Lumbar paraspinal muscle morphometry and its correlations with demographic and radiological factors in adult isthmic spondylolisthesis: a retrospective review of 120 surgically managed cases

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OBJECTIVE The objective of this study was to assess the cross-sectional areas (CSAs) of lumbar paraspinal muscles in adults with isthmic spondylolisthesis (IS), to compare them with those in the normative population, and to evaluate their correlations with demographic factors and MRI changes in various spinal elements.

METHODS The authors conducted a retrospective study of patients who had undergone posterior lumbar interbody fusion for IS, and 2 of the authors acting as independent observers calculated the CSAs of various lumbar paraspinal muscles (psoas, erector spinae [ES], multifidus [MF]) on preoperative axial T2-weighted MR images from the L-3 to L-5 vertebral levels and computed the CSAs as ratios with respect to the corresponding vertebral body areas. These values were then compared with those in an age- and sex-matched normative population and were analyzed with respect to age, sex, duration of symptoms, grade of isthesis, and various MRI changes at the level of the isthesis (pedicle signal change, disc degeneration, and facet arthropathy).

RESULTS Compared with values in normative controls, the mean CSA value for the ES muscle was significantly higher in the study cohort of 120 patients (p = 0.002), whereas that for the MF muscle was significantly lower (p = 0.009), and more so in the patients with PSC (p = 0.002). Magnetic resonance imaging signal change in the pedicle was seen in half of the patients, all of whom demonstrated a Type 2 change. Of the variables tested in a multivariate analysis, age independently predicted lower area values for all 3 muscles (p ≤ 0.001), whereas female sex predicted a lower mean psoas area value (p < 0.001). None of the other variables significantly predicted any of the muscle area values. A decrease in the mean MF muscle area value alone was associated with a significantly increased likelihood of a PSC (p = 0.039).

CONCLUSIONS Compared with normative controls, patients with IS suffer selective atrophy of their MF muscle, whereas their ES muscle undergoes a compensatory hypertrophy. Advancing age has a detrimental effect on the areas of the lumbar PSMs, whereas female sex predisposes to a decreased psoas muscle area. Multifidus muscle atrophy correlates with PSC, indicating the role of this deep stabilizer in the biomechanical stability of spondylolisthetic spines. This may be of clinical significance in targeted physiotherapy programs during the conservative management of IS.

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KEY WORDS isthmic spondylolisthesis; paraspinal muscles; morphometry; pedicle signal change; disc degeneration; facetal arthropathy; lumbar

ALTERATIONS in lumbar paraspinal muscle (PSM) morphometry have been documented in low-back pain (LBP), degenerative listhesis, with atrophy of the multifidus (MF) muscle frequently reported in these conditions. Paraspinal muscle morphometry has not been analyzed in isthmic spondylolisthesis (IS), a condition with strong physiotherapy connotations, especially in the lower grades. We hypothesized that patients with IS have atrophic PSMs and that the PSM areas in these patients have a bearing on the radiological degenerative changes in some of the spinal elements. Pedicle signal change (PSC) at the level of the pars fracture, documented...
to occur as a function of age in many patients with IS, has been construed to reflect a continuum of biomechanical stresses in the spondyloysis spine. We postulated that thinner, and hence weaker, lumbar PSMs predispose to greater PSC in IS.

Methods

Patient Population

Records for 360 patients who had undergone posterior lumbar interbody fusion with pedicle screw fixation for spondylolisthesis in the period from 2001 to 2014 (13 years) were screened. Patients with a history of previous lumbar surgery or significant trauma preceding their symptoms or those with coexisting spinal cord compression (cervical or thoracic) were excluded from the study cohort. The cohort eligible for analysis was a homogeneous group of 120 consecutive adults with IS (with subtype IIa\(^{27}\) bilateral pars fractures) in whom conservative treatment for at least 6 months had failed and whose preoperative MRI and CT scans were available in the hospital imaging system.

