Morphometrics as a predictor of perioperative morbidity after lumbar spine surgery

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OBJECT Improved objective assessments of perioperative risk after spine surgery are necessary to decrease postoperative morbidity and mortality rates. Morphometric analysis has proven utility in predicting postoperative morbidity and mortality in surgical disciplines. The aim of the present study was to evaluate whether morphometrics can be applied to the cases of patients undergoing lumbar spine surgery.

METHODS The authors performed a retrospective review of the perioperative course of 395 patients who underwent lumbar surgery at their institution from 2013 to 2014. Preoperative risk factors such as age, diabetes, smoking, coronary artery disease, and body mass index (BMI) were recorded. Preoperative MRI was used to measure the psoas muscle area at the L-4 vertebra and paraspinal muscle area at the T-12 vertebra. Primary outcomes included unplanned return to the operating room, 30- and 90-day readmissions, surgical site infection, wound dehiscence, new neurological deficit, deep vein thrombosis, pulmonary embolism, myocardial infarction, urinary tract infection, urinary retention, hospital-acquired pneumonia, stroke, and prolonged stay in the intensive care unit.

RESULTS The overall rate of adverse events was 30%, the most common event being urinary retention (12%). Greater age ($p = 0.015$) and tobacco usage ($p = 0.026$) were both significantly associated with complications for all patients, while diabetes, coronary artery disease, and high BMI were not. No surgery-related characteristics were associated with postoperative morbidity, including whether surgery required instrumentation, whether it was a revision, or the number of vertebral levels treated. Using multivariate regression analysis, male and female patients with the lowest psoas tertile had an OR of 1.70 (95% CI 1.04–2.79, $p = 0.035$) for having postoperative complications. Male patients in the lowest psoas tertile had an OR of 2.42 (95% CI 1.17–5.01, $p = 0.016$) for having a postoperative complication. The paraspinal muscle groups did not provide any significant data for postoperative morbidity, even after multivariate analysis.

CONCLUSIONS The morphometric measurement of psoas muscle size may be a sensitive predictive tool compared with other risk factors for perioperative morbidity in male patients undergoing lumbar surgery.

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KEY WORDS morphometrics; lumbar spine complications; frailty index

LOW-BACK pain is a common disorder, contributing to a large portion of health care costs.^{15,20} Over the past decade, there has been a noticeable increase in the frequency of elective lumbar surgery (decompressions and arthrodesis),^{19,28,35} perhaps due its proven effectiveness.^{32–34} However, this is associated with an increase in the frequency of postoperative complications after spinal surgery.^{3,11,25} With the current focus on cost-efficient health care, it is important to identify patients who are at greater

risk for postoperative morbidity and mortality, which may require greater resource utilization.^{3,11}

A patient's general health status is an important consideration when weighing which surgical approaches are appropriate for a given pathology, always with the aim of minimizing the potential perioperative morbidity. However, the factors that contribute to a surgeon's decision regarding patient selection and surgical approach are generally empirical and without the benefit of a validated

ABBREVIATIONS BMI = body mass index; CAD = coronary artery disease; DVT = deep vein thrombosis; HFHS = Henry Ford Health System; ICC = intraclass correlation coefficient; LOS = length of stay; MI = myocardial infarction; PE = pulmonary embolism; UTI = urinary tract infection.

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risk assessment tool. Factors such as age, smoking status, obesity, coronary artery disease (CAD), chronic obstructive pulmonary disease, diabetes, severity of symptoms, and complexity of the surgery are all important, but their relative contribution to overall perioperative risk is not well quantified. Validated risk-stratification tools provide objective data to surgeons to one aspect of a patient's operative risk (cardiovascular, pulmonary, psychological, etc.),^{8,10,16,23,26,29,30} but their utility to spinal surgery is limited. Given that the vast majority of spinal procedures are elective, surgical candidates are generally without any active exacerbations of their medical problems. Despite diligent patient selection and preoperative screening and optimization, elective spinal procedures are still potentially associated with morbidity.²⁷ Ultimately, risk calculations may be insufficient to assess the overall health of a patient, as two patients with the same preoperative risk factors (i.e., age, American Society of Anesthesiologists score, comorbidities, and disease stage) are often in clearly different stages of health. Surgeons will often “eyeball” patients to see if they are fit for surgery, and surgeons make operative decisions regardless of risk stratification.

