

A Novel Technique for Radiographic Diagnosis of Sarcopenia that Accurately Predicts Postoperative Complications in Lower Extremity Free Flap Patients

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Abstract

Introduction Sarcopenia is linked to poor outcomes throughout the surgical literature and can be assessed on preoperative imaging to potentially aid in risk stratification. This study examined the effects of sarcopenia on surgical morbidity following lower extremity (LE) reconstruction, and also compared two methods of assessment, one of which is novel (“ellipse method”).

Methods A retrospective cohort study of 50 patients receiving free flap-based reconstruction of the LE was performed. Bilateral psoas density and area were quantified at L4 through tracing (“traditional method”) and encircling (“ellipse method”) to calculate Hounsfield unit average calculation (HUAC). Logistic regression and receiving operator curve analysis for the primary outcome of any postoperative complication was used to determine HUAC cutoffs (≤ 20.7 vs. ≤ 20.6) for sarcopenia. Risk of complications associated with sarcopenia was evaluated using Fisher’s exact tests.

Results Twelve patients (24%) met criteria for sarcopenia via the traditional method and 16 (32%) via the ellipse method. By both methods, sarcopenic patients were older and more often female and diabetic. These patients also had higher American Society of Anesthesiologists scores and lower serum prealbumin levels. The ellipse method was found to be more accurate, sensitive, and specific than the traditional method in predicting postoperative morbidity ($p = 0.009$). Via the ellipse method, sarcopenic patients were at higher risk for any complication ($p = 0.002$) and were at a higher risk for a deep vein thrombus or pulmonary embolism via the traditional method ($p = 0.047$).

Keywords

- sarcopenia
- lower extremity reconstruction
- free flaps

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Conclusion Sarcopenia is associated with greater pre- and postoperative morbidity in LE reconstruction. The novel ellipse method is a simplified and accurate method of assessing sarcopenia that can be easily performed in the clinical setting.

Sarcopenia is a progressive and generalized disorder involving the degenerative loss of muscle mass and function.^{1,2} Although sarcopenia naturally occurs in advanced age, it is also influenced by a variety of genetic and lifestyle factors. Recent studies have investigated the impact of decreased activity, immobilization, and malnutrition on the early development of sarcopenia.^{3–7} Although the International Classification of Diseases-10 code for sarcopenia was developed in 2016,⁸ there remains no unified diagnostic criteria, and many physicians remain unfamiliar with the condition.

Sarcopenia may occur in both obese and nonobese individuals and has been utilized as an index for both physical and general frailty.³ Consequences of sarcopenia include reduced physical capacity,^{9–11} impaired cardiopulmonary performance,^{12,13} unfavorable metabolic effects,¹⁴ poorer quality of life, higher health care expenditures,¹⁵ and disability and mortality.^{16,17} It has been well-studied across several surgical subspecialties including general,^{18–20} vascular,^{21–23} orthopaedic,²⁴ trauma,^{25,26} and oncologic surgery^{27–29} and has been found to be a reliable prognostic factor for postoperative morbidity. Similarly, within the otolaryngology³⁰ and plastic and reconstructive literature, sarcopenia has been associated with an increased incidence of postoperative surgical site morbidity in free flap-based head-and-neck reconstruction.^{31–35} In breast reconstruction, sarcopenic obesity more strongly predicts delayed wound healing after expander placement than body mass index (BMI) alone³⁴ and is associated with delayed wound healing, increased lengths of hospital and intensive care unit stay, and increased incidence of reoperation following autologous reconstruction.³⁶ Sarcopenia has also been associated with increased rates of surgical site infection among patients undergoing flap-based reconstructions following abdominoperineal reconstruction.²⁹ However, no study has investigated the potential value of sarcopenia as a prognostic factor for surgical morbidity in lower extremity (LE) reconstruction.

