Unstable Versus Stable Degenerative Lumbar Spondylolisthesis: a Comparative Analysis of Muscle Health, Facet Joint Morphology, Spinopelvic Alignment, and Other Imaging Markers

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INTRODUCTION: Degenerative lumbar spondylolisthesis (DLS) often progresses from unstable (US) to stable spondylolisthesis (SS) following bony remodeling and local ossification. While studies have shown that DLS is associated with decreased lumbar muscle cross-sectional area (CSA) and increased fatty infiltration compared to non-DLS patients, little is known about the relationship between muscle health and US versus SS status. In this study we compared psoas and paralumbar CSA and Goutallier in patients with 1-level L4-L5 US versus SS. We analyzed facet joint orientation and tropism, disc height, slip percent, and sagittal alignment (pelvic incidence [PI], pelvic tilt, proximal and distal lumbar lordosis [LL]). We hypothesized that lumbar muscle CSA does not impact DLS stability.

METHODS:

Patients $\geq$ 18 years undergoing primary surgery for 1-level L4-L5 US or SS were included. US was defined as 1) $\geq$ 3 mm translation or 2) $\geq$ 10 degrees change between flexion and extension preoperative lateral radiographs, as is defined in the literature. CSAs were measured at mid vertebral body at L3, L4, L5. Low muscle health was defined as CSA normalized to height squared, less than the 1st gender-specific quartile. Total Goutallier grade was the sum of left and right muscle Goutallier scores. Facet joint morphology was assessed using axial T2-weighted preoperative lumbar MRIs. Specifically, the superior transverse facet angle was measured relative to the midline vertebral body at L4-L5, according to the literature. Facet orientation was the mean of the right and left facet angles while facet tropism was the absolute difference between right and left facet angles. Coronal and sagittal spinopelvic alignment were analyzed on coronal and sagittal radiographs. Continuous and categorical variables were analyzed with Wilcoxon rank-sum tests and Fisher's exact tests, respectively, for univariate analysis. Multivariate logistic regression was performed to adjust for clinical and demographic variables and to assess the independent associations of covariates with unstable spondylolisthesis. Covariates were selected based on $p < 0.20$ and those variables with high clinical relevance.

RESULTS: 251 patients (US = 50, SS = 201) were included. There were no significant differences in demographics, preoperative PROMs, Goutallier, or percentage of patients with low muscle health for psoas or paralumbars at L3, L4, or L5 between US and SS. There were significantly greater Goutallier scores in the caudal (L5 versus L4 and L4 versus L3) paralumbars in the SS, but not the US group. There were no differences in facet joint orientation, tropism, or disc height; however, the US cohort showed greater PI-LL mismatch (13.56 ± 12.75 versus 5.81 ± 14.47, $p<0.001$) and greater slip percent (19 ± 9 versus 15 ± 8, $p = 0.007$). Logistic regression showed that low multifidus total Goutallier was associated with instability (OR: 2.50, CI [1.01 - 6.20], $p = 0.047$).

DISCUSSION AND CONCLUSION: Patients with US may have lower multifidus Goutallier and greater sagittal imbalances and slip percent. Muscle CSA does not appear to impact stability in L4L5 spondylolisthesis. Further investigation into the pathophysiology of unstable and stable DLS is required to better understand this complex and multifactorial phenomenon and may open doors for potential clinical intervention and mitigation of DLS progression.

Table 1: Demographics and preoperative PROMs

	Unstable (n = 50)	Stable (n = 201)	p-value
Age (mean ± SD)	70.35 ± 10.14	67.37 ± 11.29	0.099
Sex, n (%)			1.000
female	29 (58.0)	116 (58.7)	
male	21 (42.0)	87 (41.2)	
Race, n (%)			0.179
Non-White	7 (18.0)	57 (28.4)	
White	43 (98.0)	168 (83.6)	
Ethnicity, n (%)			
Hispanic	3 (6.0)	8 (4.0)	0.455
Non-Hispanic	46 (92.0)	187 (93.0)	0.760
Unknown/Undisclosed	1 (2.0)	6 (3.0)	1.000
BMI (mean ± SD)	28.0 ± 6.37	27.95 ± 5.83	0.971
CCI (mean ± SD)	3.27 ± 1.38	3.19 ± 1.89	0.668
Smoking Status, n (%)			
Current	1 (2.0)	8 (4.0)	1.000
Former	22 (44.0)	69 (34.3)	0.187
Dyslipidemia, n (%)	24 (48.0)	93 (46.3)	0.772
Diabetes, n (%)	5 (10.0)	25 (12.4)	0.435
Preoperative Opioids, n (%)	7 (14.0)	42 (20.9)	0.422
Preoperative Symptoms Duration, weeks (mean ± SD)	96.39 ± 91.67	139.75 ± 231.51	0.608
PROMs			
ODI (mean ± SD)	37 ± 16.42	39.39 ± 18.88	0.231
PROMIS PF (mean ± SD)	36.22 ± 8.11	35.45 ± 7.12	0.339
VAS Back (mean ± SD)	3.67 ± 2.3	3.54 ± 3.05	0.980
VAS Leg (mean ± SD)	6.32 ± 2.42	5.34 ± 3	0.206

