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ORIGINAL ARTICLE

Comparative Evaluation of Imaging Techniques for Paraspinal Muscle Fat Quantification

Umaiban KV,[1] Jeevithan Shanmugam,[2] Seetharaman Cannane,[3,*] Niva B[4] and Santhosh Poyyamoli[5]

[1]*Consultant Radiologist, Cloudex Scans, Kannur, Kerala*
[2]*Professor, Department of Preventive Medicine, KMCH Institute of Health Sciences and Research, Coimbatore*
[3]*Associate Professor, Department of Radiodiagnosis, KMCH Institute of Health Sciences and Research, Coimbatore*
[4]*Consultant Radiologist, Sri Jayadeva Medicover Diagnostic Centre, Mysuru, Karnataka*
[5]*Consultant, Department of Interventional Radiology, Kovai Medical Centre and Hospital, Coimbatore*

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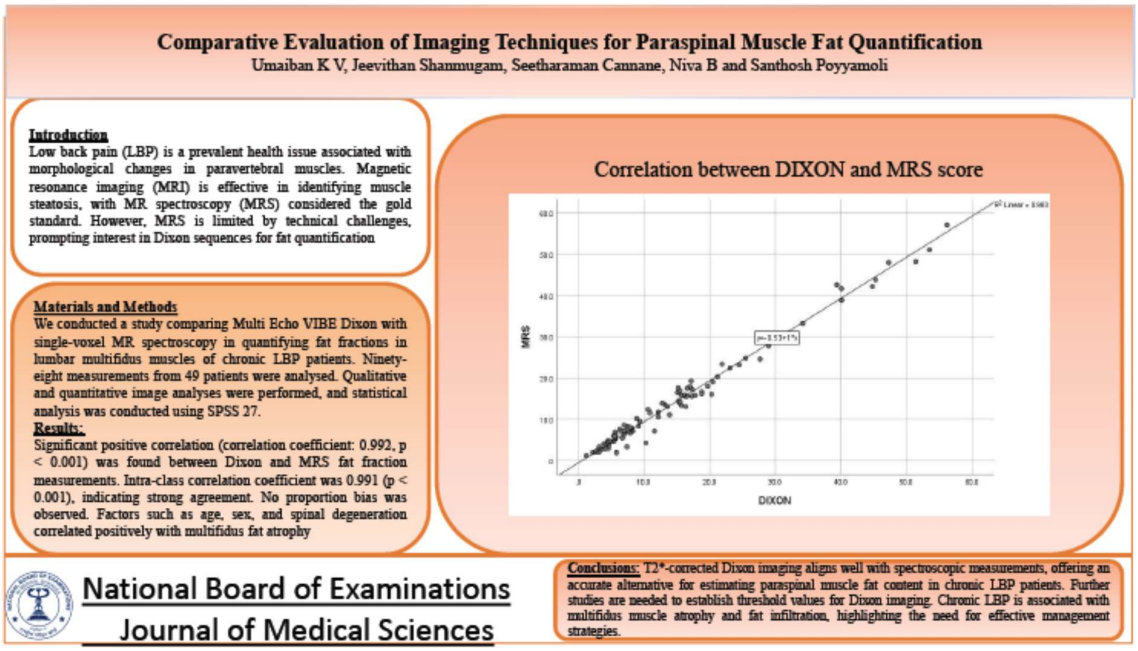
Abstract

Introduction: Low back pain (LBP) is a prevalent health issue associated with morphological changes in paravertebral muscles. Magnetic resonance imaging (MRI) is effective in identifying muscle steatosis, with MR spectroscopy (MRS) considered the gold standard. However, MRS is limited by technical challenges, prompting interest in Dixon sequences for fat quantification. **Materials and Methods:** We conducted a study comparing Multi Echo VIBE Dixon with single-voxel MR spectroscopy in quantifying fat fractions in lumbar multifidus muscles of chronic LBP patients. Ninety-eight measurements from 49 patients were analysed. Qualitative and quantitative image analyses were performed, and statistical analysis was conducted using SPSS 27. **Results:** Significant positive correlation (correlation coefficient: 0.992, $p < 0.001$) was found between Dixon and MRS fat fraction measurements. Intra-class correlation coefficient was 0.991 ($p < 0.001$), indicating strong agreement. No proportion bias was observed. Factors such as age, sex, and spinal degeneration correlated positively with multifidus fat atrophy. **Conclusion:** T2*-corrected Dixon imaging aligns well with spectroscopic measurements, offering an accurate alternative for estimating paraspinal muscle fat content in chronic LBP patients. Further studies are needed to establish threshold values for Dixon imaging. Chronic LBP is associated with multifidus muscle atrophy and fat infiltration, highlighting the need for effective management strategies.