Recently, the concept of frailty has been introduced as a measure of a patient's health status.^{9,21} Frailty is defined as “a biologic syndrome of decreased reserve and resistance to stressors, resulting from cumulative declines across multiple physiologic systems.”^{9,21} While it is a common end point to human senescence, this process is pathological and has been shown to be associated with adverse outcomes after surgery.^{1,5,14} Unfortunately, measuring human frailty relies on subjective assessments and prolonged patient cooperation, which is impractical in application.^{1,14} Surrogate markers of frailty, such as sarcopenia, may be more useful to clinicians. Morphometrics is the measurement of patient attributes that are indicative of sarcopenia and thus frailty by proxy. Morphometric analysis has proven utility in predicting postoperative morbidity and mortality following major general, vascular, and transplant surgery.^{2,4,6,7,12,13,17,18,22,24,31} This study evaluates whether morphometrics can be used as a reliable predictor of perioperative morbidity in patients undergoing lumbar spine surgery.

Methods

Chart Review

This is a retrospective cohort study of patients undergoing lumbar surgery within the Henry Ford Health System (HFHS). After obtaining institutional review board approval, we compiled a list of all patients who had undergone lumbar surgery (T-11 through S-1, inclusive) at HFHS from 2013 to 2014. We used the Current Procedural Terminology (CPT) codes for lumbar laminectomy, lumbar posterior/posterolateral arthrodesis, and lumbar interbody arthrodesis and identified 466 patients. Using the electronic medical records, each patient's preoperative risk factors, including age, sex, and status pertaining to diabetes, smoking, CAD, and body mass index (BMI), were entered into the database. Variables pertaining to operative details as well as immediate postoperative stay included the number of vertebral levels treated, whether the surgery

was a revision, whether there was instrumentation, the length of stay (LOS), and disposition at discharge (home, skilled nursing facility, acute rehabilitation facility). Primary outcomes recorded included any 90-day postoperative complications including: death, unplanned return to surgery, 30- and 90-day hospital readmission, surgical site infection, wound dehiscence, new neurological deficit, deep vein thrombosis (DVT), pulmonary embolism (PE), myocardial infarction (MI), urinary tract infection (UTI), urinary retention, hospital-acquired pneumonia, stroke, and prolonged stay (> 3 days) in the intensive care unit.

Analytical Morphometrics

Our analytical morphometrics methodology has been adopted from that described by Englesbe et al.^{2,31} and applied to preoperative MRI. Using the freehand region of interest tool on Philips ePACS viewer, the circumferential area of each patient's psoas muscles at L-4 and paraspinal muscles at T-12 were measured on axial T2-weighted MRI sequences (Fig. 1). Muscle area was calculated in cubic centimeters, and the areas for each muscle were entered in our database. For a reliability assessment of the freehand identification of the region of interest, a random sample of 40 patients (20 males and 20 females) was selected and measured by 3 observers (H.Z., B.G., and V.C.) independently.