The clinical diagnosis of sarcopenia involves an assessment of muscle strength or physical performance along with an estimated quantification of skeletal muscle mass.³ One method of measuring this mass is the Hounsfield unit average calculation (HUAC) score of the psoas muscles.³⁷ The HU is a measure of radiation attenuation that can be detected on computerized tomography (CT) imaging. The HUAC score represents the mean HU across the psoas cross-sectional area and is influenced by muscle density and intramuscular fat infiltration. As such, lower HUAC values signify the atrophic and fatty muscle characteristic of sarcopenia. However, clinical assessment of this value can be complicated by the relative hassle of precisely tracing each psoas, in addition to the requirement for advanced software with the requisite capacity to perform these calculations. In response to these obstacles, we describe a rapid, novel method of estimating

the HUAC score with the simple ellipse tool on the widely used Centricity PACS (CPACS) workstation (GE Healthcare, Chicago, IL). The goals of this study are to analyze the impact of multiple indices of sarcopenia on surgical outcomes in microsurgical reconstruction of the LE, and to compare the two variants of HUAC quantification.

Methods

Patient Selection and Chart Review

Following Institutional Review Board approval, a retrospective cohort study was performed for 50 consecutive patients that underwent LE reconstruction with 50 free flaps at an academic, level 1 trauma center in New Orleans, LA from 2017 to 2020. Patients were identified using surgeon and procedural codes for free tissue transfer to the LE. Patients were excluded if the requisite preoperative imaging study was not available for analysis. Patient demographics, reconstructive indication and course, perioperative serum prealbumin and albumin, and postoperative complications were collected. The primary outcome measure was any complication, with secondary outcomes compromising individual complications including total and partial flap failure, problems with venous outflow, deep vein thrombosis (DVT) or pulmonary embolism (PE), dehiscence, infection, and hardware removal. For DVT prophylaxis, patients typically received enoxaparin (Lovenox) 40 mg daily or 30 mg twice a day versus 5,000 units of subcutaneous heparin dependent on diagnosis and renal function. This is restarted 6 to 8 hours after surgery and continued in the postoperative period.

Evaluation of Sarcopenia

Preoperative CT scans of the abdomen and LEs were examined to diagnose sarcopenia by a single reviewer blinded to postoperative outcomes. Sarcopenia was evaluated by calculating the HUAC score through two different techniques: the “traditional method” via Philips IntelliSpace Portal (ISP; Amsterdam, Netherlands) and the novel “ellipse method” via CPACS. The traditional method was performed by tracing the bilateral psoas at spinal level L4 with the Spline contour tool and calculating bilateral psoas surface area and HU measurements. By this method, an exact tracing of psoas borders is performed, accurately quantifying the total psoas area.^{19,29,37} HUAC could then be calculated with the formulae: $HUAC = (RHUC + LHUC)/2$, where $RHUC = (\text{right HU} \times \text{right psoas area})/\text{total psoas area}$, $LHUC = (\text{left HU} \times \text{left psoas area})/\text{total psoas area}$, and $\text{total psoas area} = \text{right psoas area} + \text{left psoas area}$.^{19,29,37}

To perform the novel ellipse method, bilateral psoas density and area measurements were again obtained at L4, but using the Ellipse tool instead of the Spline tool. This involved generating an ellipse and encircling as much of each