Keywords: Low back pain, multifidus muscle, MRI, Dixon imaging, MR spectroscopy.

*Corresponding author: Seetharaman C
Email: drcseetharaman@gmail.com

Graphical Abstract



Introduction

Low back pain (LBP) poses a significant health concern and is a primary cause of disability among working-age individuals. Over the past decade, the prevalence of low back pain in adults has doubled, with a particular rise noted in the aging population [1]. Scholars have long acknowledged the link between chronic low back pain and morphological alterations in the paravertebral muscles. Substantial research efforts have been dedicated to investigating fatty infiltrations and reductions in paravertebral muscle volume as potential clinical indicators for post-operative outcomes, spinal stability, and certain chronic conditions like age-related sarcopenia [2]. Histologically, the decline in muscle endurance often correlates with changes in muscle structure, such as atrophy of muscles and infiltration of fat, which can be identified through cross-sectional imaging techniques [3].

Among various imaging modalities such as ultrasonography, computed tomography, and magnetic resonance imaging (MRI), MRI stands out as the most objective and sensitive method for detecting and quantifying muscle steatosis. MR imaging offers superior accuracy in identifying and quantifying fat infiltration within the muscles of the lumbar spine, particularly in patients experiencing low back pain. MR spectroscopy, a technique within MRI, accurately displays increased fat signal fractions in lumbar paraspinal muscles and is considered the "gold standard" for fat quantification in MR imaging. This spectroscopic method has found widespread use in measuring fat deposition not only in the liver, heart, pancreas, and skeletal muscle but also in bone marrow [3-5]. Although MR spectroscopy is lauded for its ability to detect even minute amounts of fat, it is not commonly utilized in routine clinical settings due to several drawbacks. Firstly, the technique is time-consuming, which limits its feasibility for widespread use. Secondly, it requires specialized technical

expertise, making it challenging to perform reliably in routine practice. Additionally, MR spectroscopy is susceptible to sampling errors stemming from the arbitrary placement of the region of interest and the relatively low spatial resolution compared to other imaging modalities. These factors collectively contribute to its limited adoption in everyday clinical practice.[5] Quantitative Dixon sequences have emerged as a promising and dependable tool for both fat suppression and fat quantification [6]. When compared to MR spectroscopy (MRS), the Dixon method offers several notable advantages, including rapid and volumetric data acquisition, the visualization of anatomical structures, and the ability to determine fat content within a defined region of interest (ROI) [7]. Multi-echo variants that has been developed recently enhances the separation of fat and water signals consistently, correcting for confounders that may introduce systematic errors in fat-signal fractions.

The primary objective of our study is to compare Multi Echo VIBE Dixon with single-voxel MR spectroscopy in quantifying fat signal fractions within the lumbar paraspinal muscles. Specifically, we aim to estimate the degree of fat infiltration in the multifidus muscle among patients experiencing chronic low back pain. Additionally, we seek to explore whether factors such as age, sex, duration of pain, degenerative disc disease, nerve compression, and endplate changes exert any influence on the fat content of paraspinal muscles.

Materials and Methods

This study was conducted at the Radiology department of a tertiary care hospital in South India, with approval from the Institute's ethical and scientific committee and obtaining written informed consent from all research participants. The study included adult patients aged >18 years experiencing chronic low back pain (defined as “disabling pain in the lower spine persisting for more than 3 months”) who underwent MRI examination of the lumbosacral spine at the hospital between August 2019 and July 2021. Patients with general MRI contraindications, a history of prior spine surgery, or patient motion during acquisition were excluded, along with cases of inflammation that could interfere with total water fraction measurements. Those who were eligible for the study were contacted by the principal investigator and were explained about the background for the study, need for the study, its objectives and other ethical considerations. The Patient Information sheet was given to them, and adequate time was given to understand the contents. Those who were willing to participate were requested to sign the written informed consent form.

MRI sequences were supplemented by multi-echo Dixon and MR spectroscopy to quantify fatty degeneration of bilateral lumbar multifidus muscles at the L4-L5 intervertebral level.