Statistical Analysis

To assess differences in demographic and surgical information and morphometric measurements associated with complications, chi-square tests were performed for categorical/binary variables and 2-sample t-tests for the continuous variables. A Wilcoxon 2-sample nonparametric test was used to compare patients with and without complications for number of vertebral levels treated. Due to sex differences in the morphometric measurements, cut-points for the tertiles were determined separately for males and females. Chi-square and Kruskal-Wallis tests were performed to assess the association between the tertile measurements and specific complications and total number of complications. Multivariate logistic regression was done to adjust for potential confounders when assessing the relationship between experiencing any complication and psoas tertiles. Kruskal-Wallis tests were used to assess the association of LOS with total psoas and total paraspinal tertiles. The associations of discharge disposition and tertiles for total psoas and paraspinal muscles were investigated using chi-square tests. Sex differences in the morphometric measurements were tested using 2-sample t-tests. Intraclass correlation coefficients (ICCs) were computed to assess the reliability among observers of the morphometric measurements of the right and left psoas and paraspinal muscles, as well as the total psoas and paraspinal muscles. All testing was done at the 0.05 level. SAS version 9.4 was used for data analysis.

Results

Participants

A total of 466 patients were identified and their data entered in the database. Of the 466 patients, 8 were excluded

FIG. 1. Examples of morphometric measurements on T2-weighted MR images obtained in patient with (A–C) and without (D–F) sarcopenia. **A:** Sagittal image of a patient with sarcopenia. The white lines through the L-4 and T-12 vertebrae are example cross-sections from which morphometric measurements were taken. **B:** Axial image, of the same patient, taken at the L-4 vertebra showing a small psoas muscle measuring 5.33 cm². **C:** Axial image, of the same patient, obtained at the T-12 vertebra showing a small paraspinal muscle measuring 9.32 cm². **D:** Sagittal image of a patient without sarcopenia. The white lines through the L-4 and T-12 vertebrae again show example cross-sections from which morphometric measurements were taken. **E:** Axial image, of the patient, demonstrating a large psoas muscle measuring 21.48 cm². **F:** Axial image, of the same patient, demonstrating a large paraspinal muscle measuring 23.32 cm².

due to duplicate records, 19 were excluded due to having undergone nonlumbar surgery, and 30 were excluded due to inadequate imaging (i.e., MR images not available or incorrectly formatted for morphometric analysis). Of the remaining 409 patients, 14 were excluded due to incomplete medical records, leaving 395 patients for statistical analysis. Three patients had two elective surgeries recorded, but only the first one was used in the analysis.

Descriptive Data

A summary of descriptive information can be found in Table 1. The mean age of all patients was 63.3 years (SD $\pm$ 12.48, median 63, range 23–88). Of the 395 patients, 51% (n = 203) were female, 24% (n = 94) had diabetes, 27% (n = 105) were smokers, 16% (n = 62) had CAD, and mean BMI was 30.92 (SD $\pm$ 6.44, median 30, range 16.45 to 55.51). Of the 395 surgeries, 54% (n = 213) were instrumentations and 29% (n = 113) were revisions. Regarding complexity, 30% (n = 119) were 1-level procedures, of which 43% were instrumented and 25% were revisions; 31% (n = 122) were 2-level procedures, of which 58% were instrumented and 28% were revisions; the remaining 39% (n = 154) were multilevel operations, of which 60% were instrumented and 34% were revisions. Only 14 cases were minimally invasive surgeries (MIS), complementing 4% of our patient population.

Outcome Data

Table 2 contains the types of the complications and their respective rates, as well as LOS and discharge disposition. Of the 395 patients who had surgery, 30% (n = 120) had at least one complication, with the most common complication being urinary retention (12%, n = 46), followed by surgical site infection (9%, n = 36) and unplanned readmission within 90 days (9%, n = 36) (Table 2). The mean LOS was 3.89 days (SD $\pm$ 2.97, median 3, range 0–27 days), with 71% (n = 278) of patients being discharged home immediately thereafter (Table 2).

