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Magnetic Resonance Imaging Characteristics and Age-Related Changes in the Psoas Muscle: Analysis of 164 Patients with Back Pain and Balanced Lumbar Sagittal Alignment

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■ OBJECTIVE: **The psoas muscle (PS), 1 of the paravertebral core muscles, is associated with sarcopenia. It also has clinical relevance in lateral-access spinal surgery (LASS) as a determinant structure affecting the operative window. We aimed to identify age-related patterns of PS degeneration, and we propose that our results be used to evaluate the operative window in LASS.**

■ METHODS: **We included 164 participants with back pain, no leg symptoms or claudication, and normal lumbar lordosis and sagittal balance. We evaluated the cross-sectional morphology of the PS on magnetic resonance imaging, specifically assessing the anterior to posterior (AP)/medial to lateral (ML) ratio and the cross-sectional area (CSA). We assessed the locational relationship of the PS and the intervertebral disc using the anterior margin gap (AMG; the distance between the anterior margins of the PS and the intervertebral disc) and the center gap, and compared all measurements by surgical level, sex, and age group.**

■ RESULTS: **At the L2–3 to L4–5 levels, the PS showed a decreased AP/ML ratio, increased CSA, ventral retraction of the anterior margin without center shift, and decreased operative window length. The degeneration patterns were decreased ML width and CSA and dorsal retraction of the anterior margin. Youth, male sex, and lower lumbar level were associated with higher AMGs, indicating an increased need for the transpsoas approach in LASS.**

■ CONCLUSIONS: **In patients without sagittal imbalance, the PS showed significant imaging characteristics. Our detailed data may aid the identification of degeneration patterns and specific preoperative planning regarding the operative window for LASS.**

INTRODUCTION

Among aging individuals, degeneration in the musculoskeletal system is important medically and socioeconomically.[1-6] Indeed, observational studies have revealed that muscle mass decreases by approximately 1% per year after the age of 40 years.[7] This age-related loss of skeletal muscle mass is termed sarcopenia, which has recently been noticed as being related to a variety of geriatric disorders.[8-12] In particular, degeneration of the psoas muscle (PS), 1 of the paravertebral core muscles, is suggested to be associated strongly with sarcopenia. Reports have described significant associations between the

Key words
- Degenerative lumbar
- Direct lateral lumbar interbody fusion
- Lateral lumbar spinal surgery
- Psoas muscle
- Sarcopenia
- Transpsoas approach

Abbreviations and Acronyms
AMG: Anterior margin gap
AP: Anterior to posterior
CG: Center gap
CSA: Cross-sectional area
CT: Computed tomography
ICC: Interclass and intraclass correlation coefficient
IVD: Intervertebral disc
LASS: Lateral-access spinal surgery
ML: Medial to lateral
MRI: Magnetic resonance imaging
PS: Psoas muscle
SD: Standard deviation
SVA: Sagittal vertical axis

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cross-sectional area (CSA) of the PS and morbidity in elderly patients with multiple traumas, and affecting the mortality of patients with aortic aneurysms.[13,14] Additionally, because the PS is anatomically positioned close to the intervertebral discs (IVDs) and the neurovascular complex, it affects the operative window for minimally invasive lateral-access spinal surgery (LASS), which is increasingly being performed. This novel procedure uses the PS as a key landmark for the prevention of complications.[15-18] To our knowledge, despite these clinically important findings, no detailed radiologic assessment of serial anatomic and morphologic changes in the PS due to aging has been reported.

Therefore, as primary outcomes, we analyzed the magnetic resonance imaging (MRI) characteristics, including cross-sectional morphology and locational relationship with the index IVD, of the PS and age-related changes of the muscle to identify degeneration patterns. As secondary outcomes, we correlated these imaging data during LASS and evaluated the operative window for the index IVD in relation to PS location by surgery level, patient sex, and age group.

