DOI: 10.4274/jarem.galenos.2024.72621
J Acad Res Med 2024;14(3):100-5

Magnetic Resonance Imaging- Defined Lumbar Paraspinal Muscle Morphometry and Lumbopelvic Parameters in Patients with Lumbar Isthmic Spondylolisthesis

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Cite this article as: Akkaya S, Sağlam Akkaya G. Magnetic Resonance Imaging-Defined Lumbar Paraspinal Muscle Morphometry and Lumbopelvic Parameters in Patients with Lumbar Isthmic Spondylolisthesis. J Acad Res Med. 2024;14(3):100-5

ABSTRACT

Objective: Lumbar isthmic spondylolisthesis (LIS) is a mechanical process characterized by an abnormality in the pars interarticularis that results in anterior translation of the lumbar vertebra. This study aimed to evaluate the multifidus (MF) and erector spinae (ES) cross-sectional areas (CSAs) and lumbopelvic parameters in patients with LIS using magnetic resonance imaging (MRI) and to examine the association of these findings with the spondylolisthesis grade and slip percentage.

Methods: This study included 55 patients and 45 healthy individuals. The total CSA (TCSA), functional CSA (FCSA), relative CSA (rCSA), and ratios of the MF and ES muscles, lumbar lordosis angle (LLA), upper lumbar lordosis (ULLA), lower lumbar lordosis, and sacral slope angle were compared between the patient and control groups and between the spondylolisthesis grades. The correlations between these findings and the slip percentage were assessed.

Results: The functional and relative CSAs of the MF and ES muscles, MF FCSA/TCSA, and ES FCSA/TCSA were decreased in the patient group. Fatty degeneration was more pronounced in grade 2 LIS than in grade 1. ULLA was elevated in the patient group, and a weak negative correlation was observed between the slip percentage and the MF FCSA/ES FCSA ratio.

Conclusion: Patients with LIS demonstrated greater fatty degeneration in MF and ES, and increased ULLA. MRI-based assessments of ES and MF may serve as indicators of LIS progression and spinal instability. The findings of this study highlight the significance of quantitative muscle and lumbopelvic measurements, which may be beneficial in implementing exercise protocols.

Keywords: Isthmic spondylolisthesis, magnetic resonance, atrophy, multifidus, erector spinae

INTRODUCTION

Low back pain (LBP) is a prevalent and significant health issue that causes disability worldwide. It has significant socioeconomic implications because of its high prevalence and long-term morbidity. LBP has various potential causes among adults, with mechanical or non-specific causes being the most frequent. According to studies, 97% of the occurrences of mechanical LBP are caused by spinal components, such as bone, ligaments, discs, joints, nerves, and meninges (1-3).

Lumbar isthmic spondylolisthesis (LIS) is a mechanical process that causes LBP. The condition is characterized by an abnormality in the pars interarticularis that leads to anterior translation of the lumbar vertebra relative to the next caudal segment (4). The reported incidence of LIS in adult patients with LBP ranges from 3.7% to 8% in various studies. It occurs most commonly at L5-S1 and second most frequently at L4-5 (5-7). Factors contributing to the development of LIS include lumbar spine stresses that are highest at lower lumbar levels, and the facets being more coronally oriented, resulting in additional strain for the pars interarticularis at the lumbosacral junction. Moreover, the cross-sectional architecture of the pars is rather thin in the lower lumbar spine. Stress fractures may result from a congenitally dysplastic pars as well as an increase in the pressures focused across the pars with lumbar extension (8).

The paraspinal muscles (PM) are essential for maintaining the stability of the vertebral column, particularly when load-carrying is involved. Atrophy and fatty degeneration of PM can cause instability of the surrounding vertebrae, ultimately leading to LIS.

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Received Date: 13.10.2024 **Accepted Date:** 11.12.2024

J Acad Res Med 2024;14(3):100-5

Previous studies on the role of PM and several spinal pathologies have demonstrated conflicting results (9-14).

The objective of this study was to evaluate the lumbopelvic parameters, cross-sectional area (CSA) of the erector spinae (ES) and multifidus (MF) muscles, and fat infiltration level in adults with LIS. Additionally, this study aimed to assess the association between these findings and spondylolisthesis grade and slip percentage.