A) MRI Technique

All MRI procedures were conducted using a 3.0 Tesla MRI system (Siemens) with dedicated spine coils. Standard clinical MR imaging protocols for low back pain assessment were performed, including whole spine T2 sagittal, lumbar spine T1 sagittal, IR sagittal, IR and T1 coronal SI joint, and T2 axial sequences. Additionally, a T2-weighted multi-echo VIBE Dixon sequence with 6 echoes was added to the protocol, providing water-

only, fat-only, fat fraction, and R2* mapping image series with corrections for multiple resonance lines in the fat spectrum. Single-voxel point-resolved MR spectroscopy was also acquired as a standard reference.

B) Qualitative Image Analysis

Standard MR imaging sequences were assessed for spinal degenerative features such as disc desiccation, facet arthropathy, endplate signal changes, nerve root compression, and spondylolisthesis, with findings recorded for each patient.

C) Quantitative Image Analysis

MR Spectroscopy (MRS)

Single voxel point-resolved MR spectra were obtained by placing spectroscopy voxels in bilateral multifidus muscles on axial T2-weighted MR images at the L4-L5 intervertebral level. Fat fraction (FF) was automatically calculated based on signals from fat and water at each echo time, with spectroscopy voxel positioning documented for reference in Dixon fat fraction mapping images.

Dixon

Regions of interest (ROIs) were drawn on automatically generated axial fat fraction mapping images from the T2*-corrected six-echo VIBE Dixon sequence, corresponding to the location of spectroscopic voxels. Two independent observers recorded FF values for Dixon and MRS, blinded to each other's measurements except for the voxel position. The diameter of the circular ROI was determined based on the voxel size of MR spectroscopy. Imaging parameters for Dixon were as follows:

- Echo Time: 1.05 ms
- Repetition Time: 9.00 ms
- Field of View (FOV): 450 mm
- Matrix: 111 x 160
- Bandwidth: 1080 Hz/Pixel
- Acquisition Time: 13 sec
- Slice Thickness: 3.5 mm

Data were inputted into an Excel spreadsheet and analyzed utilizing SPSS version 27. Categorical variables were depicted as proportions or percentages, while numerical variables were presented as mean ± standard deviation (SD) or median with interquartile range (IQR). To compare the Multi Echo VIBE Dixon with single-voxel MR spectroscopy in measuring fat signal fraction within the lumbar multifidus muscles of patients experiencing chronic low back pain, Spearman's rank correlation was utilized. The difference in mean fat fraction concerning study variables was evaluated using either the Mann-Whitney U test or Kruskal-Wallis test. Additionally, intra-class correlation was computed to assess the relationship between both methods. A Bland-Altman plot was generated to elucidate the agreement between the two techniques. Statistical significance was defined as a p-value below 0.05.

Results

A total of 98 measurements of spectroscopic fat fraction were obtained from 49 patients, evenly split between males and females. All patients underwent bilateral examinations, and those with incomplete assessments were excluded. Spectroscopic values served as the reference standard.

Age of the study participants ranged from 22 to 77 years, while the mean age was 50.56±14.01 years. The duration of back pain Ranged from 3 months to 6 years,

with a mean duration of 25.95±26.35 months. Most patients (67.3%) couldn't localize their pain, while 17.3% reported left-sided pain and 15.3% reported right-sided pain. Conditions observed included nerve compression (68.4%), facet arthropathy (48%), spondylolisthesis or spondylolysis at L4/L5 (12.2%), modic end plate changes (37.8%), and ligamentous flavum atrophy (26.5%). Additionally, 42.9% had mild disc desiccation, 25.5% had moderate desiccation, and 18.4% had severe desiccation (Table 1).

Table 1. Socio demographics and clinical parameters of study population

Parameter	Sub classification	FREQUENCY	PERCENTAGE
AGE	Below 30 years	9	9.1
	31 - 40 years	18	18.4
	41 - 50 years	20	20.5
	51 - 60 years	26	26.6
	Above 60 years	25	25.4
SEX	Male	48	49.0
	Female	50	51.0
SIDE OF PAIN	Indifferent	66	67.3
	Left	17	17.3
	Right	15	15.4
NERVE COMPRESSION	Present	67	68.4
	Absent	31	31.6
FACET ARTHROPATHY	Present	47	48
	Absent	51	52
SPONDYLOLISTHESIS/ SPONDYLOLYSIS AT L4/L5	Present	12	12.2
	Absent	86	87.8
ASSOCIATED MODIC END PLATE CHANGES	Present	37	37.8
	Absent	61	62.2
DISC DESSICATION	No	13	13.3
	Mild	42	42.9
	Moderate	25	25.5
	Severe	18	18.4