MATERIALS AND METHODS

Study Participants

We included 218 participants with simple lower back pain without leg symptoms or claudication, normal lumbar lordosis (>40°), sagittal balance (sagittal vertical axis [SVA] <50 mm), and MRI radiologic data. The mean age of the participants was 47.2 years (range, 20–79 years). We tried to ensure that patient ages were distributed evenly, with approximately 30 patients in each age group (<30 years, 30–39 years, 40–49 years, 50–59 years, 60–69 years, and >70 years). The inclusion of at least 30 patients in each group was based on the statistical central limit theorem.[19] We excluded patients who had previously undergone spinal surgery or surgery in the PS region (ie, vascular surgery, kidney surgery, and surgical procedures using a retroperitoneal approach) and those who had spinal fractures or spinal disorders that could affect sagittal or coronal alignment (eg, spondylolisthesis, kyphosis). We also excluded patients with scoliosis and hip joint disorders because those conditions could affect the morphologic difference between the left and right PSs.[20,21]

MRI Protocol and Measurement Methods

We used a 1.5-Tesla Sonata MRI scanner (Siemens, Erlangen, Germany) and the following criteria for T2-weighted image acquisition: repetition time/echo time, 3200/101 ms; thickness, 4 mm; increment, 0.5 mm; field of view, 320 mm; matrix, 307 × 512; 3 excitations; and echo train length, 17. During scanning, the patient's knee (40°) and hip joints (25°) were flexed using a 20-cm block under the lower leg to minimize the gap between the back and the detector. We measured each variable on the T2-weighted axial images at the IVD-bisecting levels of L2–3, L3–4, and L4–5 using picture archiving and communication systems software (Syngo MR A30 4VA30A [Siemens MAGNETOM Trio, Munich, Germany]). We excluded the L1–2 (close to the PS origin) and L5–S1 (abruptly elongated anterior to posterior [AP] length and ventral retraction) levels because the PS shape and margins were not clearly distinguishable in the conventional MRI scanning field. Because the right PS can be affected by anatomic variance in the inferior vena cava and the right common iliac vessel, and most LASSs are performed on the left side, we measured only the left PS.[16,17,22]

To evaluate the MRI characteristics of the PS, we divided our measurement methods into 2 subgroups. First, we analyzed the cross-sectional morphology using the AP length/medial to lateral (ML) width ratio and the CSA (Figure 1A). We subsequently divided each measured CSA by the CSA of the IVD to minimize differences based on individual physique and sex.[23-25] In other words, in an attempt to decrease the bias caused by relative body size, the area of the muscle compartment was divided by the disc area at the same level (muscle/disc ratio) to represent the relative muscle compartment volume in each individual.[5,26,27] Therefore, we present absolute and relative values together. Using this method, the IVD CSA was used to normalize the PS CSA, as in several previous studies. For the second measurement, we measured the anatomic location in the axial plane to determine the location in relation to the index IVD. We defined the anterior margin gap (AMG) as the vertical distance between the anterior margins of the PS and the IVD, and we defined the center gap (CG) as the distance between the center points of the PS and the IVD (Figure 1B). If the anterior margin or center of the PS was more anterior than the IVD, the value was positive (+); in the opposite circumstance, the value was negative (−). We also measured various parameters (including the pelvic incidence, pelvic tilt, sacral slope, SVA, lumbar lordosis, and coronal Cobb angle) on full-length whole-spine radiographs to evaluate conditions possibly affecting sagittal alignment and PS morphology. Two independent orthopedic surgeons (H.D.J. and S.H.W.) performed all measurements twice at intervals of ≥2 weeks to permit assessment of intraobserver agreement.

Statistical Analysis

We performed all statistical analyses with SPSS 21.0 software (SPSS Inc., Richmond, CA, USA). The Student t test was performed to analyze sex-based differences in measurements, and analysis of variance was used to examine differences by surgical level. To analyze changes in each variable with age, we performed correlation analyses and derived correlation coefficients (r values). We considered 2-tailed P values <0.05 to indicate statistical significance. The interobserver and intraobserver reliability of the 2 sets of measurements taken by the 2 observers were also measured by interobserver and intraclass correlation coefficients (ICCs).