METHODS

Study Population

Fifty-five patients aged between 22-87 years, diagnosed with isthmic spondylolisthesis, and who underwent lumbar spine magnetic resonance imaging (MRI) in the last 12 months were included in this cross-sectional study. The exclusion criteria were the presence of neurological disease, spinal fractures, lumbosacral spinal surgery, scoliosis, and diseases that may cause sarcopenia (cancer, coronary heart disease, heart failure, thyroid/parathyroid disorders). A control group of 45 subjects similar to the patient group in terms of age and sex were enrolled in the study. The exercise status and smoking habits of all participants were noted. Based on the study of Lee et al. (9), the minimum sample size was calculated to be 90 (45 patients and 45 controls), assuming a power of 80%, a significance level (α) of 0.05, and an effect size of 0.6 for the variable of ES functional CSA. G*POWER 3.1 version (Heinrich-Heine University of Dusseldorf, Germany) was utilized to estimate the sample size. This study was approved by the Karadeniz Technical University Scientific Research Ethics Committee (IRB number: 2023/88, date: 13.07.2023).

Radiological Analysis

The degree of spondylolisthesis was determined according to the Meyerding classification of the slip, which categorizes slip severity into five grades: 0% to 25% is grade I, 25% to 50% is grade II, 50% to 75% is grade III, 75% to 100%; and grade V, greater than 100%. Axial T2-weighted MRI images were analyzed at the level of the L4 inferior endplate using the FIJI (National Institutes of Health, Bethesda, Maryland), which is an open-source image-processing software. MRI measurements were performed individually for the MF and ES muscles. The total cross sectional area (TCSA) of the muscles was measured by tracing their outlines. Functional cross-sectional area (FCSA) is the fat-free area of CSA measured by selecting a threshold signal intensity that includes only pixels within the lean muscle. The threshold for lean muscle tissue was defined by drawing six sample regions of interest (ROIs) within the lean muscle tissue of bilateral PM to avoid the inclusion of any visible pixels of fat. The maximum signal intensity obtained from the six ROIs was selected as the threshold for distinguishing lean muscle tissue from fat (Figure 1). Subsequently, the ratio of the FCSA to TCSA was calculated for the MF and ES muscles. To compensate for the influence of individual body shape, body weight, and height on the CSA of the muscles, the relative total and functional CSAs (rTCSA and rFCSA), which were defined as the ratio of the CSA of the muscles to the CSA of the L4 inferior endplate, were then obtained. The MF TCSA/ES TCSA and MF FCSA/ES FCSA ratios were also calculated.

The lumbopelvic angles were measured on T2-weighted MRI images using a Syngo.via VB60A workstation (Siemens Healthineers, Erlangen, Germany). The lumbar lordosis angle [(LLA) angle between the superior endplates of L1 and S1], upper lumbar lordosis [(ULLA) angle between the superior endplates of L1 and L4], lower lumbar lordosis [(LLLA) angle between the superior endplates of L4 and S1], and sacral slope angle [(SSA) angle between the superior endplate of S1 and the horizontal plane] were measured, as shown in Figure 2. The degree of spondylolisthesis was determined according to the Meyerding classification, and the slip percentage was recorded.

All MRI measurements were performed independently twice (with a 1-month interval) to minimize the potential for error in defining muscle margins by a radiologist with 14 years of experience. The average values of the two measurements were used for statistical analysis.

Statistical Analysis

The statistical analysis was performed using the Statistical Package for the Social Sciences (version 23.0; IBM Inc., Armonk,