Normative Population

Age- and sex-matched nonlisthetic subjects (120) from the neurosciences outpatient department were selected as controls to compare their PSM morphometry with that in the study group. These subjects did not report radicular pain in the lower limbs, significant back pain, or previous trauma, and they had undergone lumbar sacral spine MRI as part of a screening protocol during their neurological evaluation. Subjects with significant disc disease or any intradural pathology in the lumbar region were excluded.

Radiographic Evaluation

The presence of bilateral pars fractures was confirmed on preoperative CT scans. The degree of listhesis was graded based on the Meyerding classification. Digital images of the preoperative lumbar spine MRI for the patients included in this study were retrieved from the hospital radiographic system (Synapse, Fujifilm Health Systems, USA). The same MRI protocols were used for measurements in the controls and the patients. Magnetic resonance images were acquired on a Signa CVi/NVi 1.5-T magnet (General Electric) using a standard spine array coil. Measurement parameters were as follows: slices 11 (sagittal) and 20 (axial); slice thickness 4 mm and space 1 mm; FOV 240 × 200 mm (sagittal) and 180 × 180 mm (axial); TR 4000 msec (sagittal) and 3000 msec (axial); TE 118.04 msec (sagittal) and 82.32 msec (axial); matrix size 384 × 224 (sagittal) and 256 × 192 (axial); number of excitations 2; flip angle 90°.

Two consultant neurosurgeons (S.T. and L.S.) functioned as independent observers for all measurements. They were blinded to clinical history, the radiologist’s report at the time of imaging, and group allocation (patients vs controls). Computed tomography and parasagittal MRI sequences demonstrating the pars defects were not provided to them during the cross-sectional area (CSA) measurements. Axial sections of conventional T2-weighted spin echo images were taken parallel to the disc spaces and perpendicular to the PSMs. From these, the sections at the upper vertebral endplates from L-3 to L-5 were used to measure the CSA of the PSMs. The measured muscles included the psoas, erector spine (ES), and MF (Fig. 1). The CSA was measured by creating a region of interest (ROI) for each muscle bilaterally. Given the strong correlations established between muscle mass and skeletal CSA,\(^{22}\) we assumed that the muscle areas biomechanically corresponded to the morphometry of the vertebral body (VB) at any given level.\(^{23}\) Thus, muscle CSA/VB CSA ratios (rather than absolute muscle CSA values) were used to eliminate biases arising from variations in patient build. The CSA of the VB was measured at the same cuts as those taken for the measurement of the muscle areas. The mean muscle CSA/VB CSA ratios were then calculated for each subject. The mean of these area ratios obtained by the 2 observers was used for analysis.

Pedicle signal change was recorded as per the technique and grading described by Ulmer et al.\(^{24}\) The 2 observers independently reviewed the sagittal T1- and T2-weighted images for the presence of signal change within 1 or both pedicles at the level of the pars defect. The signals of the pedicle on each side were compared with those of the pedicle on the same side of the spine at the higher level. If the 2 observers did not agree that a pedicle had a signal significantly different from its rostral neighbor, then the pedicle was scored as Type 0. When both observers agreed that a pedicle adjacent to a pars defect had a signal different from its neighbor, the signal change was assigned by consensus into 1 of 3 types. Disc degeneration was graded on a 5-point ordinal scale, as described by Pfirrmann et al.\(^{27}\) Facetal arthropathy at the level of the listhesis was recorded as categorical variables based on established MRI criteria.\(^{12}\)

Statistical Methodology

Data were entered into an Excel spreadsheet (Microsoft Inc.) and analyzed using SPSS version 20 (SPSS Inc.). Means and standard deviations were computed for continuous variables. The paired t-test was used to compare differences between area ratios in the normative population and in the study cohort. Correlation of age with the muscle area ratios was analyzed using Pearson’s correlation test, while ANOVA was used for analyzing the effect of various categorical variables on the muscle area values. Multivariate analysis included a linear regression analysis to predict various muscle area ratios from demographic and radiological factors, and a logistic analysis to predict the influence of various radiological factors on PSC. Interobserver variability was measured using the intraclass correlation coefficient (ICC) and standardized ratings of agreement.\(^{22}\)