RESULTS

A total of 164 participants (91 men and 73 women) were included in the study, with >30 participants in each age group except the ≥70-years group (n = 14). The parameters related to sagittal and coronal alignment were as follows: pelvic incidence, 50.73° ± 10.7° (27.4° to 83.3°); pelvic tilt, 15.3° ± 8.8° (2.1° to 52.7°); sacral slope, 32.0° ± 13.1° (5.1° to 66.8°); SVA, 7.4 ± 29.0 mm (−47.1 to 41.3 mm); lumbar lordosis, 51.2° (41.2° to 72.7°); and coronal Cobb angle, 4.3° (0° to 9.8°).

Measurement Reliability

The 2 observers showed good agreement on measurements taken using the 4 methods (Table 1). The degree of interobserver

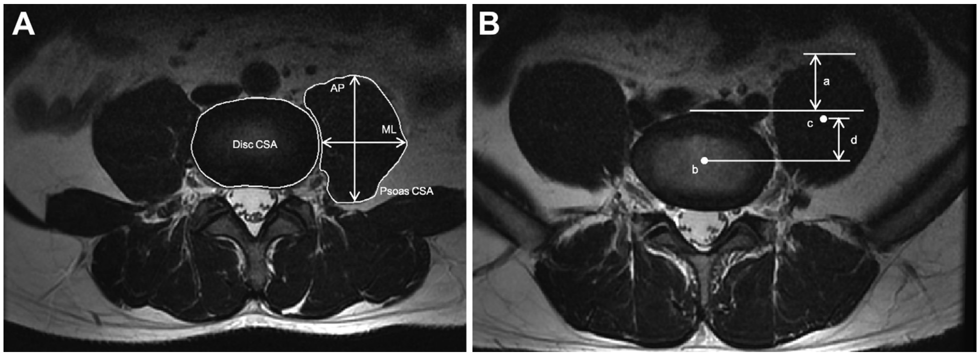

Figure 1. Measurement methods for imaging characteristics (cross-sectional morphology, locational relationship with index intervertebral disc) of the psoas muscle. Determination of the anterior to posterior (AP) length / medial to lateral (ML) width ratio of the psoas muscle and the cross-sectional area (CSA) of the psoas muscle and intervertebral disc using the region of interest tool (**A**). Anterior margin gap and center gap of the psoas muscle relative to the intervertebral disc (**B**). (a) Distance between the anterior margins of the psoas muscle and intervertebral disc. (b) Center of the intervertebral disc. (c) Center of the psoas muscle. (d) Distance between the centers of the psoas muscle and intervertebral disc.

reliability was high, with high ICCs (>0.85) for all measured values. Similar results were obtained for intraobserver reliability: the ICCs of the first and second observers were >0.80 for all measured values.

Morphologic Characteristics of the PS

AP/ML Ratio. The AP length was ≥2 times greater than the ML width at L2–3, reflecting a long oval shape. However, the ratio decreased toward the lower lumbar level to 1.2–1.3 at L4–5, reflecting progression toward a more circular shape (Table 2). The increase in ML width by level was greater than the decrease in AP length, with a resulting decrease in the AP/ML ratio in the lower lumbar region. Women had higher AP/ML ratios than did men at all levels, but men had higher absolute AP and ML values. AP/ML ratios at all levels increased significantly with age ($P < 0.001$; L2–3, $r = 0.417$; L3–4, $r = 0.348$; L4–5, $r = 0.262$). At L2–3, the AP/ML ratio showed the steepest increasing trend with age; the AP lengths were 2 and 3 times greater than the ML widths in the 40- to 49-years and ≥70 years age groups, respectively (Figure 2). These findings were the result of much larger changes in ML width than in AP length as age increased. In brief, the cross-sectional morphology of the PS changed with surgical level, sex, and age, and the ML width changed more than the AP length.

Cross-Sectional Area. The absolute and relative CSAs of the PS increased toward the lower lumbar level, with values for men being approximately 1.6-fold to 1.8-fold higher than those for women (Table 2). At all levels, the absolute and relative CSAs decreased with age ($P < 0.001$), with significant correlations. The most significant correlation of age with CSA was at L4–5 (Table 3). The CSA of the PS was 50% to 80% relative to that of the IVD in the <30-years age group but decreased to 205 to 50% in the ≥50-years groups.