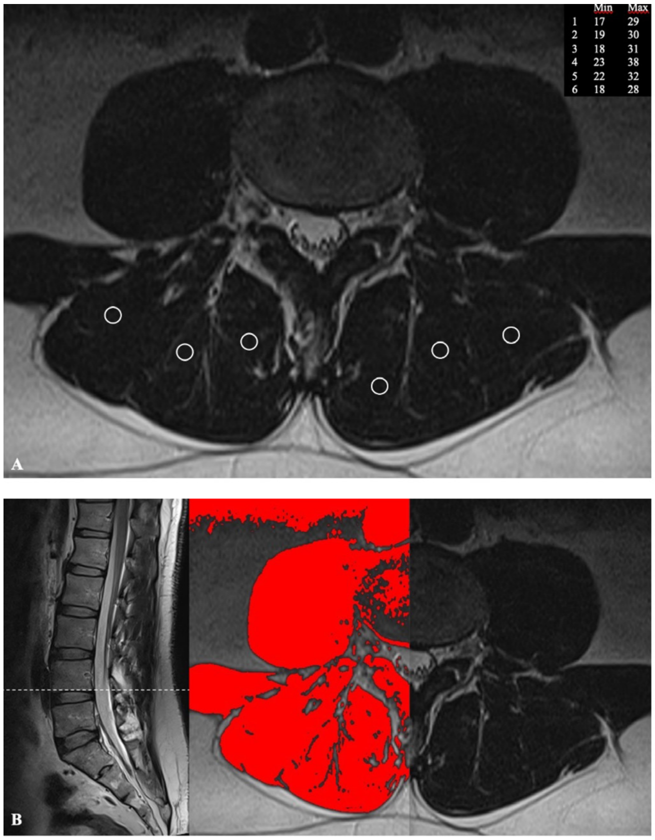

Figure 1. Quantitative paraspinal muscle measurement. (A) Selection of six different regions of interest to define upper and lower threshold limits. (B) Sagittal and axial T2-weighted magnetic resonance images showing the measurement of the total and functional cross-sectional areas of the multifidus and erector spinae muscles at the level of the L4 inferior endplate.

New York). Quantitative data were expressed as means ± standard deviation or medians and interquartile range, as appropriate. Qualitative data are presented as numbers and percentages. The Kolmogorov-Smirnov test was used to check the normality of the distribution. The variables were compared using Student's t-test, the Mann-Whitney U test, and the chi-squared test for normally distributed, non-normally distributed, and categorical variables, respectively. Statistical significance was set at p-values 0.05.

RESULTS

Demographics of Participants

A total of 55 patients (30 females, 25 males) and 45 healthy individuals (24 females, 21 males) were included in this study. The mean ages of the patient and control groups were 64.5±14.5 years and 61±5.7 years, respectively. There were no statistically significant differences between the patient and control groups in terms of gender (p=0.904), smoking status (p=0.267), exercise status (p=0.889), or age (p=0.108) (Table 1).

Radiological Characteristics

In the spondylolisthesis group, 41 patients (74.6%) had L5/S1 spondylolisthesis. Thirty-six patients (65.5%) had grade I spondylolisthesis. Table 2 lists the spondylolisthesis features of the patient group.

Comparison of the groups in terms of MF and ES muscle areas revealed that MF rFCSA, ES FCSA, ES rFCSA, MF FCSA/TCSA, and ES FCSA/TCSA were decreased in patients with spondylolisthesis compatible with an increase of fatty degeneration. ULLA was higher in the spondylolisthesis group (19.78±10.74) than in the control group (13.64±6.84). MRI measurements of the PM and lumbar lordosis are summarized in Table 3.

MF FCSA, MF rFCSA, ES FCSA, MF FCSA/TCSA, and ES FCSA/TCSA were lower in patients with grade 2 spondylolisthesis. No significant difference was detected between grade 1 and 2 spondylolisthesis groups regarding lumbar lordosis angle (Table 4). A weak negative correlation was found between the percentage of slip and the MF FCSA/ES FCSA ratio (Table 5).

Table 1. Demographic features of the groups

		Patient group		Control group		p
		Number	%	Number	%	
Gender	Female	30	54.5	24	53.3	0.904*
	Male	25	45.5	21	46.7	
Smoking	(+)	22	40	23	51.1	0.267*
	(-)	33	60	22	48.9	
Exercise status	None	39	70.9	30	66.6	0.889*
	1-2 days/week	7	12.7	7	15.6	
	≥ 3 days/week	9	16.4	8	17.8	
Age, mean ± SD		64.5±14.5		61±5.7		0.108**

*:chi-square test, **:independent sample t-test SD: standard deviation

DISCUSSION

The paraspinal muscles directly affect the segmental stability of the lumbar spine. Thus, assessment of the CSA of these muscles is crucial for managing LBP (9,10). Previously, only a limited number of studies have investigated the role of PM in patients with spondylolisthesis. Degeneration of the PM and reduced isometric force of the lumbar spine are detected in patients with degenerative spondylolisthesis (DSL). Atrophy of the MF muscle is the most commonly observed morphometric alteration in these cases (11-14). However, the LIS has been under-investigated in terms of PM morphometry (15-17). In the present study, our findings demonstrated that the LIS group exhibited a greater degree of fat deposition in both the MF and ES than the control group, and