LIGAMENTUM FLAVUM ATROPHY	Present	26	26.5
	Absent	72	73.5

Table 2. ICC values for Fat measurement between DIXON and MRS

ICC	95% Confidence Interval		Significance	
	Lower limit	Upper limit	F Value	P Value
0.991	0.984	0.994	235.97	<0.001

Regarding fat content measurements, the mean percentage fat content of the multifidus muscle was 14.87±12.89 using the MRS method and 15.46±12.84 using the DIXON method. (Table 2) There was a strong positive correlation (correlation coefficient: 0.992, $p < 0.001$) between fat fractions derived from DIXON and MRS methods. The intra-class correlation coefficient between MRS and DIXON was 0.991 indicating strong agreement between the two methods (Fig. 1) Analysis of agreement limits showed no proportion bias between fat fraction values from MRS and DIXON (Fig. 2).

Statistical analysis revealed a positive correlation between multifidus fat atrophy, spinal degenerative factors, increasing age, and female sex. The association between disc desiccation grades and paraspinal muscle fat percentage also indicated higher fat fraction values with increasing severity of desiccation.

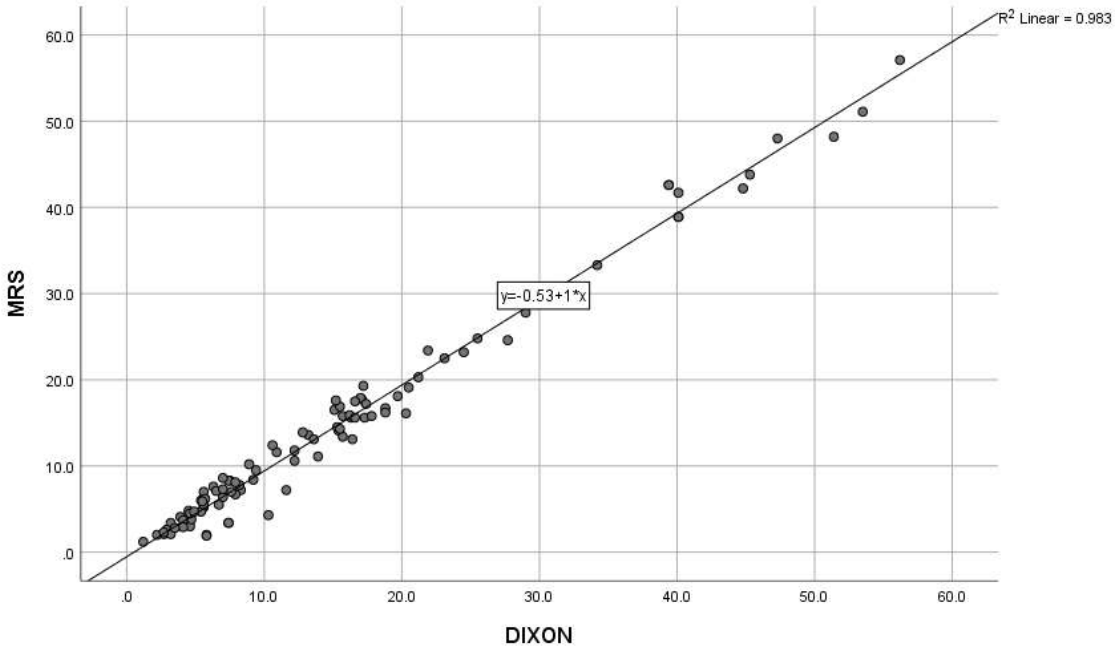


Figure 1. Correlation between DIXON and MRS score

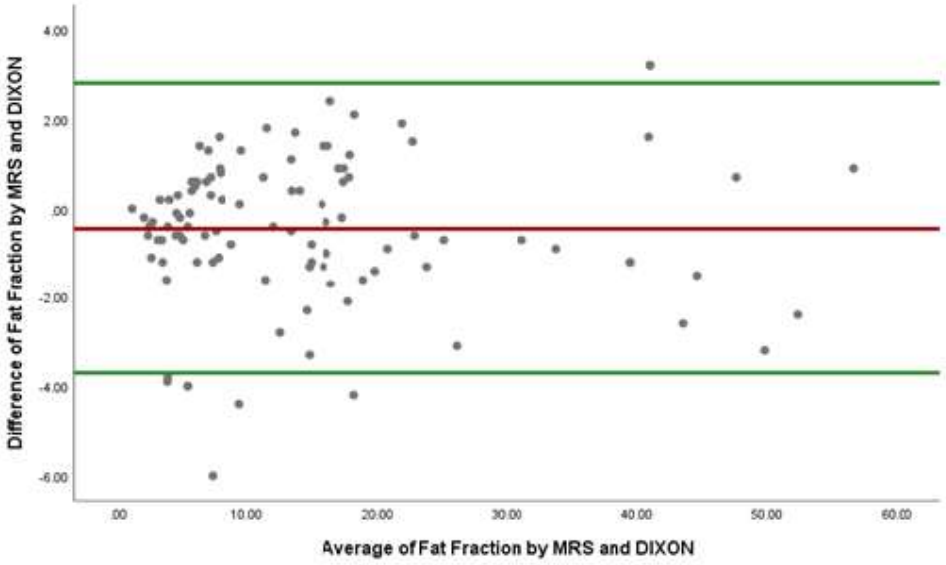


Figure 2. Bland Altman Plot

Discussion

MRI is widely acknowledged as a reliable and effective method for investigating muscles due to its excellent soft-tissue contrast. Continuous advancements in technology, along with the introduction of new sequences and tools, have led to improving accuracy in assessing pathological changes in tissues [8]. Many studies have emphasized the importance of quantitatively evaluating muscle fat content for precise detection and grading of diseases, even when muscles are minimally affected [9]. Advanced MR imaging techniques, such as MR spectroscopy, have been utilized to evaluate and quantify fatty atrophy in muscles such as the supraspinatus and paraspinal muscles. There has been considerable research focused on quantifying local fat levels in skeletal muscle, liver, and bone marrow lesions using various techniques. Among these, single-voxel MRS imaging is commonly considered the gold standard for accurate local fat analysis in vivo [4]. However, MRS poses technical challenges and is prone to sampling errors due to its low spatial resolution [5]. Conversely, Dixon sequences enable precise analysis of muscle fat and its distribution in large volumes with superior spatial resolution and minimal sampling errors in clinical settings [7].