Table 1. Interobserver and intraobserver reliability of both observers' sets of Measurements Using ICCs

Measurement	Interobserver Reliability	Intraobserver Reliability: First Observer ICC	Intraobserver Reliability: Second Observer ICC
AP / ML ratio	0.85	0.84	0.83
CSA	0.89	0.90	0.91
AMG	0.87	0.87	0.85
CG	0.88	0.92	0.90

ICC, intraclass correlation coefficient; AP / ML, anterior to posterior / medial to lateral; CSA, cross-sectional area; AMG, anterior margin gap; CG, center gap.

Anatomic Location of PS Relative to IVD

Anterior Margin Gap. The AMG, defined as the distance between the anterior margins of the PS and the IVD, increased toward the lower lumbar level. At all levels, mean values were approximately 5–6 mm lower in women than in men ($P < 0.001$). All values for women were negative, indicating that the anterior margin of the PS was posterior to the IVD. By contrast, in men, the PS was located posterior to the IVD at L2–3 and L3–4 but anterior to it at L4–5 (Table 2). All values decreased with age, with significant correlations. The most significant correlation of age with the AMG was at L2–3, which reflected the tendency toward prominent age-related dorsal retraction of the PS anterior margin at the upper lumbar level. At L4–5, values for all age groups were positive (Table 3).

Center Gap. The CG method was used to analyze the locational relationship in the axial plane between the centers of the PS and the IVD. This analysis determined the degree of anterior or posterior shifting of the central axis of the PS relative to the IVD. The CG increased toward the lower lumbar level, with values

Table 2. Measurements of Psoas Muscle by Levels and Gender

Measurement	Total	Male (n = 92)	Female (n = 73)	*P* Value*
AP / ML ratio				
L2–3	2.09 ± 0.73	1.78 ± 0.50	2.46 ± 0.79	<0.001
L3–4	1.57 ± 0.44	1.44 ± 0.34	1.73 ± 0.49	<0.001
L4–5	1.25 ± 0.31	1.22 ± 0.21	1.3 ± 0.39	0.113
AP length (mm)				
L2–3	38.92 ± 6.63	42.01 ± 6.34	35.18 ± 4.83	<0.001
L3–4	42.68 ± 6.41	46.86 ± 4.59	37.42 ± 4.08	<0.001
L4–5	44.19 ± 7.74	48.93 ± 5.75	38.22 ± 5.45	<0.001
ML width (mm)				
L2–3	20.74 ± 7.62	25.09 ± 6.90	15.48 ± 4.50	<0.001
L3–4	29.01 ± 8.43	34.01 ± 7.26	22.71 ± 4.82	<0.001
L4–5	36.42 ± 7.70	40.9 ± 5.93	30.76 ± 5.70	<0.001
Absolute CSA (cm^2)				
L2–3	6.87 ± 3.23	8.71 ± 2.81	4.72 ± 2.21	<0.001
L3–4	10.22 ± 4.15	12.77 ± 3.37	7.18 ± 2.69	<0.001
L4–5	12.91 ± 4.37	15.56 ± 3.69	9.74 ± 2.70	<0.001
Relative CSA (%)†				
L2–3	39.70 ± 17.34	46.73 ± 15.72	31.37 ± 15.45	<0.001
L3–4	56.09 ± 22.17	65.59 ± 19.28	44.62 ± 19.99	<0.001
L4–5	70.17 ± 24.81	79.04 ± 22.52	59.46 ± 23.29	<0.001
Anterior margin gap (mm)‡				
L2–3	−9.02 ± 4.89	−6.67 ± 4.22	−11.95 ± 4.03	<0.001
L3–4	−5.24 ± 5.54	−2.70 ± 5.09	−8.45 ± 4.31	<0.001
L4–5	2.09 ± 7.54	4.56 ± 7.03	−1.02 ± 7.02	<0.001
Center gap (mm)§				
L2–3	−10.23 ± 5.64	−8.18 ± 5.66	−12.79 ± 4.48	<0.001
L3–4	−6.65 ± 4.5	−5.12 ± 4.04	−8.58 ± 4.33	<0.001
L4–5	1.39 ± 6.04	2.33 ± 5.38	0.21 ± 6.64	0.028