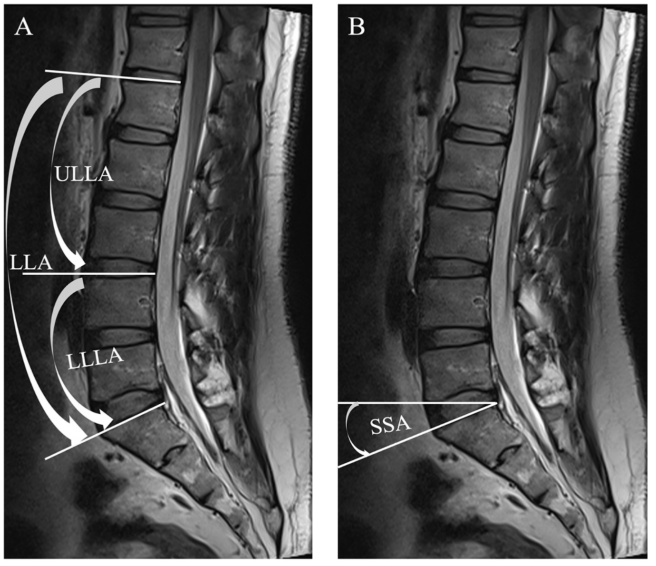

Figure 2. Measurement of lumbopelvic angles. (A) Lumbar lordosis angle (LLA) between the superior endplates of L1 and S1, upper lumbar lordosis angle (ULLA) between the superior endplates of L1 and L4, and lower lumbar lordosis angle (LLLA) between the superior endplates of L4 and S1 were measured using T2-weighted sagittal images. (B) The sacral slope angle (SSA) between the horizontal plane and the superior endplate of S1 was investigated.

Table 2. Sponylolisthesis features of the patient group

		Patient group	
		Number	%
Spondylolisthesis level	L3-4	2	3.6
	L4-5	12	21.8
	L5-S1	41	74.6
Spondylolisthesis grade	Grade 1	36	65.5
	Grade 2	19	34.5
	Grade 3	0	0
	Grade 4	0	0
Slip percentage, mean ± SD		22.73±8.63	

SD: standard deviation, L: lumbar vertebra this difference was more pronounced among patients with grade 2 LIS compared with grade 1 LIS. A higher slip percentage was associated with MF atrophy. In addition, ULLA was increased in patients with LIS.

The relationship between DSL and PM has been investigated in several studies. Some studies on the role of PM have been conducted by measuring CSAs; however, the results have been controversial. A retrospective study included 62 female patients with DSL and evaluated the CSAs of lumbar PM and fatty degeneration. The patient group showed no significant difference in the total CSA of the MF or ES compared with the control group. Patients with DSL showed greater fat infiltration in the MF muscle and smaller FCSA. In contrast,

Table 3. Comparison of MRI parameters between the patient and control groups

Muscle and lumbar lordosis parameters	Patient group	Control group	p
LLA	57.33±12.41	52.84±11.17	0.063*
ULLA	19.78±10.74	13.64±6.84	**0.001***
LLLA	38±10.35	39.56±6.6	0.365*
SSA	46.84±9.07	44±7.92	0.103
MF TCSA (mm^2)	2290.87±447.42+	2122.62±369.25+	**0.046***
MF FCSA (mm^2)	1686 (794)†	1940 (564)†	0.192**
MF rTCSA	1.71±0.39+	1.69±0.37+	0.783*
MF rFCSA	1.31±0.39+	1.49±0.33+	**0.019***
MF FCSA/TCSA (%)	78.86 (20)†	90.56 (10)†	**<0.001****
ES TCSA (mm^2)	3817.72±851.23+	3540.58±816.47+	0.101*
ES FCSA (mm^2)	2630.76±702.69+	2955.18±780.49+	**0.031***
ES rTCSA	2.94 (1.08)†	2.73 (0.70)†	0.747**
ES rFCSA	1.87 (0.86†	2.32 (0.48)†	**0.001****
ES FCSA/TCSA (%)	69.91±14.32+	83.08±9.27+	**<0.001***
MF TCSA/ES TCSA	0.62±0.18+	0.61±0.12+	0.764*
MF FCSA/ES FCSA	0.69±0.20+	0.66±0.15+	0.423*