In this study, we aimed to validate whether chemical shift imaging with Dixon sequences could accurately calculate the fat percentage of paraspinal skeletal muscles, comparable to MRS.

Our study yielded consistent findings, demonstrating a significant positive correlation between fat fraction measurements obtained from T2-corrected multi-echo Dixon and MR spectroscopy. Several researchers have investigated the quantification of skeletal muscle fat using MR imaging in various anatomical regions, such as thigh muscles, rotator cuff, and paraspinal muscles, employing the Dixon technique with or without T2 correction.

Yoo et al., in their study, highlighted that fat fraction derived from T2-corrected six-echo VIBE Dixon sequences displayed superior agreement with MR spectroscopic fat fraction data, in

contrast to non-T2 corrected two-echo and T2-corrected three-echo VIBE Dixon data. This finding is consistent with previous research in liver fat fraction analysis, which has demonstrated that T2 correction enhances the precision of fat fraction calculation in multi-echo VIBE Dixon sequences [10].

Contrary to the findings by Yoo et al., Fisher et al. observed that T2 correction did not result in a stronger correlation compared to non-T2 corrected multi-echo sequences when compared with spectroscopic fat fraction data. They proposed that this inconsistency might be due to the decrease in signal-to-noise ratio (SNR) that occurs following T2 correction [9]. Another study by Gaeta et al. reported that T2 correction did not offer greater benefits than the non-T2 corrected method in skeletal muscle fat quantification [11].

Although the necessity of T2 correction for estimating skeletal muscle fat remains uncertain, we opted to incorporate T2 correction into the six-echo VIBE Dixon sequence. This decision was based on the consideration of potential factors that could induce T2 decay in skeletal muscle. Multiple investigations have underscored the association between chronic low back pain and the reduced strength and endurance of paraspinal muscles [12,13]. However, whether these changes are causative factors or consequences of back pain remains a subject of debate. Researchers have specifically noted that among paraspinal muscles, fatty degeneration in chronic low back pain is particularly prominent in the multifidus muscle, which plays a crucial role in lumbar segmental stability [14].