Postoperative Complication Analysis

Table 3 contains the comparisons for patients with and without complications. The differences between the groups were significant for age (patients who had complications were an average of 3 years older [65.6 vs 62.3 years, p = 0.015]) and smoking (patients who had complications were less likely to be smoking [19% vs 30%, p = 0.026]). Female sex approached significance in terms of having more complications than males (p = 0.068). No significant association was found for diabetes, CAD, BMI, number of vertebral levels treated, and whether surgery involved instrumentation or was a revision. These same comparisons of patients with and without complications were performed for females and males due to the observed

TABLE 1. Summary of descriptive features*

Variable	All Patients (n = 395)
Demographics	
Age (yrs)	
Mean $\pm$ SD	63.30 $\pm$ 12.48
Median (range)	64 (23–80)
Sex	
Female	203 (51%)
Male	192 (49%)
Risk factors	
Diabetes	94 (24%)
Smoking	105 (27%)
CAD	62 (16%)
BMI	
Mean $\pm$ SD	
Median (range)	30.92 $\pm$ 6.44 30 (16.45 to 55.51)
Surgical information	
Instrumented	213 (54%)
Revision	113 (29%)
MIS	14 (4%)
No. of levels treated	
1	119 (30%)
2	122 (31%)
3	77 (19%)
4	48 (12%)
5	21 (5%)
6	3 (1%)
7	3 (1%)
8	1 (0%)
10	1 (0%)
Mean $\pm$ SD	
Median (range)	2.40 $\pm$ 1.37 2 (0 to 10)

MIS = minimally invasive surgery.

* Values are presented as the mean $\pm$ SD, median (range), or number (%).

sex differences. For females, the only significant difference observed was that patients with complications had a higher mean BMI than patients without complications ($p = 0.021$), while age ($p = 0.098$) and smoking ($p = 0.064$) trended toward significance. For males, trends were also seen for age (males with complications on average were older [$p = 0.076$]) and CAD (30% patients with complications had CAD, whereas 18% those without complications had CAD [$p = 0.063$]). No significant differences in complication rates were seen when comparing cases of minimally invasive surgery and open surgery (Table 3).

Morphometric Results

The ICCs for the psoas muscles were extremely high or almost perfect with a range from 0.988 to 0.991, indicating that the 3 independent observers were able to each precisely measure psoas muscle sizes. For the paraspinous muscles, the ICCs were lower than the psoas, but were still very good with a range from 0.842 to 0.857. Table

TABLE 2. Outcomes and complications

Variable	All Patients (n= 395)
Complications	
Mortality	1 (0%)
Unplanned return to OR	20 (5%)
Unplanned readmission 30 days	30 (8%)
Unplanned readmission 90 days	36 (9%)
Surgical site infection	36 (9%)
Wound dehiscence	24 (6%)
New neurological deficit	7 (2%)
DVT	12 (3%)
PE	6 (2%)
MI	4 (1%)
UTI	18 (5%)
Urinary retention	46 (12%)
Pneumonia	9 (2%)
Prolonged ICU stay >3 days	7 (2%)
CVA	1 (0%)
Any complication	120 (30%)
Other outcomes	
LOS, days	
Mean $\pm$ SD	3.89 $\pm$ 2.97
Median (range)	3 (0–27)
Disposition	
Home	278 (71%)
Acute rehab	38 (10%)
Skilled nursing facility	78 (20%)

CVA = cerebrovascular accident; ICU = intensive care unit; OR = operating room.

4 contains descriptive information for the morphometric measurements for all patients. For each morphometric location, the average area and total muscle area (psoas or paraspinous) were used. Average here refers to the mean between the right and left muscle area within a particular individual, and the total refers to the sum of both muscles for each individual. For all measurements, the differences were significant, with males having higher muscle sizes than females when comparing average psoas areas (14.98 ± 4.24 vs 9.66 ± 2.57 , $p < 0.001$), total psoas areas (29.96 ± 8.49 vs 19.32 ± 5.14 , $p < 0.001$), average paraspinous areas (19.01 ± 6.28 vs 14.65 ± 4.56 , $p < 0.001$), and total paraspinous areas (37.96 ± 12.61 vs 28.98 ± 8.41 , $p < 0.001$). Paraspinous area measurements were not obtained in all patients due to the heterogeneity of the overall MRI protocols (i.e., many studies were performed outside HFHS and then uploaded to our ePACs system), several of which did not include axial images up to T-12.

