or more planes. (d) Grade 3, equal amounts of fat and muscle. (e) Grade 4, the amount of fat is greater than that of the muscle.

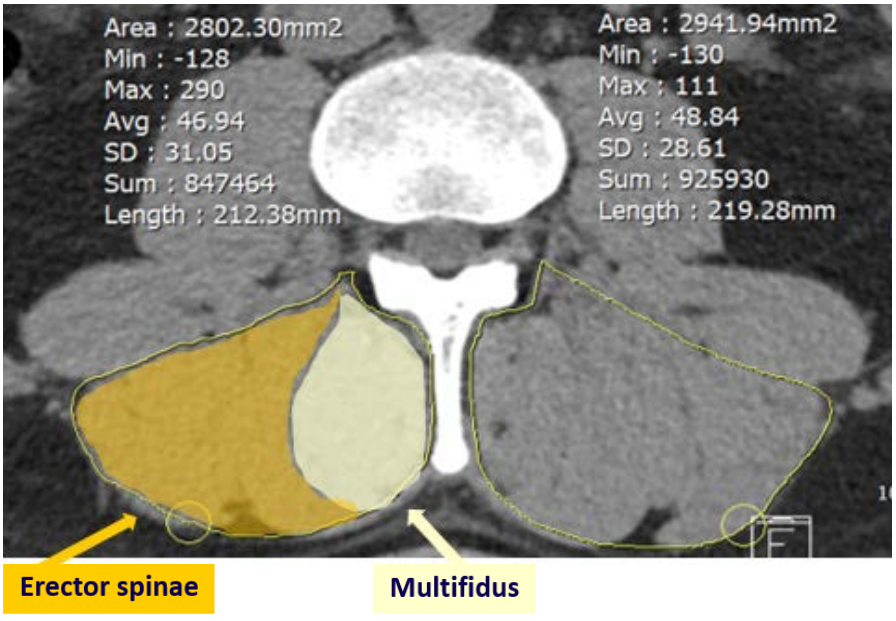

Fig. 3. Region of interest for measurement of Hounsfield unit is drawn around the thoracolumbar fascia.

CT showed almost perfect reliabilities for inter- and intra-observer agreements (kappa: 0.82 and 0.99, respectively).

The correlation between qualitative data and HIVD assessment at each predefined level was analyzed. On MRI, L1-L2, L2-L3, and L4-L5 levels showed statistically significant correlations (Table 1). On CT, L1-2, and L3-4 levels showed statistically significant correlations. For quantitative data on CT, positive correlations with disc pathology were observed at L1-2, L2-3, and L3-4 levels (Table 2).

Then we analyzed correlations of measured data with patient's age and sex. For qualitative data on both MRI and CT, patient's age showed statistically significant correlations at all levels. However, there was no statistically significant correlation between sex and qualitative data on MRI or CT (Table 3).

DISCUSSION

Although the precise mechanism accounting for the association between PSFI and low back pain is not well understood yet, there have been hypotheses supporting that PSFI is either caused by disuse or denervation (15). Degenerative disease of the lumbar spine in the form of discal height loss and close opposition between facet joints can increase intervertebral segmental mobility and lead to direct and indirect injuries of spinal muscles (15, 16). Lumbar disc herniation or facet joint osteoarthritis may result in inhibition of muscle activation and affect ipsilateral paraspinal muscles at all lumbar levels. It can be a cause or result of atrophy as demonstrated by Ploumis et al. (16). Previous studies have shown that multifidus muscle can significantly increase atrophy at and above the level of the affected exiting nerve (16, 17). Atrophy of these muscles is thought to be due to dysfunction of the muscles in those who have not undergone back surgery (15).

Our main finding was that there was a statistically significant association between disc herniation and PSFI at the L1-2 level. This suggests that specific muscle denervation change at a specific level can be caused by a herniated disc. Similar results have been shown by Sun et al. (18) after evaluating lumbar multifidus atrophy correlation with lumbar disc herniation in patients with mono-segmental L4-5 level disc herniation without evidence of multilevel disc degeneration. They found a smaller muscle volume at L4-5 compared to that at L5-S1 level (18). Another MRI study has shown that the cross sectional area of the multifidus muscle is significantly reduced at the L4-5 intervertebral disc level in asymptomatic patients with disc herniation at the L4-5 level (1). However, there was no qualitative assessment of muscles. In addition, the overall degree of PSFI might have been underestimated. This finding of unilateral level-specific PSFI can be explained by unilateral and exclusive innervation of the lumbar multifidus muscle by the dorsal rami of the nerve root at the same level. We did not exclude patients with disc degeneration from our study. Thus, we cannot exclude disuse atrophy as a contributing factor to this finding. However, this is unlikely due to the predominance of disc degeneration at lower lumbar levels.