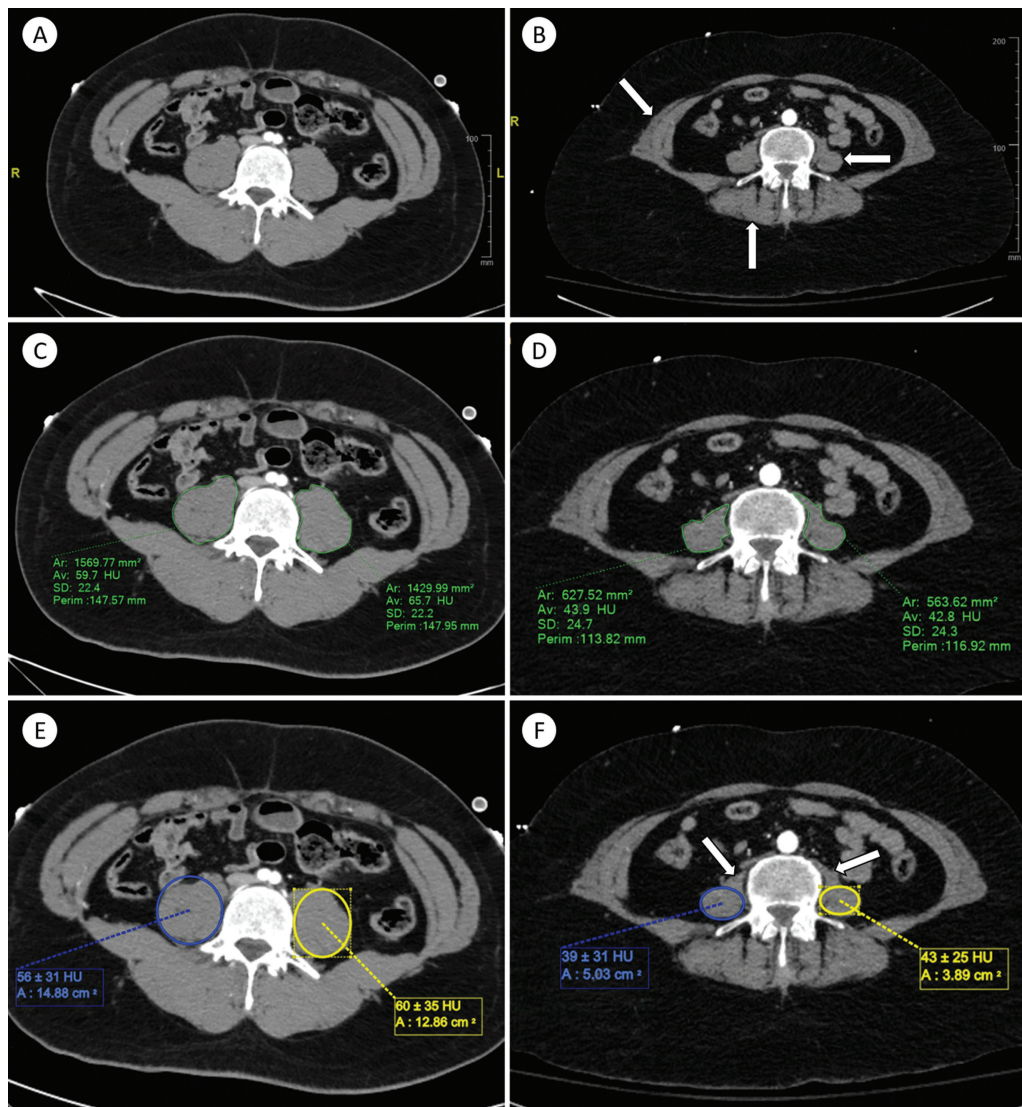


Fig. 1 Assessment of Hounsfield unit average calculation (HUAC) in a single nonsarcopenic (A, C, E) and sarcopenic (B, D, F) patient via the traditional (C, D) and ellipse (E, F) methods. (A, B) Computed tomography angiograms at the L4 spinal level demonstrating substantially less skeletal muscle mass and greater fatty infiltration (arrows) in the sarcopenic patient (B) relative to the nonsarcopenic patient (A). (C, D) Traditional method demonstrating tracing of bilateral psoas muscles to obtain HU and area measurements. (E, F) Ellipse method demonstrating encircling of bilateral psoas muscles to obtain HU and area measurements. Notably, a section of psoas is excluded to avoid incorporation of adjacent structures, which is arguably more significant in the sarcopenic patient (arrows).

psoas as exclusively as possible. Segments of the psoas that could not be encircled without including vertebral bone or substantial areas of non-psoas such as extramuscular adipose, kidney, or the inferior vena cava were excluded (► Fig. 1). HUAC was then calculated using the measurements obtained. While total psoas area was not as completely quantified with this technique compared with the traditional method, it required only a few seconds and could be performed easily from the electronic medical record (EPIC Systems; Verona, WI).