We then compared the morphometric psoas and paraspinal muscle measurements of patients who did not have complications with those who did have complications (Table 5). We divided patients into tertiles based on the size of their psoas and paraspinal muscles, with the highest tertile having the largest muscle sizes and the lowest tertiles having the smallest. Cases in the smallest tertile in terms of average and total psoas areas approached sig-

TABLE 3. Comparison of patients with and without complications*

Variable	No Complications (n = 275)	Complications (n = 120)	p Value
All patients			
Mean age (yrs)	62.29 ± 12.31	65.61 ± 12.61	0.015
Sex			0.068
Female	133 (48%)	70 (58%)	
Male	142 (52%)	50 (42%)	
Diabetes	63 (23%)	31 (26%)	0.530
Smoking	82 (30%)	23 (19%)	0.026
CAD	39 (14%)	23 (19%)	0.198
Mean BMI	30.65 ± 6.16	31.52 ± 7.02	0.215
Instrumented	147 (53%)	66 (55%)	0.777
Revision	83 (30%)	30 (25%)	0.295
MIS	12 (4%)	2 (2%)	0.182
Mean no. of levels treated	2.42 ± 1.36	2.35 ± 1.41	0.562
Female patients			
Mean age (yrs)	62.37 ± 12.65	65.46 ± 12.42	0.098
Diabetes	25 (19%)	18 (26%)	0.252
Smoking	34 (26%)	10 (14%)	0.064
CAD	14 (11%)	8 (12%)	0.817
Mean BMI	30.26 ± 6.53	32.62 ± 7.59	0.021
Instrumented	87 (65%)	44 (63%)	0.717
Revision	46 (35%)	21 (30%)	0.509
MIS	5 (4%)	1 (1%)	0.351
Mean no. of levels treated	2.41 ± 1.29	2.37 ± 1.52	0.568
Male patients			
Mean age (yrs)	62.22 ± 12.02	65.82 ± 13.01	0.076
Diabetes	38 (27%)	13 (26%)	0.917
Smoking	48 (34%)	13 (26%)	0.295
CAD	25 (18%)	15 (30%)	0.063
Mean BMI	31.02 ± 5.78	29.99 ± 5.87	0.279
Instrumented	60 (42%)	22 (44%)	0.830
Revision	37 (26%)	9 (18%)	0.251
MIS	7 (5%)	1 (2%)	0.372
Mean no. of levels treated	2.43 ± 1.42	2.32 ± 1.24	0.792

* Mean values are presented ± SD. Boldface indicates statistical significance.

nificance in predicting postoperative morbidity ($p = 0.096$ and $p = 0.052$, respectively). Paraspinal muscle tertiles did not show any significant associations with morbidity. Given the significant difference in psoas size between sexes, we analyzed males and females separately. For female patients, there was no observed trend for either psoas muscles or paraspinal muscles. Male patients with smaller average psoas areas and with smaller total psoas areas were significantly more likely to have postoperative morbidity ($p = 0.014$ for both). For the morphometric tertiles, differences were significant for average psoas area ($p = 0.032$) and total psoas area ($p = 0.008$), with patients in the lowest tertile having a greater incidence of complications. There was no observed trend for paraspinal muscle area and morbidity for male patients.

Odds Ratio and Multivariate Analysis of Morphometrics

Multivariate logistic regression was done to adjust for potential confounders when assessing the relationship between the lowest total psoas tertile versus the middle/highest tertile (Table 6). The association of complications and BMI remained significant for all patients and for female patients after adjusting for age, CAD, and smoking. The difference between the lowest total psoas tertile and the upper two tertiles remained significant; patients in the lowest tertile had an OR of 1.70 that they would experience complications compared with the other two tertiles (95% CI 1.04–2.79, $p = 0.035$). This association was especially prominent in male patients, with an OR of 2.42 (95% CI 1.17–5.01, $p = 0.016$) of experiencing a postoperative morbidity.