*: independent samples t-test, **: Mann-Whitney U test, +: mean±standard deviation, †: median (interquartile range), LLA: lumbar lordosis angle, ULLA: upper lumbar lordosis angle, LLLA: lower lumbar lordosis angle, SSA: sacral slope angle, TCSA: total cross-sectional area, FCSA: functional CSA, MF: multifidus, ES: erector spinae, r: relative

Table 4. Comparison of MRI between spondylolisthesis grades

Muscle and lumbar lordosis parameters	Grade 1	Grade 2	p
LLA	56.03±11.91+	59.79±13.29+	0.309*
ULLA	19±10.51+	21.26±11.31+	0.463*
LLLA	37.5 (9)†	41 (13)†	0.451**
SSA	45.5±8.39+	49.37±9.98+	0.134
MF TCSA (mm^2)	2337.92±433.24+	2201.74±471.98+	0.287*
MF FCSA (mm^2)	1958.5 (808)†	1540 (718)†	**0.042****
MF rTCSA	1.72±0.39+	1.67±0.41+	0.600*
MF rFCSA	1.41±0.32+	1.19±0.35+	**0.022***
MF FCSA/TCSA (%)	80.92 (21)†	73.87 (19)†	**0.031****
ES TCSA (mm^2)	3729.35±723.25+	3984.74±1054.3+	0.294*
ES FCSA (mm^2)	2872.68±620.83+	2482.35±647.5+	**0.033***
ES rTCSA	2.73 (0.95)†	3.09 (1.18)†	0.280**
ES rFCSA	1.87 (0.91)†	1.87 (0.93)†	0.608**
ES FCSA/TCSA (%)	69.99±14.39+	59.77±13.58+	**0.013***
MF TCSA/ES TCSA	0.64±0.14+	0.59±0.23+	0.338*
MF FCSA/ES FCSA	0.71 (0.28)†	0.60 (0.28)†	0.089**

*: independent samples t-test, **: Mann-Whitney U test, +: mean±standard deviation, †: median (interquartile range), LLA: lumbar lordosis angle, ULLA: upper lumbar lordosis angle, LLLA: lower lumbar lordosis angle, SSA: sacral slope angle, TCSA: total cross-sectional area, FCSA: functional CSA, MF: multifidus, ES: erector spinae, r: relative, MRI: magnetic resonance imaging

Table 5. Correlation between muscle and lumbar lordosis parameters and slip percentage

Muscle and lumbar lordosis parameters	Correlation Coefficient	p
LLA	-0.062	0.654*
ULLA	0.184	0.178*
LLLA	-0.331	0.113*
SSA	-0.092	0.502*
MF TCSA (mm^2)	-0.142	0.302*
MF FCSA (mm^2)	-0.120	0.382**
MF FCSA/TCSA (%)	-0.055	0.690**
MF rTCSA	-0.043	0.754*
MF rFCSA	-0.057	0.678*
ES TCSA (mm^2)	0.257	0.058*
ES FCSA (mm^2)	0.240	0.077*
ES FCSA/TCSA (%)	0.570	0.681*
ES rTCSA	0.172	0.209**
ES rFCSA	0.226	0.097*
MF TCSA/ES TCSA	-0.239	0.079*
MF FCSA/ES FCSA	-0.340	**0.011***

*: Pearson test, **: Spearman test, LLA: lumbar lordosis angle, ULLA: upper lumbar lordosis angle, LLLA: lower lumbar lordosis angle, SSA: sacral slope angle, TCSA: total cross-sectional area, FCSA: functional CSA, MF: multifidus, ES: erector spinae, r: relative

the ES muscle showed a large FCSA in DSL patients. These results indicate increased fat infiltration in the MF of patients undergoing DSL (18). An observational study revealed that the percentage of slip in DSL patients was not associated with MF CSA (11), whereas a case-control study showed PM hypertrophy in comparison with controls (12).