Statistical Analysis

Simple association between traditional and ellipse HUAC measures was assessed via Spearman's correlation analysis. For each HUAC method, logistic regression with receiving operator curve (ROC) analysis was used to

determine the HUAC value that best discriminated cases according to the primary outcome, any postoperative complication. The HUAC value that maximized the Youden's index was chosen as the cutoff value for sarcopenia.³⁸ Overall accuracy, sensitivity, and specificity for the final classification was reported for each HUAC method. Baseline patient characteristics among sarcopenic and nonsarcopenic patients were compared using Fisher's exact and Mann-Whitney tests for categorical and continuous variables. Risk of complications associated with sarcopenia was evaluated using Fisher's exact tests. We compared the predictive power of risk factors using model fit statistics from simple logistic regression models of any complication. Adjusted coefficient of determination ($\tilde{R}^2$)³⁹ for the simple logistic regression models were compared with identify risk factors with the greatest predictive

power. Due to high correlation among risk factors, multivariable analysis was not conducted.

Results

There was a high concordance between both HUAC measures ($\rho = 0.83$, $p < 0.0001$). ► **Table 1** contains the logistic regression ROC summary for each of the HUAC methods: traditional and ellipse approximation. The threshold for sarcopenia was determined to be ≤ 20.7 for the traditional method and ≤ 20.6 with the ellipse approximation (► **Table 1**). Classification via the ellipse HUAC had greater overall accuracy in predicting postoperative complications when compared with the traditional HUAC (70% vs. 60%).

Patient demographics and characteristics for the overall sample and among sarcopenic and nonsarcopenic groups can be seen in ► **Table 2**. The sample was 70% male and 60% white. Patients ranged from 17 to 82 years old, with a median age of 41 years. The majority of reconstructive procedures were indicated by trauma (78%) and involved fasciocutaneous flaps (88%). The mean time from presentation to free flap was 12.8 days. Sixteen (32%) patients were classified as sarcopenic under the ellipse method and 12 (24%) under the traditional method. There was a higher incidence of multiple comorbidities among those classified as sarcopenic; significant differences were observed among sex, age, diabetes, American Society of Anesthesiologists (ASA) scores, and serum prealbumin levels between the two groups in both methods, and in hypertension under the ellipse method. There were no differences in race, BMI, or tobacco use. While sarcopenic groups appear to have had a greater number of procedures indicated by osteomyelitis and involving myocutaneous flaps, these differences were not statistically significant.

The incidence of postoperative complications in the sample, overall, and between sarcopenic and nonsarcopenic groups, is depicted in ► **Table 3**. Overall, 42% of patients had some form of postoperative complication, with infection being the most common (26%). Under the ellipse HUAC classification, 75% of sarcopenic patients experienced some form of complication compared with 26.5% of nonsarcopenic patients ($p = 0.002$). For this method, all forms of postoperative complication occurred at a greater frequency in the sarcopenic group, although differences for individual complications were not significant. Under the traditional HUAC classification, 58.3% of sarcopenic patients experienced a complication compared with 36.8% of nonsarcopenic patients ($p = 0.3145$). For this method, there was a signifi-

cantly greater rate of DVT or PE among the sarcopenic patients compared with nonsarcopenic patients (33.3% vs. 7.9%, $p = 0.048$).