BMI, body mass index; CCI, Charlson comorbidity Index; PROMs, patient reported outcome measures; ODI, Oswestry disability index; PROMIS PF, patient-reported outcomes measurement information system for physical function; VAS, visual analog scale; SD, standard deviation

Table 2: Unstable versus stable spondylolisthesis - psoas and paralumbar muscle health

	Unstable	Stable	p-value
L3			
Low Psoas Muscle Health, n (%)	14 (28.0)	49 (24.4)	0.589
Psoas Vertebral Index (mean ± SD)	0.75 ± 0.22	0.76 ± 0.23	0.645
Low Paralumbar Muscle Health, n (%)	11 (26.0)	39 (24.0)	0.817
Psoas PL ratio (STRA/(PL+CSA/BH))	4.52 ± 1.68	4.25 ± 1.11	0.986
LSA (°) (mean ± SD)	12 ± 5.8	12.42 ± 6.13	0.694
LSA Psoas Total Goutallier ≥ 1, n (%)	30 (100.0)	196 (97.5)	0.388
LSA Erector Spinae Total Goutallier ≥ 1, n (%)	20 (40.0)	100 (49.8)	0.208
LSA Multifidus Total Goutallier ≥ 1, n (%)	20 (40.0)	75 (38.5)	0.828
L4			
Low Psoas Muscle Health, n (%)	11 (26.0)	39 (24.0)	0.817
Psoas Vertebral Index (mean ± SD)	0.92 ± 0.29	0.96 ± 0.27	0.522
Low Paralumbar Muscle Health, n (%)	13 (30.0)	48 (29.0)	0.588
Psoas PL ratio (STRA/(PL+CSA/BH))	4.12 ± 2.18	3.86 ± 1.79	0.769
L4-L5 (°) (mean ± SD)	12.34 ± 7.77	13.26 ± 6.92	0.571
L4-L5 Psoas Total Goutallier ≥ 1, n (%)	50 (100.0)	197 (98.0)	0.387
L4-L5 Erector Spinae Total Goutallier ≥ 1, n (%)	39 (52.0)	89 (54.3)	0.880
L4-L5 Multifidus Total Goutallier ≥ 1, n (%)	34 (38.0)	52 (31.9)	0.609
L5			
Low Psoas Muscle Health, n (%)	14 (28.0)	48 (23.9)	0.384
Psoas Vertebral Index (mean ± SD)	0.96 ± 0.24	0.97 ± 0.24	0.266
Low Paralumbar Muscle Health, n (%)	14 (28.0)	49 (24.4)	0.589
Psoas PL ratio (STRA/(PL+CSA/BH))	8.18 ± 3.11	8.19 ± 3.27	0.881
L5S1 (°) (mean ± SD)	10.77 ± 5.73	12.48 ± 7.02	0.352
L5S1 Psoas Total Goutallier ≥ 1, n (%)	49 (98.0)	199 (99.0)	0.488
L5S1 Erector Spinae Total Goutallier ≥ 1, n (%)	8 (34.0)	42 (20.9)	0.154
L5S1 Multifidus Total Goutallier ≥ 1, n (%)	9 (18.0)	31 (15.4)	0.660

STRA, normalized total psoas area (normalized to height squared); BH, CSA/BH, paralumbar (erector spinae and multifidus) cross-sectional area normalized to body mass index; LSA°, lumbar lordosis tilt; SD, standard deviation

Table 3: Comparison between lumbar levels of total Goutallier less than or equal to 2, by muscle group

	Psoas	Multifidus	Erector Spinae
L3-L4 versus L4-L5, (aL3-L4) - (aL4-L5)			
Unstable Spondylolisthesis	30/30 (p = 1.000)	30/30 (p = 0.291)	20/30 (p = 0.310)
Stable Spondylolisthesis	196/197 (p = 1.000)	75/152 (**p = 0.048**)	**100/197 (p < 0.002)**
L4-L5 versus L5-S1, (aL4-L5) - (aL5-S1)			
Unstable Spondylolisthesis	50/50 (p = 1.000)	14/50 (p = 0.342)	36/50 (p = 0.100)
Stable Spondylolisthesis	197/199 (p = 0.681)	72/191 (**p = 0.013**)	**69/192 (p = 0.004)**
L3-L4 versus L5-S1, (aL3-L4) - (aL5-S1)			
Unstable Spondylolisthesis	50/49 (p = 1.000)	20/49 (**p = 0.027**)	**20/49 (p = 0.024)**
Stable Spondylolisthesis	196/199 (p = 0.449)	72/191 (p = 0.800)	**100/192 (p < 0.001)**