AP / ML, anterior to posterior / medial to lateral; CSA, cross-sectional area.
**P* value: comparative analysis of the measured values between male and female.
†Relative CSA: CSA of psoas muscle compared with CSA of the intervertebral disc.
‡Anterior margin gaps: distance between the anterior margins of the intervertebral disc and psoas muscle. If the anterior margin of the psoas muscle was more anterior than the intervertebral disc, the value is presented as (+); in the opposite case, the value is presented as (−).
§Center gap: distance between the centers of the intervertebral disc and psoas muscle. Positive (+) value of center gap means center point of the psoas muscle located more anterior than the those of the intervertebral disc; in the opposite case, the value is presented as (−).

significantly larger in men than in women (Table 2). No significant correlation according to age was found at any measurement level (Table 3). Unlike the results from the 3 previously noted measurement methods, this finding indicates that the locational relationship between the centers of the PS and the IVD in the axial plane did not change with increasing age.

Clinical Implications for LASS

The AMG and CG results have implications for the operative window in LASS. Given the average AMG of −9 mm at L2–3, a direct approach through this trajectory to the index IVD without PS damage is possible (Figure 3A). However, at L3–4 (AMG −2.7 mm in women, −8.45 mm in men), sex was an important determinant of window length. At L4–5, the average AMG was 2 mm, indicating