Discussion

Key Results

The overall rate of adverse events after lumbar spinal surgery is high, with 30% of patients experiencing some sort of postoperative morbidity. For all patients, the preoperative characteristics of age and tobacco usage were both significantly associated with complications ($p = 0.015$ and $p = 0.026$, respectively), while diabetes, CAD, and BMI were not. No surgical characteristics were associated with postoperative morbidity, including whether the surgery required instrumentation, whether it was a revision, or the number of levels treated. Important sex differences were observed. Female sex trended toward greater risk for morbidity ($p = 0.068$), and BMI was associated with increased morbidity in females ($p = 0.021$).

TABLE 4. Morphometric measurements*

Measurements	All Patients (n = 395)	Female (n = 203)	Male (n = 192)	p Value
Average L-4 psoas area	12.25 ± 4.38	9.66 ± 2.57	14.98 ± 4.24	<0.001
Total L-4 psoas area†	24.48 ± 8.76	19.32 ± 5.14	29.96 ± 8.49	<0.001
Average T-12 paraspinous area‡	16.70 ± 5.85	14.65 ± 4.56	19.01 ± 6.28	<0.001
Total T-12 paraspinous area§	33.18 ± 11.49	28.98 ± 8.41	37.96 ± 12.61	<0.001

* Values presented as the mean ± SD. "Average" refers to the mean between the right and left muscle area within a particular individual, and "total" refers to the sum of both muscles for each individual.

† Overall 394 patients; 203 females and 191 males.

‡ Overall 355 all patients; 188 females and 167 males.

§ Overall 346 all patients; 184 females and 162 males.

TABLE 5. Morphometric comparisons of patients with and without complications

Variable & Response	No Complications	Complications	p Value*
All patients	275	120	
Average psoas tertiles			0.096
Lowest	83 (30%)	48 (40%)	
Middle	102 (37%)	33 (28%)	
Highest	90 (33%)	39 (33%)	
Total psoas tertiles			0.052
Lowest	83 (30%)	50 (42%)	
Middle	99 (36%)	31 (26%)	
Highest	92 (34%)	39 (33%)	
Average paraspinous tertiles			0.826
Lowest	78 (32%)	40 (35%)	
Middle	81 (33%)	37 (33%)	
Highest	83 (34%)	36 (32%)	
Total paraspinous tertiles			0.791
Lowest	76 (32%)	39 (36%)	
Middle	82 (35%)	36 (33%)	
Highest	79 (33%)	34 (31%)	
Female patients	133	70	
Average L-4 psoas area†	9.58 ± 2.40	9.82 ± 2.88	0.512
Total L-4 psoas area†	19.15 ± 4.80	19.65 ± 5.75	0.512
Average T-12 paraspinous area†	14.47 ± 4.40	14.99 ± 4.85	0.458
Total T-12 paraspinous area†	28.48 ± 7.55	29.91 ± 9.83	0.315
Average psoas tertiles			0.673
Lowest	43 (32%)	24 (34%)	
Middle	48 (36%)	21 (30%)	
Highest	42 (32%)	25 (36%)	
Total psoas tertiles			0.673
Lowest	43 (32%)	24 (34%)	
Middle	48 (36%)	21 (30%)	
Highest	42 (32%)	25 (36%)	
Average paraspinous tertiles			0.848
Lowest	40 (33%)	23 (35%)	
Middle	42 (34%)	20 (30%)	
Highest	40 (33%)	23 (35%)	
Total paraspinous tertiles			0.821
Lowest	39 (33%)	22 (34%)	
Middle	43 (36%)	20 (31%)	
Highest	38 (32%)	22 (34%)	
Male patients	142	50	
Average L-4 psoas area†	15.43 ± 4.32	13.71 ± 3.73	0.014
Total L-4 psoas area†	30.86 ± 8.68	27.43 ± 7.45	0.014
Average T-12 paraspinous area†	19.35 ± 6.85	18.14 ± 4.47	0.183
Total T-12 paraspinous area†	38.68 ± 13.76	36.09 ± 8.84	0.159
Average psoas tertiles			0.032
Lowest	40 (28%)	24 (48%)	
Middle	54 (38%)	12 (24%)	
Highest	48 (34%)	14 (28%)	