Wilcoxon ranked-sum tests were used to compare between L3-L4 versus L4-L5, L4-L5 versus L5-S1, and L3-L4 versus L5-S1. Total Goutallier was calculated as a sum of left and right Goutallier scores for each muscle at each level. Higher Goutallier scores indicate greater fatty infiltration. Significant p-values are bolded.

Table 4: Unstable versus stable spondylolisthesis - other radiographic and imaging markers

	Unstable	Stable	p-value
Facet Joint Orientation (mean ± SD)	45.07 ± 9.74	47.01 ± 11.82	0.178
Facet Joint Tropism (mean ± SD)	8.33 ± 7.48	8.29 ± 8.37	0.813
Facet Joint Dysmorphia, n (%)	17 (34.0)	41 (20.4)	0.062
Facet Joint Cyst, n (%)	2 (4.0)	20 (10.0)	0.285
Spondylolisthesis Grade 2 or more, n (%)	11 (22.4)	24 (12.1)	0.078
Slip Percentage (mean ± SD)	19 ± 9	15 ± 8	**0.007**
Lateralizsthesis, n (%)	3 (6.1)	13 (6.6)	1.000
Anterior Disc Height (mean ± SD)	7.29 ± 3.19	7.88 ± 3.64	0.407
Posterior Disc Height (mean ± SD)	4.31 ± 2.35	4.71 ± 3.34	0.408
Vacuum Disc, n (%)	17 (36.0)	57 (28.4)	1.000
Concentrated ZDP, n (%)	48 (96.0)	193 (97.5)	0.631
Coronal Cobb Major Curve (mean ± SD)	6.01 ± 5.72	5.68 ± 6.26	0.471
Coronal Cobb Fractional Curve (mean ± SD)	5.13 ± 3.81	4.93 ± 5.39	0.661
Pelvic Incidence (mean ± SD)	58.44 ± 9.89	56.21 ± 10.74	0.092
Pelvic Tilt (mean ± SD)	24.95 ± 8.76	21.33 ± 8.17	**0.014**
Sacral Slope (mean ± SD)	34.43 ± 8.27	35.88 ± 9.11	0.492
Proximal Lumbar Lordosis (mean ± SD)	21.82 ± 9.54	22.89 ± 10.9	0.388
Distal Lumbar Lordosis (mean ± SD)	23.84 ± 9.47	27.16 ± 9.28	**0.017**
PI-LL (mean ± SD)	13.56 ± 12.75	5.81 ± 14.47	**0.001**

PI-LL, pelvic incidence minus lumbar lordosis; SD, standard deviation; ZDP, herniated nucleus pulposus; significant p-values are bolded.

Table 5: Factors associated with unstable spondylolisthesis

	VIF	Adjusted Odds Ratio	95% CI	p-value
Age	1.44	1.02	0.98 - 1.06	0.399
Facet Dysmorphia	1.14	1.98	0.87 - 4.54	0.107
Facet Orientation	1.12	0.99	0.95 - 1.02	0.493
Spondylolisthesis Grade 2	1.14	0.87	0.32 - 2.34	0.779
Pelvic Incidence	1.85	1.03	0.96 - 1.07	0.537
Pelvic Tilt	2.14	1.02	0.96 - 1.08	0.610
Distal Lumbar Lordosis	2.00	0.98	0.91 - 1.02	0.192
PI-LL	2.79	1.02	0.97 - 1.06	0.483
Low L4 Psoas Muscle Health	1.24	0.64	0.31 - 2.20	0.740
Low L4 Paralumbar Muscle Health	1.24	0.94	0.38 - 2.34	0.892
L4L5 Erector Spinae Total Goutallier 2 or lower	1.24	1.05	0.44 - 2.52	0.908
L4L5 Multifidus Total Goutallier 2 or lower	1.41	2.50	1.01 - 6.20	**0.047**
L4 Psoas Vertebral Index	1.60	0.46	0.08 - 2.58	0.384

PI-LL, pelvic incidence minus lumbar lordosis; VIF, variance inflation factor; CI, confidence interval; significant p-values are bolded.