Results

Demographics and Radiological Characteristics

Thirty-seven males and 83 females were in the study cohort, with a mean age of 47.48 ± 10 years (range 25–68 years). The mean duration of symptoms was 7.54 ± 5.32 months. Table 1 lists the various radiological characteristics of the cohort.
Muscle Areas in Normative Population Versus Study Cohort

Compared with the value in the normative population, the mean muscle area value for the MF was significantly lower in the study cohort \( (p = 0.009) \), while that of the ES was significantly higher \( (p = 0.002; \text{Table 2}) \). The mean muscle area value for the psoas muscle was not significantly different in the 2 groups.

Univariate Analysis

Pearson’s correlation analysis demonstrated a negative correlation of the muscle area values with increasing age \( (p < 0.05; \text{Fig. 2}) \). Female sex correlated with decreased psoas muscle area values (Fig. 3). Duration of symptoms did not correlate with any of the muscle area values \( (p > 0.05) \). Various radiological factors (PSC, disc degeneration, and facet arthropathy) were analyzed for their influence on muscle area values. For these factors, the MF muscle demonstrated significantly decreased area values in the subgroup with PSC compared with values in the subgroup without PSC (Fig. 4). Analysis of variance showed that disc degeneration was correlated with MF atrophy \( (p = 0.049) \), whereas facet arthropathy did not correlate with the muscle area values \( (p > 0.05) \).

Multivariate Analysis

A linear regression analysis was performed to predict the influence of age, sex, duration of symptoms, disc degeneration, and grade of listhesis on paraspinal muscle area values (Table 3). In assessing the overall fit of the linear regression model, we found the variables significantly predicted all the muscle area values. Of the variables tested, age independently predicted lower area values for all the muscles, whereas female sex added statistical significance to the prediction only for a lower mean psoas muscle area value. None of the other variables significantly predicted any of the muscle area values.

Logistic regression analysis was performed to predict the influence of age, sex, mean muscle area values, duration of symptoms, disc degeneration, facet degeneration, and grade of listhesis on PSC. The binomial logistic regression model was statistically significant (chi-square \[ 12 \] = 24.971, \( p = 0.015 \)). The model explained 25\% of the variance in PSC at the level of listhesis and correctly classified 69.2\% of the cases. A decrease in the mean MF area value alone was associated with a significantly increased likelihood of PSC (regression coefficient = 2.15, SE = 2.53, \( p = 0.039 \)).
TABLE 1. Radiological features of the study cohort of 120 patients

<table>
<thead>
<tr>
<th>Radiological Feature</th>
<th>No. of Patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of listhesis</td>
<td></td>
</tr>
<tr>
<td>L3–4</td>
<td>3 (2.50)</td>
</tr>
<tr>
<td>L4–5</td>
<td>58 (48.33)</td>
</tr>
<tr>
<td>L5–S1</td>
<td>59 (49.16)</td>
</tr>
<tr>
<td>Listhesis grade</td>
<td></td>
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<tr>
<td>1</td>
<td>44 (36.67)</td>
</tr>
<tr>
<td>2</td>
<td>67 (55.83)</td>
</tr>
<tr>
<td>3</td>
<td>9 (7.50)</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>PSC type</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>59 (49.17)</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>61 (50.83)</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Disc degeneration grade</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>3 (2.50)</td>
</tr>
<tr>
<td>2</td>
<td>30 (25.00)</td>
</tr>
<tr>
<td>3</td>
<td>52 (43.33)</td>
</tr>
<tr>
<td>4</td>
<td>32 (26.67)</td>
</tr>
<tr>
<td>5</td>
<td>3 (2.50)</td>
</tr>
<tr>
<td>Facetal arthropathy grade</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>115 (95.83)</td>
</tr>
<tr>
<td>1</td>
<td>4 (3.33)</td>
</tr>
<tr>
<td>2</td>
<td>1 (0.83)</td>
</tr>
</tbody>
</table>

Interobserver Variability

Agreement between the 2 observers for the measurement of disc degeneration and facetal arthropathy was almost perfect (weighted kappa coefficients: 0.88 and 0.94, respectively), whereas that for the muscle area measurements was substantial (weighted kappa coefficients: 0.79 for psoas, 0.73 for ES, and 0.75 for MF).