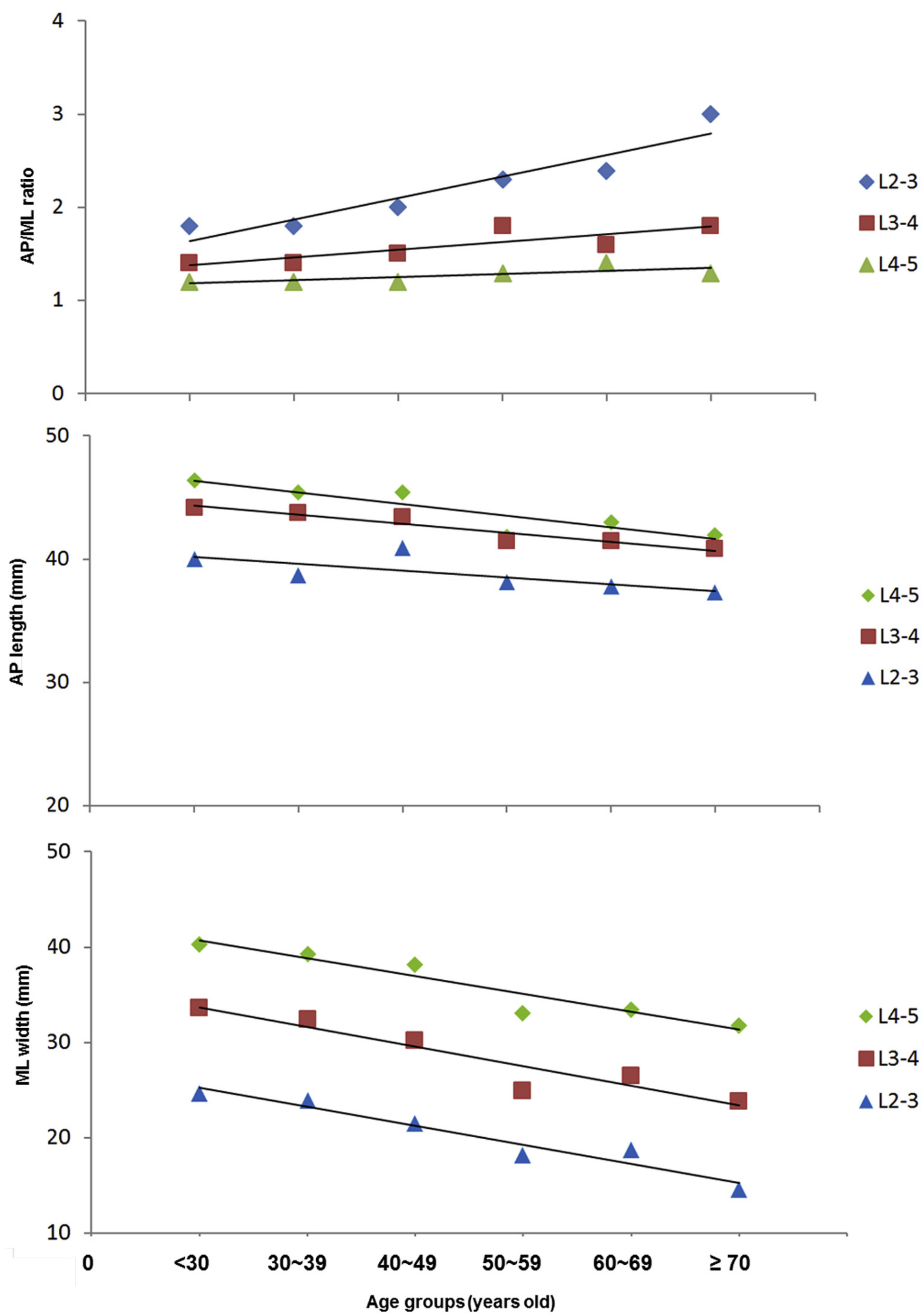

Figure 2. Correlations between aging and changes in the anterior to posterior (AP) length, medial to lateral (ML) width, and their ratio in the psoas muscle. The AP/ML ratio showed an increasing trend with age. Among the 3 levels, the AP/ML ratio at L2–3 showed a steep inclination with age compared with L3–4 and L4–5. The AP length and ML width decreased with age. The amount of reduction in ML width was much greater than that in AP length, resulting in an increased AP/ML ratio with age.

the need to use a transpsoas approach for direct lateral access. To avoid damage to the PS, an anterolateral oblique approach using the corridor in front of the PS must be used (**Figure 3B**). Moreover, because the muscle center shifts by 1–3 mm with increasing age, the AMG is the primary determinant of the operative window for LASS. At L2–3, an operative window of at least 7 mm is achievable

Table 3. Correlation Between Age and Cross-Sectional Area, Anterior Margin Gap, and Center Gap of Psoas Muscle

Measurement	Coefficient of Correlation	Age Group (Years) <30	30–39	40–49	50–59	60–69	≥70
Absolute CSA (cm^2)							
L2–3	−0.331*	8.2	7.6	7.9	6.0	5.6	5.1
L3–4	−0.341*	12.1	11.4	10.9	8.8	8.9	8.3
L4–5	−0.392*	14.9	14.5	14.0	11.4	10.8	10.7
Relative CSA† (%)							
L2–3	−0.495*	50.5	47.3	45.5	32.9	30.3	26.6
L3–4	−0.510*	70.2	69.5	59.1	45.1	44.2	42.0
L4–5	−0.551*	84.2	87.7	77.6	56.8	53.9	53.3
Anterior margin gap (mm)‡							
L2–3	−0.301*	−7.0	−7.5	−9.2	−10.0	−9.7	−12.3
L3–4	−0.266*	−3.6	−2.9	−5.6	−6.3	−6.7	−7.5
L4–5	−0.177 (0.023)	3.6	4.0	1.4	1.8	0.3	0.9
Center gap (mm)§							
L2–3	−0.199 (0.080)	−7.9	−8.8	−10.8	−10.0	−9.9	−10.9
L3–4	−0.117 (0.244)	−5.9	−6.2	−6.5	−6.4	−5.9	−7.0
L4–5	−0.015 (0.059)	1.0	1.4	1.5	1.0	1.3	2.0

CSA, cross-sectional area.
**P* value <0.001.
†Relative CSA: CSA of psoas muscle compared with CSA of intervertebral disc.
‡Anterior margin gaps: distance between the anterior margins of the intervertebral disc and psoas muscle.
§Center gap: distance between the centers of the intervertebral disc and psoas muscle.

in all age groups, whereas at L4–5, the direct lateral transpsoas approach is unavoidable because of the positive AMG and CG values in all age groups.