Our second major finding was that atrophy greater than grade 2 was seen most frequently at L5-S1 levels, consistent with results of a study of Danneels et al. (19). They showed a statistically significant difference in the cross-sectional area of paraspinal muscles at the lower end plate of L4 of patients with chronic LBP. At the lower endplate of L4, the multifidus muscle forming approximately one-third of the bulk of paraspinal muscles is important for maintaining lumbar stability and selective atrophy of the multifidus muscle in patients with chronic LBP (19). Ploumis et al. (16) have also found unilateral paraspinal muscle atrophy on the symptomatic side above and below the level of disc pathology. It was thought to be related to disuse atrophy or lumbar dysfunction (16). In our study, since there was no significant correlation with the presence of HIVD and PSFI at the L5-S1 level, grade 2 atrophy might be due to either generalized disuse atrophy or multifidus dysfunction. Our results are consistent with results of a study done by Sun et al. (18). They also showed L5-S1 paraspinal atrophy. However, these correlations were without statistical significance. In this group, the atrophy was observed at one level below the level of disc herniation, which was thought to be due to disuse atrophy or multifidus dysfunction.

There was no correlation between PSFI and HIVD on CT at L2-3 or L4-5 level, different from results on MR. One of the reasons for this difference might be due to measurement errors. In a CT study, Keller et al. (12) have determined observer and equipment errors in measuring paraspinal cross-sectional area density and muscle in 31 subjects. As in their study, measurement error might have resulted from inclusion of intramuscular fat and fat at the fascial outline of muscle border during manual outlining of the total cross-sectional area of the paraspinal muscle at that level by the observer, which is especially true for the L4-5 level (12). Another reason might be that CT does not have as high soft

Table 1. Correlations between Goutallier Grades on MRI and Disc Pathologies at Each Disc Level

MR		n = 358	Total_RT_GG					Total_LT_GG					n = 72	L1/L2_RT_GG					L1/L2_LT_GG				
			0	1	2	3	4	0	1	2	3	4		0	1	2	3	4	0	1	2	3	4
Normal/ mild bulging	0	154	0.558	0.325	0.110	0.006	0.000	0.565	0.338	0.091	0.006	0.000	58	0.655	0.276	0.069	0.000	0.000	0.655	0.276	0.069	0.000	0.000
Diffuse disc bulging	1	118	0.119	0.449	0.331	0.059	0.042	0.144	0.441	0.322	0.051	0.042	8	0.000	0.750	0.250	0.000	0.000	0.000	0.625	0.375	0.000	0.000
Protrusion, extrusion	2	86	0.198	0.372	0.360	0.023	0.047	0.233	0.372	0.337	0.012	0.047	6	0.500	0.167	0.000	0.000	0.333	0.500	0.167	0.000	0.000	0.333
Correlation coefficient																		0.57 (P < 0.01)					

MR		n = 72	L2/L3_RT_GG					L2/L3_LT_GG					n = 72	L3/L4_RT_GG					L3/L4_LT_GG				
			0	1	2	3	4	0	1	2	3	4		0	1	2	3	4	0	1	2	3	4
Normal/ mild bulging	0	46	0.652	0.283	0.065	0.000	0.000	0.674	0.304	0.022	0.000	0.000	30	0.467	0.433	0.100	0.000	0.000	0.467	0.467	0.067	0.000	0.000
Diffuse disc bulging	1	20	0.300	0.300	0.400	0.000	0.000	0.300	0.400	0.300	0.000	0.000	32	0.188	0.375	0.313	0.125	0.000	0.250	0.375	0.281	0.094	0.000
Protrusion, extrusion	2	6	0.000	0.333	0.167	0.167	0.333	0.333	0.000	0.333	0.000	0.333	10	0.600	0.200	0.200	0.000	0.000	0.600	0.200	0.200	0.000	0.000
Correlation coefficient							0.36 (P < 0.05)											0.28 (P > 0.05)					