Discussion

The reported incidence of spondylolysis in the general population ranges from 4.4% to 5.8%, whereas that of IS ranges from 2.6% to 4.4%. While there is no consensus as yet about the role of nonoperative versus operative care in IS, nonoperative care remains the mainstay of treatment for patients with the first 2 grades. Symptom resolution reportedly occurs in as many as 70% of patients after physiotherapy and other conservative measures. It is therefore surprising that the analysis of PSMs in IS was not done until now. Further, it is well recognized that among patients with IS, pathological onset occurs in childhood or early adolescence, and the few symptomatic patients present many years after onset. A long-term study in patients with bilateral pars fractures even reported a clinical course that was similar to that in the general population. While the causal relationship between disc degeneration and symptomatic IS has been established, a possible role of PSMs in the biomechanics of these listhetic spines has not been studied.

Lumbar PSM Morphometry and Its Correlations

A longitudinal study in healthy subjects reported that changes in lumbar PSM morphometry are associated with age and body mass index and not with factors like physical activity and LBP. However, various cross-sectional studies have reported PSM atrophy in LBP. While the deleterious influence of advancing age on the PSM area was demonstrated in our study as well, there was an unexpected predisposition for the female sex to have smaller psoas muscle area values. While the MF muscle has been reported to be particularly indicative of localized disc or root pathology, atrophy of this and other muscles (ES, quadratus lumborum, and psoas) has not demonstrated any correlation with symptom duration or pain scores in previous studies. In our study as well, the duration of symptoms did not influence the PSM areas. Disc degeneration did have a correlation with MF muscle area values in our study, but it lost significance in the multivariate analysis. One study on PSMs in degenerative listhesis reported MF muscle atrophy and ES muscle hypertrophy, paralleling the findings in our cohort with IS. Of interest in our study was the finding that while MF muscle atrophy was observed in the entire study cohort compared with controls, it was most pronounced in the patients exhibiting PSC.

Pedicle Signal Change and Its Implications

Marrow signal intensity changes in the lumbar pedicles on MRI have been associated with fractures in the pars or pedicles and, less commonly, with degenerative facets. They represent a continuum of biomechanical stress–related bony changes ranging from marrow ischemia and remodeling (Type 1 change) to a fatty metamorphosis of the marrow (Type 2 change) and thence to sclerosis following chronic stress and degeneration (Type 3 change). Resolution of these changes, especially in the early stages, has been associated with improved functional testing and decreased pain levels, underlining the enhanced importance of physiotherapy and other conservative measures in patients with such PSC. All patients in our study with a PSC demonstrated a Type 2 change adjacent to the pars defect, and this did not correlate with age at presentation, as in a previous study, or with factors like disc or facet degeneration. While studies, including ours, have reported a 40%–50% incidence of PSC in IS, it has remained unclear until now as to why a majority of these biomechanically unstable spines do not demonstrate PSC. Our study demonstrates for the first time that the thickness, and hence the strength, of the MF muscle negatively correlates with PSC in IS. It can be inferred that stronger
MF muscles provide the biomechanical stability required to prevent pedicle marrow changes from setting in.

**Physiotherapy in LBP and Spondylolisthesis**

There is significant variation in the types of prescribed exercises and their proposed mechanisms of effect in LBP and spondylolisthesis. Traditionally, lumbar physiotherapy programs have focused on exercises that activate co-contraction of the trunk flexors and extensors to control spinal motion.15,24 There have also been proponents of lumbar extension exercises over flexion exercises in LBP and spondylolisthesis.31 Recently, there has been growing interest in a “specific exercise” regimen in these patients26 that aims to activate the MF muscle and deep abdominal muscles independent of the other PSMs in the initial stages of rehabilitation. Incorporation of appropriate MF muscle activation into functional activities is then encouraged.23,26 This leads to an automatic feed-forward recruitment of the deep core muscles,25 a mechanism that eventually lends stability to an unstable spine core.