DISCUSSION

Based on MRI data from participants with balanced lumbar sagittal alignment, the PS was found to have a decreased AP/ML ratio (becoming nearly circular) and increased CSA toward the lower lumbar level. The AMG and CG increased, reflecting a more anterior location of the PS. In men, the AP length, ML width, CSA, AMG, and CG were all increased, although the AP/ML ratio was larger in women. The AP length, ML width, and CSA findings indicate that the cross-sectional mass of the PS increases toward the lower lumbar region,[28] and considering that men generally have larger muscles than do women, the results reflect an anatomically natural situation. By contrast, we consider the shape changes resulting mostly from the increased ML width and female-associated characteristics (long, narrow oval shape and negative AMG values at all measurement levels) to be significant findings of this study. We divided each measured CSA of the PS by the CSA of the IVD to minimize differences based on individual physique and sex. Given the strong correlation established between muscle mass and skeletal CSA, we assumed that the muscle area biomechanically corresponded to the morphometry of the vertebral body and IVD at any given level.[27,29-31] Thus, muscle/disc ratios, rather than absolute muscle CSA values, were used to eliminate biases arising from variations in patient build.

It was surprising that the mean AMG is positive at L4–5 in all age groups, although the L4–5 AMG values in women were negative at all ages at all levels and approximately 45% cohort being women. The subgroup analysis by age groups showed that the mean L4–5 AMG (years old) was 5.2 ± 6.1 (<30), 5.2 ± 8.2 (30–39), 4.0 ± 7.7 (40–49), 2.4 ± 5.5 (50–59), 2.8 ± 6.6 (60–69), and 1.8 ± 7.7 (≥70) in men and −1.7 ± 5.6 (<30), −1.0 ± 5.1 (30–39), −2.6 ± 8.0 (40–49), 1.3 ± 7.8 (50–59), −2.5 ± 7.3 (60–69), and −0.8 ± 7.6 (≥70) in women, respectively. In other words, the L4–5 AMG in men at all ages showed a significantly greater positive value compared with those of women, so that the overall mean L4–5 AMG was a positive value for all ages, even though the L4–5 AMG in women (nearly half of the study participants) were negative values.

Recently, sarcopenia has become accepted as a new disease entity.[8,10] Age-related muscle degeneration appears in various forms, such as decreased CSA, morphologic changes, and fat infiltration,[32] and among the paravertebral core muscles, the PS is known to be strongly associated with sarcopenia.[13,14] We found major characteristics of age-related degeneration in the PS. Indeed, an increased AP/ML ratio, due mainly to decreased ML width, decreased CSA, and

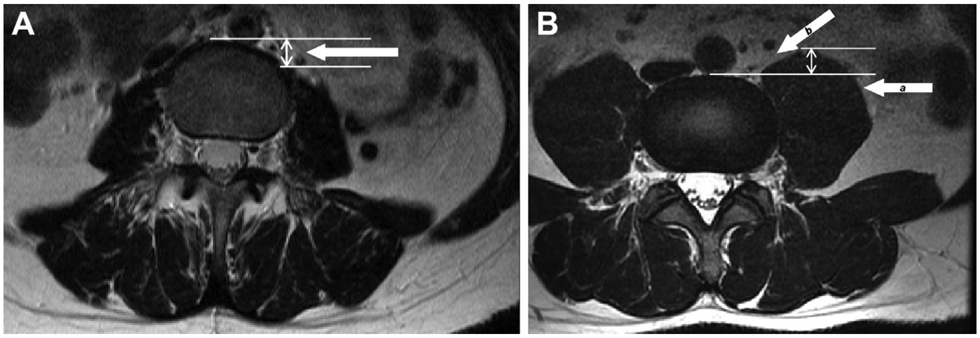

Figure 3. Comparison of the intraoperative windows for lateral-access lumbar spinal surgery at L2–3 and L4–5. At the L2–3 level, through the gap between the anterior margins of the psoas muscle and the intervertebral disc, lateral access to the index disc is possible without psoas muscle damage (**A**). At the L4–5 level, a direct (extreme) lateral approach is needed to penetrate the psoas muscle because its ventral part blocks the operative window to the intervertebral disc (**B**). To avoid involving the psoas muscle (a), the oblique approach (b) should be attempted.