(continued)

TABLE 5. Morphometric comparisons of patients with and without complications (*continued*)

Variable & Response	No Complications	Complications	p Value*
Male patients (<i>continued</i>)	275	120	
Total psoas tertiles			0.008
Lowest	40 (28%)	26 (52%)	
Middle	51 (36%)	10 (20%)	
Highest	50 (35%)	14 (28%)	
Average paraspinous tertiles			0.602
Lowest	38 (32%)	17 (36%)	
Middle	39 (33%)	17 (36%)	
Highest	43 (36%)	13 (28%)	
Total paraspinous tertiles			0.573
Lowest	37 (32%)	17 (38%)	
Middle	39 (33%)	16 (36%)	
Highest	41 (35%)	12 (27%)	

* Boldface indicates statistical significance.

† Values are presented as the mean ± SD.

For all patients, small total psoas tertiles approached significance for being associated with postoperative morbidity ($p = 0.052$). These results were significant with multivariate regression analysis, with the lowest psoas tertile having an odds ratio of 1.70 (95% CI 1.04–2.79, $p = 0.035$) for a postoperative complication for all patients. For male patients, a small total psoas size and being in the lowest psoas tertile were both significant predictors of postoperative morbidity ($p = 0.014$ and $p = 0.008$, respectively). For males, the multivariate regression analysis calculated an OR of 2.42 (95% CI 1.17–5.01, $p = 0.016$). The paraspinal muscle groups did not provide any significant data for postoperative morbidity, even after multivariate analysis. It is important to note that for males, the only variable in the multivariate analysis that was associated with higher risk of complication was being in the lowest psoas tertile.

Interpretation

This is the first time that morphometric analysis has been validated in spinal surgery, illustrating that psoas size may be used as a sensitive preoperative risk factor for perioperative morbidity in patients undergoing lumbar spine surgery. Morphometric analysis of psoas size was more sensitive than analyses of other preoperative risk factors (age, diabetes, smoking, CAD, and BMI) in predict-

ing postoperative morbidity. Psoas size is particularly accurate in predicting postoperative morbidity, with smaller psoas sizes having statistically significant increased odds of complications. This is in agreement with the work of authors in other surgical disciplines.^{3,7,12,13,17,18,22,24} The association with preoperative psoas size and postoperative morbidity is especially apparent in male patients. It is important to note that our morphometric analysis was not predictive or statistically significant in female patients. There are two reasons for this. First, women have statistically significant smaller psoas muscles than males (Table 2). If the proposed model of sarcopenia and frailty is correct, female sex could represent an indirect risk factor for complications. Indeed, we did observe that women trended toward having an increased rate of complications compared with males (Table 4, $p = 0.068$). Second, the psoas muscle may not be the best choice to measure sarcopenia and frailty in women. This is evidenced by the fact that the size of the paraspinal muscles, which have an antagonistic action to the psoas muscles, was not predictive of postoperative morbidity in any situation. This suggests that not all muscle groups may be accurate when used for morphometric analysis and that there may be a better, more sensitive muscle group yet to be identified.