**Role of the MF Muscle and Study Implications**

The deep fibers of the MF muscle have been proven to have a much higher percentage of Type I (slow twitch) muscle fibers than other PSMs.30 These fatigue-resistant fibers are suited to low-load tonic activity and are reportedly more vulnerable to the unfavorable effects of pain and immobilization than the Type II (fast twitch) muscle fibers.1 Perhaps this explains the selective atrophy of the MF muscle seen in our patients, all of whom had prior LBP and external immobilization. Hypertrophy of the superficially placed ES muscle, a phenomenon that generally reflects poor stabilization of the lumbosacral spine,19 would have occurred as a compensatory phenomenon in the setting of MF muscle atrophy.
Various studies have established a prominent role of the MF muscle in controlling segmental motion.16,26 The biomechanical basis for this finding is that the deep fibers of the MF muscle control intervertebral shear without generating torque, and thus do not require co-contraction of antagonists. The benefit of targeted MF muscle strengthening programs utilizing this functional peculiarity has been demonstrated in acute and chronic LBP.16,17,21 A study of subjects with acute back pain has demonstrated normalization of the MF areas within a month following a specific motor re-education exercise.17 The results of our morphometric study indirectly prove the benefit of strong MF muscles in IS as well. Our findings show that MF muscle atrophy has a causal relationship with PSC. Hence, targeted strengthening of the MF muscle, especially in the early stages of IS, may prevent the clinicoradiological progression of IS.

Our study has the inherent limitations of a retrospective design. The unavailability of certain data (like a validated clinical outcome measure and the age of the pars fractures) precluded analysis with respect to these factors. Availability of PSM area values at follow-up would have yielded information on changes in the CSAs of the MF and ES muscles following intervention. Finally, our study findings need further validation with a randomized controlled trial in patients with IS.

Conclusions

Compared with normative controls, patients with IS suffer selective atrophy of their MF muscle, whereas their ES muscle undergoes a compensatory hypertrophy. Advancing age has a detrimental effect on the areas of the lumbar PSMs, whereas female sex predisposes to decreased psoas muscle area. Multifidus muscle atrophy correlates with PSC, indicating the role of this deep stabilizer in the biomechanical stability of spondylolisthetic spines. This may be of clinical significance in targeted physiotherapy programs during the conservative management of IS.

References


<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean Psoas Area/VBA Ratio</th>
<th>Mean ES Area/VBA Ratio</th>
<th>Mean MF Area/VBA Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>SE</td>
<td>p Value</td>
</tr>
<tr>
<td>Age</td>
<td>-0.006</td>
<td>0.002</td>
<td>0.000</td>
</tr>
<tr>
<td>Sex</td>
<td>0.245</td>
<td>0.032</td>
<td>0.000</td>
</tr>
<tr>
<td>Duration of symptoms</td>
<td>0.031</td>
<td>0.013</td>
<td>0.764</td>
</tr>
<tr>
<td>Disc degeneration</td>
<td>0.002</td>
<td>0.017</td>
<td>0.890</td>
</tr>
<tr>
<td>Grade of lisssthesis</td>
<td>0.050</td>
<td>0.024</td>
<td>0.052</td>
</tr>
</tbody>
</table>

B = regression coefficient; VBA = vertebral body area.
* Boldface type indicates statistical significance.


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**Disclosures**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

**Author Contributions**

Conception and design: Thakar. Acquisition of data: Thakar, Sivaraju. Analysis and interpretation of data: Thakar. Drafting the article: Thakar, Aryan. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Thakar. Statistical analysis: Thakar, Sai Kiran. Administrative/technical/material support: Thakar, Aryan, Mohan, Sai Kiran. Study supervision: Hegde.

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