MR		n = 72	L4/L5_RT_GG					L4/L5_LT_GG					n = 70	L5/S1_RT_GG					L5/S1_LT_GG				
			0	1	2	3	4	0	1	2	3	4		0	1	2	3	4	0	1	2	3	4
Normal/ mild bulging	0	6	0.667	0.333	0.000	0.000	0.000	0.667	0.333	0.000	0.000	0.000	14	0.000	0.429	0.500	0.071	0.000	0.000	0.429	0.500	0.071	0.000
Diffuse disc bulging	1	32	0.063	0.563	0.250	0.094	0.031	0.094	0.531	0.250	0.094	0.031	26	0.000	0.423	0.423	0.000	0.154	0.000	0.385	0.462	0.000	0.154
Protrusion, extrusion	2	34	0.206	0.500	0.265	0.029	0.000	0.235	0.529	0.206	0.029	0.000	30	0.033	0.333	0.633	0.000	0.000	0.033	0.367	0.600	0.000	0.000
Correlation coefficient							0.38 (P < 0.05)											-0.10 (P > 0.05)					

GG = Goutallier grade; LT = left; RT = right

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Table 2. Correlations between Goutallier Grades on CT and Disc Pathologies at Each Disc Level

CT		n = 358	Total_RT_GG					Total_LT_GG					n = 72	L1/L2_RT_GG					L1/L2_LT_GG				
			0	1	2	3	4	0	1	2	3	4		0	1	2	3	4	0	1	2	3	4
Normal/ mild bulging	0	150	0.740	0.180	0.080	0.000	0.000	0.773	0.153	0.073	0.000	0.000	56	0.857	0.107	0.036	0.000	0.000	0.875	0.089	0.036	0.000	0.000
Diffuse disc bulging	1	120	0.175	0.433	0.317	0.042	0.033	0.200	0.442	0.308	0.017	0.033	10	0.000	0.600	0.400	0.000	0.000	0.000	0.700	0.300	0.000	0.000
Protrusion, extrusion	2	88	0.261	0.375	0.432	0.000	0.045	0.295	0.352	0.307	0.000	0.045	6	0.667	0.000	0.000	0.000	0.333	0.667	0.000	0.000	0.000	0.333
Correlation coefficient																		0.53 (P < 0.01)					

CT		n = 72	L2/L3_RT_GG					L2/L3_LT_GG					n = 72	L3/L4_RT_GG					L3/L4_LT_GG				
			0	1	2	3	4	0	1	2	3	4		0	1	2	3	4	0	1	2	3	4
Normal/ mild bulging	0	46	0.761	0.196	0.043	0.000	0.000	0.804	0.152	0.043	0.000	0.000	30	0.733	0.200	0.067	0.000	0.000	0.800	0.167	0.033	0.000	0.000
Diffuse disc bulging	1	18	0.389	0.500	0.111	0.000	0.000	0.444	0.444	0.111	0.000	0.000	32	0.344	0.344	0.250	0.063	0.000	0.375	0.375	0.250	0.000	0.000
Protrusion, extrusion	2	8	0.500	0.000	0.250	0.000	0.250	0.500	0.125	0.125	0.000	0.250	10	0.500	0.300	0.200	0.000	0.000	0.500	0.300	0.200	0.000	0.000
Correlation coefficient							0.29 (P > 0.05)											0.40 (P < 0.05)					

CT		n = 72	L4/L5_RT_GG					L4/L5_LT_GG					n = 70	L5/S1_RT_GG					L5/S1_LT_GG				
			0	1	2	3	4	0	1	2	3	4		0	1	2	3	4	0	1	2	3	4
Normal/ mild bulging	0	8	0.750	0.250	0.000	0.000	0.000	0.750	0.250	0.000	0.000	0.000	10	0.000	0.400	0.600	0.000	0.000	0.000	0.400	0.600	0.000	0.000
Diffuse disc bulging	1	30	0.067	0.533	0.300	0.100	0.000	0.100	0.533	0.300	0.067	0.000	30	0.033	0.333	0.500	0.000	0.133	0.033	0.333	0.500	0.000	0.133
Protrusion, extrusion	2	34	0.294	0.529	0.176	0.000	0.000	0.353	0.471	0.176	0.000	0.000	30	0.000	0.400	0.600	0.000	0.000	0.033	0.367	0.600	0.000	0.000
Correlation coefficient							0.33 (P > 0.05)											-0.03(P > 0.05)					