It is not surprising that age is associated with increased

TABLE 6. Multivariate results using lowest total psoas tertile vs other two tertiles*

Variable	All Patients		Males Only		Female Only	
	OR (95% CI)	p Value	OR (95% CI)	p Value	OR (95% CI)	p Value
Female sex	1.46 (0.93–2.28)	0.103				
Age (increase of 10)	1.14 (0.94–1.40)	0.185	1.06 (0.78–1.45)	0.704	1.19 (0.91–1.56)	0.195
CAD	1.34 (0.73–2.48)	0.346	1.65 (0.75–3.64)	0.214	0.96 (0.36–2.59)	0.940
Smoking	0.65 (0.38–1.12)	0.118	0.75 (0.35–1.61)	0.465	0.55 (0.25–1.21)	0.138
BMI (increase of 5)	1.22 (1.02–1.46)	0.030	0.99 (0.72–1.36)	0.942	1.32 (1.05–1.66)	0.016
Total psoas (low vs middle & high tertiles)	1.70 (1.04–2.79)	0.035	2.42 (1.17–5.01)	0.016	1.22 (0.62–2.43)	0.564

* Boldface indicates statistical significance.

risk for postoperative complications ($p = 0.015$). Increasing age is a known risk factor for senescence and sarcopenia, which is indirectly being measured with our morphometric analysis. However, while age is sensitive for predicting sarcopenia, it is not specific, as there are persons of advanced age who have not lost muscle mass.^{9,21} It is noteworthy that diabetes, CAD, and BMI were not predictive of postoperative morbidity in all patients. Given that the majority of surgery performed in this study was elective in nature, these disease processes may have been under adequate control such that they did not impact the rate of postoperative complications; however, this might not be the case in the setting of an acute neurological deficit following an urgent or semielective operation. Our findings also underscore the relative imprecision of traditional methods for risk stratification in predicting postoperative morbidity. Our multivariate analysis shows that being in the lowest psoas tertile was more accurate at predicting postoperative morbidity than were age and all other premorbid states except for BMI in females. This suggests that morphometrics as a quantitative measure of sarcopenia and frailty may be more indicative of a patient's general health and their physiological reserve for tolerating surgery.

These findings are especially important in the current health care environment in the United States, as multiple parties (i.e., payers, the federal government, hospital administrators, and regulatory bodies) have begun to focus on the cost and value of care. As payments become bundled by procedure, and health care providers can potentially be penalized or withheld compensation for complications after routine procedures, it will be vital to identify predictors that put patients at a higher risk of morbidity. If a surgeon must perform a needed procedure in a potentially high-risk patient, a reliable model for risk stratification could provide some justification of perioperative morbidity. Regardless of the economic implications, a better understanding of the factors that will put a patient at increased risk of an adverse event after surgery is an important consideration for surgeons as they counsel patients and their families. Setting realistic expectations and providing accurate prognostic information is a key component in the delivery of care.

Limitations

The chief limitation of this study is its retrospective nature and relatively heterogeneous study population. Despite the robustness of our electronic medical record, we cannot account for potential bias and reporting error without standardization in data collection with each individual case. In addition, we considered all lumbar operations as a whole and did not stratify by indication (degenerative vs infection, tumor, trauma, etc.). Our findings highlight the need for future prospective multicenter trials.

Conclusions

Morphometric analysis of psoas size can be used as a sensitive tool to predict perioperative morbidity after lumbar spine surgery. Our results can be generalized to other institutions, as they were based on the experience of 12 surgeons across multiple hospitals, each with different

practice patterns and techniques (i.e., minimally invasive surgery versus traditional open techniques).

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Disclosure

Dr. Chang reports being a consultant for Globus Medical.

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Conception and design: Zakaria, Chang, Griffith. Acquisition of data: Zakaria, Chang, Mossa-Basha, Griffith. Analysis and interpretation of data: Chang, Zakaria, Schultz, Griffith. Drafting the article: Zakaria, Chang, Schultz. Critically revising the article: Chang, Zakaria, Schultz, Griffith. Reviewed submitted version of manuscript: Chang, Zakaria, Schultz, Griffith. Approved the final version of the manuscript on behalf of all authors: Chang. Statistical analysis: Schultz. Study supervision: Chang.

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