dorsal retraction of the anterior margin with no significant change in the center of the PS were found. The causes of the age-related dorsal retraction of the anterior margin of the PS are thought to be a result of decreasing overall muscle mass (CSA) or a larger decrease in the anterior half of the PS relative to the posterior half. The authors are planning more detailed analyses and further research from this perspective in future studies.

In LASS with a retroperitoneal approach, the PS is used as a key landmark to prevent critical complications because of its anatomic location in relation to adjacent neurovascular structures.[15,16,18] Moreover, because the PS has a definitive impact on the operative window for the index IVD, comprehensive evaluation of the locational relationships of these structures in the axial plane is of great importance; only with this evaluation can surgeons determine the appropriate corridor for the minimization of muscle damage and establishment of a clear view of the surgical field. From a similar perspective, Voyadzis et al.[18] reported the "rising psoas sign" (lateral and ventral elevation of the PS away from the vertebral body), which disrupts safe docking onto the IVD. Another important point with regard to surgery is that PS location cannot be verified by image intensifiers because it is not a bony structure. In particular, adjacent structures cannot be viewed sufficiently through narrow tubular retractors (usually 22 mm in diameter); thus, preoperative radiologic planning with regard to related structures becomes even more essential.[22,33,34] Considering this clinical significance, the present study was meaningful because it provided detailed data on the IVD—PS relationship and the amount of muscle margin retraction based on factors such as surgical level, sex, and age.

The present study has several limitations. First, the study population consisted of 164 patients with spinal disorders, and we included participants according to the required age-related distribution. This approach resulted in the inclusion of a relatively small number of patients ($n > 30$) per age group. Second, neither method used (estimation of PS shape by the AP/ML ratio and expression of muscle shift using the CG) was supported by any existing study as a reference. We used the AP/ML ratio because most PSs are round and because the length/width ratio is generally a useful tool for the expression of circular shapes. We also considered the CG to be a theoretically sound indicator for assessment of the direction and amount of center shifting, and we did obtain statistically and clinically significant results. Third, LASS-related clinical data were absent in this study, because the main purpose of this study was to emphasize the detailed morphologic characteristics of the PS. However, this study is meaningful as a basic study to evaluate the radiologic characteristics of PS and age-related changes of the muscle to help identify degeneration patterns. A further case-control series is under way with patients undergoing LASS as an experimental group. Last, because this study was designed for patients with simple back pain, the ability to apply the results directly to actual degenerative lumbar surgery and provide applicable information for practitioners is limited. We should consider morphologic changes of the PS according to disc height, especially in degenerative lumbar disease, wherein the loss of disc height is a prominent feature.

In summary, from L2—3 to L4—5, the PS showed several imaging characteristics with clinical implications, including a decreasing AP/ML ratio (becoming nearly circular), increasing CSA, ventral retraction of the anterior margin relative to the IVD, and a shorter operative window for LASS. All measurement values except the AP/ML ratio were greater in men than in women. The primary age-related degeneration changes we observed were decreased ML width and CSA and dorsal retraction of the anterior margin without shifting of the muscle center. Youth, male sex, and lower lumbar level were associated with large AMGs, indicating the need to use the transpsoas approach in LASS because the PS blocks the index IVD.

CONCLUSIONS

In patients with balanced lumbar sagittal alignment, the PS showed significant MRI characteristics according to surgical level, sex, and age group. Our detailed data could aid the identification of age-related degeneration patterns in the PS and the creation of specific preoperative plans regarding the operative window for IVDs in LASS.

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