Kjaer et al. presented compelling evidence from a sizable population sample, demonstrating a robust association between fat infiltration in the lumbar multifidus muscle and low back pain in adults [15]. Likewise, Mengiardi et al. discovered significantly elevated fat content in the multifidus muscles of individuals experiencing low back pain compared to asymptomatic volunteers, with no notable difference observed in the fat content of the longissimus muscle. In our investigation, we observed that the percentage of multifidus fat content in patients with chronic low back pain was around 15%, which is notably lower than the 23.6% reported by Mengiardi et al. [5] This discrepancy may be attributed to differences in patient selection criteria and the average duration of symptoms in our patients was shorter compared to those in prior studies, although the age of patients was comparable.

Our study revealed a significant correlation between age and gender with multifidus fat fraction, suggesting that differences in body composition may contribute to variations in multifidus muscle fat content between males and females. This raises questions regarding whether grading scales and cutoff points for fat percentage should be unique for each gender. Additionally, we observed a higher prevalence of fat infiltration in paraspinal muscles among the elderly, irrespective of the duration of back pain [16].

However, further longitudinal studies are needed to elucidate the extent to which age and duration of low back pain contribute to the development of fat atrophy in the lumbar multifidus muscle. Numerous authors have reported declines in cross-sectional area (CSA) and density of back muscles with age, underscoring the importance of considering age as a confounding factor in studies evaluating the association between paraspinal muscle fat

content, spinal degeneration, and low back pain. Additionally, personal factors such as activity level, smoking, type II diabetes mellitus, and cardiovascular diseases may influence fatty infiltration of paraspinal muscles, necessitating further investigation into these influences.

Although body mass index (BMI) was not recorded in our study subjects, previous research has failed to establish a significant association between BMI and muscle fat concentration. Similarly, the thickness of subcutaneous fat has not been found to correlate significantly with the quantity of fat accumulated in muscles [17].

We observed a positive correlation between spinal degeneration features such as disc desiccation, facet arthropathy, modic endplate changes, nerve compression, ligamentum flavum hypertrophy, and spondylolisthesis with multifidus fat content. Disc desiccation and modic endplate changes were found to be independently associated with increased fat percentage of the multifidus muscle.

While lumbar disc herniation with compression of nerve roots can lead to muscle dysfunction [18], we did not observe a statistically significant correlation between the side of pain and muscle fat atrophy in our study. However, severe fatty infiltration of the lumbar multifidus muscle was observed in a patient with unilateral disc protrusion and severe nerve compression on the same side, indicating a potential link between nerve compression and muscle fat atrophy [19].

Numerous studies have reported associations between spinal degeneration, spinal muscular fat, and low back pain. However, it remains unclear whether fat infiltration of the lumbar multifidus muscle serves as a prognostic indicator or if patients with both low back pain and multifidus fat atrophy require special treatment [20,21].

Our study has limitations, including its single institutional nature with a limited number of subjects. Additionally, we used MR spectroscopy as the standard of reference rather than conventional histopathology confirmation via muscle biopsy, which is invasive and may not always be feasible due to ethical concerns. Moreover, clinical data such as pain intensity, functional ability, BMI, and level of physical activity were not evaluated in our study, and there was no control group.

Conclusion

Our study demonstrates that T2-corrected multi-echo VIBE Dixon measurements align well with T2-corrected spectroscopic measurements of fat fraction estimates in the lumbar multifidus muscles of patients with chronic low back pain. Therefore, T2*-corrected Dixon imaging can be favoured over MR spectroscopy in routine clinical practice as it offers an accurate alternative for estimating paraspinal skeletal muscle fat content. However, further large-scale studies are warranted to establish threshold values for chemical shift Dixon imaging that indicate fatty degeneration within the muscle.

Chronic low back pain is associated with atrophy and fat infiltration of the multifidus muscle. Our findings also reveal a significant association between various spinal degenerative factors and multifidus fat infiltration. It is crucial to conduct further research to determine the effectiveness of specific approaches for managing low back pain and preventing progressive fat infiltration of the lumbar paraspinal muscles and spinal degeneration.

Statements and Declarations

Conflicts of interest

The authors declares that they do not have conflict of interest.

Funding

No funding was received for conducting this study.

Ethics approval

Ethical approval obtained from all patients.

Human and animal rights

This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent

For this type of study formal consent is not required.

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