GG = Goutallier grade; LT = left; RT = right

Table 3. Correlations of Goutallier Grades with Age and Sex

Total		MR (GG)		CT (GG)		CT (HU)		
		B	P < value	B	P < value	B	P<value	beta
Linear regression	Age	0.021	P < 0.01	0.022	P < 0.01	-0.734	P = 0.00	
	Sex	0.454	P = 0.026	0.424	P = 0.044	-20.255	P = 0.01	
Multiple regression	Sex	0.192	P = 0.251	0.142	P = 0.399	-11.625	P = 0.01	-0.298
	Age	0.019	P < 0.01	0.021	P < 0.01	-0.633	P = 1.95	-0.644

GG = Goutallier grade; HU = Hounsfield unit

tissue resolution as MRI. Thus, qualitative evaluation on CT might have been further limited.

Our study showed substantial and almost perfect inter-observer reliability and moderate to substantial intra-observer reliability in grading PSFI on CT and MRI, respectively. Such relatively lower intra-observer reliability compared to inter-observer reliability might be due to the inherent limitation of the qualitative GGS. Our results were comparable to a study of Battaglia et al. (11) who used the GGS to grade PSFI on MRI. In this study, positive correlation was found between the quality of the paraspinal back muscle and disc pathology on preoperative images. PSFI is reversible with back extensor intensive rehabilitation exercises which can be useful for improving the clinical outcome and for preventing possible worsening of surgical outcome (20).

Our study showed higher Goutallier grading and density measurements in older women than in older men, consistent with our hypothesis that older female patients would show poorer qualitative score on MR and lower HU values on quantitative CT assessment. This is supported by a large study done by Kalichman et al. (21) who evaluated the association of lumbar paraspinal muscle density with age, sex, and body mass index (BMI) and another study that described the normal cross sectional muscle area and density in healthy men and women (22).

There is growing evidence that PSFI is significantly more common in those with chronic low back pain (CLBP) than in healthy individuals. Parkkola et al. (23) have noted that paraspinal muscles are smaller in patients with CLBP than in healthy control subjects. Previous MRI studies have shown earlier fatty infiltration of the multifidus muscle in patients with CLBP than in asymptomatic volunteers matched for age, sex, and BMI (15, 24) and in patients with referred lower leg pain without the presence of spinal pathology (6). Although our study included patients with low back pain, we did not have the exact clinical information regarding their chronicity. In addition, PSFI only showed correlation with disc pathology on certain levels rather than at all levels.

This study has several limitations. First, the sample size was relatively small. However, measurements of muscles at each disc level and on both sides (right and left) resulted in numerous data for each person. Second, our simplified method of measuring muscles including intra- and inter-muscular fat without separating erector spinae and multifidus muscles might have oversimplified fatty degeneration of paraspinal back muscles, but we wanted to evaluate paraspinal back muscles as a whole because they all might play an important role in supporting the trunk and posture. We also tried to use a simple method that could be used even by trainees. Third, we did not correlate the degree of muscle atrophy with BMI, severity of low back pain, pain duration, or disability. Thus, we cannot exclude the possibility of disuse atrophy contributing to the muscle atrophy. Fourth, we did not assess the presence of facet arthrosis, side of herniation, or asymmetry of the paraspinal muscle CSA. Fifth, we used an arbitrary grading system for disc pathology to group disc pathologies according to severity. Last, there was a clinical correlation between PSFI and disc pathologies only at certain levels possibly due to varying incidence of disc pathologies at different levels of L-spine. There might be confounding effects of age, sex, and BMI that we did not account for.

In conclusion, we qualitatively and quantitatively assessed PSFI on CT and MRI and found that the GGS and HU measurements could be useful for evaluating PSFI. There were positive correlations between PSFI and disc pathologies only at certain levels. Further investigation is needed to provide an explanation for how PSFI and disc pathologies are related.

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