Reports on LIS and PM have yielded inconsistent results. A computed tomography study demonstrated that PM CSAs were significantly larger in patients with LIS (14). Thakar et al. (17) assessed patients who underwent posterior interbody fusion for LIS. In contrast to our results, this study demonstrated selective atrophy of the MF, whereas compensatory hypertrophy was observed in the ES. The discrepancy between our study and previous investigations may be attributable to differences in study populations. Various factors, including pain and symptom duration, pain intensity, age, race, gender, hormonal status, occupation, body mass index, and physical activity level, can potentially contribute to diverse structural changes in muscle groups. Consequently, ES compensatory hypertrophy as a protective mechanism may not be observed in all patients.

Park et al. (19) investigated the role of lumbar PM mass and slip percentage in DSL and LIS using MRI. MF CSAs were negatively correlated with slip percentage in patients with LIS, and no muscle measurements exhibited any correlation with slip percentage in the DSL group. Our study indicated that the decrease in ES and MF CSA was associated with the LIS grade, which demonstrates segmental instability. MF atrophy was more pronounced than ES atrophy in terms of the slip percentage. An additional observational study including both patients with DSL and those with LIS detected a negative correlation between slip percentage and MF CSA as well as a positive correlation between slip percentage and ES CSA (20).

Previous studies have reported that patients with DSL exhibited significantly higher segmental lumbar lordosis at the upper lumbar spine, specifically at the L1-L2 and L2-L3 levels, compared to those without DSL. This finding is consistent with our study, which revealed elevated ULLA in patients with LIS compared with healthy controls. Based on these observations, the compensatory mechanism for anterior translation of the L4 vertebral body may increase the degree of lordosis in the upper portion of the lumbar spine (21,22).

Fatty degeneration occurs with the replacement of PM tissue with adipose tissue and is considered an indicator of muscle atrophy. Unilateral back pain is linked to ipsilateral PM atrophy. The suppression of the long-loop reflex to protect damaged tissue at the symptomatic vertebral level is a potential mechanism of PM atrophy (23,24). Increased sagittal instability resulting from spondylolisthesis may lead to stretching and thinning of the paraspinal musculature, as anterior displacement of a vertebra in spondylolisthesis results in increased lumbar lordosis. This explains the structural alterations and their association with PM (19). Our results suggest that fatty degeneration and functional loss occur in the MF and ES of LIS patients. Thus, the substitution of muscular tissue with fat may influence the muscle's function, while its TCSA may remain relatively unchanged.

This study has several limitations. First, retrospective patient data did not include clinical information. Consequently, there is an absence of data regarding the reflection of fatty degeneration observed in clinical findings beyond the muscle groups. Further research will be beneficial to evaluate the clinical findings by comparing the changes in fatty degeneration in the ES and MF muscles through a prospective analysis. Second, the relationship between PM muscle measurements, symptom duration, and pain intensity was not evaluated. The strengths of this study were as follows: a matched control group was included, various MRI-based measurements were performed, and quantitative methods were used to accurately measure fat infiltration. Lumbopelvic parameters have not been addressed in previous studies. Furthermore, the results of this study indicate the importance of providing detailed descriptions of PM fatty degeneration and grading in radiology reports to plan physical therapy programs for patients with LIS. This information can also be used in follow-up examinations to monitor treatment responses and to facilitate rehabilitation.

CONCLUSION

The assessment of PM CSAs is important in patients with LIS because these muscles affect the segmental stability and control of the lumbar spine. In this study, ES and MF functional areas were decreased in patients with LIS due to fatty degeneration.

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Prospective studies are needed to evaluate the clinical significance of PM fatty degeneration on pain, functionality, and exercise programs.

Ethics

Ethics Committee Approval: This study was approved by the Karadeniz Technical University Scientific Research Ethics Committee. (IRB number: 2023/88, date: 13.07.2023).

Informed Consent: Retrospective study.

Footnotes

Author Contributions: Surgical and Medical Practices - S.A.; Concept - S.A., G.S.A.; Design - S.A., G.S.A.; Data Collection and/or Processing - S.A., G.S.A.; Analysis and/or Interpretation - S.A.; Literature Search - S.A., G.S.A.; Writing - S.A., G.S.A.

Conflict of Interest: The authors have no conflict of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

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