► **Table 4** provides a comparison of model fit for logistic regression models of postoperative complications across competing risk factors. Each model includes only one risk factor. Higher R^2 values indicate better model fit and greater predictive power. Sarcopenia (using the ellipse HUAC classification; $(\tilde{R}^2) = 26\%$, $p = 0.001$) and age ($(\tilde{R}^2) = 22.8\%$, $p = 0.002$) had the greatest predictive power regarding postoperative complications. Other variables significantly associated with poor outcomes, but with lower predictive power, include ASA score ($(\tilde{R}^2) = 16.1\%$, $p = 0.0413$), prealbumin ($(\tilde{R}^2) = 15.4\%$, $p = 0.0289$), albumin ($(\tilde{R}^2) = 11.5\%$, $p = 0.0361$), and diabetes ($(\tilde{R}^2) = 11.5\%$, $p = 0.0262$).

Discussion

Sarcopenia is an objective quantification of a patient's core muscle mass that may be linked with poor nutritional status, fitness, and frailty; it has been associated with significant morbidity in various surgical fields. Here, we identified higher rates of morbidity among sarcopenic patients undergoing free flap reconstruction of the LE. Moreover, we assessed two distinct methods of quantifying the psoas HUAC score to evaluate sarcopenia: the standard technique performed via tracing of the muscle border, and a novel approach of approximating it via ellipse encircling.

Research on the etiology, pathophysiology, and consequences of sarcopenia has been growing rapidly given the growth in elderly populations.^{1,3,40,41} While its mechanisms are not fully elucidated, sarcopenia results from an imbalance between anabolic and catabolic pathways culminating in the transition of type II to type I muscle fibers, fatty infiltration, and a decrease in satellite stem cells necessary to regenerate the muscle.^{7,42–46} Poor nutrition, inactivity, chronic disease, tobacco, trauma, and iatrogenic influences such as drug administration may further exacerbate these physiologic changes, even in a relatively young individual.^{3,47–54} The influence of nonage-related factors may be noticeably more appreciable in the context of LE reconstruction.

There may be unique considerations for the sarcopenic patient undergoing LE reconstruction relative to other surgical patients. Since traumatic injury is the most common indication for LE reconstruction worldwide,⁵⁵ many patients requiring LE reconstruction may be young and otherwise previously healthy. This is supported by the

Table 1 Receiver operating curve (ROC) analysis ($N = 50$)

Method	Likelihood ratio test p -value	AUC	Predicted probability	Accuracy	Sensitivity	Specificity	Value
Traditional HUAC	0.0656	0.6404	0.4	60	57.1	62.1	20.7
Ellipse HUAC	0.0089 ^a	0.7077	0.42	70	66.7	72.4	20.6

Abbreviations: AUC, area under the curve; HUAC, Hounsfield unit average calculation.

^a $p < 0.01$.

Table 2 Cohort characteristics by sarcopenia classification (N = 50)

Characteristics	Overall (%) (N = 50)	Traditional HUAC (≤ 20.7)			Ellipse HUAC (≤ 20.6)		
		Nonsarcopenic (%) (n = 38)	Sarcopenic (%) (n = 12)	p-Value	Nonsarcopenic (%) (n = 34)	Sarcopenic (%) (n = 16)	p-Value
Demographics							
Sex				0.0271 ^a			0.0019 ^c
Female	15 (30)	8 (21.1)	7 (58.3)		5 (14.7)	10 (62.5)	
Male	35 (70)	30 (79.0)	5 (41.7)		29 (85.3)	6 (37.5)	
Race				0.7699			1.0000
White	30 (60)	22 (57.9)	8 (66.7)		20 (58.8)	10 (62.5)	
Black	16 (32)	12 (31.6)	4 (33.3)		11 (32.4)	5 (31.3)	
Other	4 (8)	4 (10.5)	0 (0.0)		3 (8.8)	1 (6.3)	
Age, median (range)	41 (17–82)	35 (17–82)	57 (40–70)	< 0.0001 ^c	35 (17–56)	57 (25–82)	< 0.0001 ^c
BMI, median (range)	28.6 (18.5–70)	28.1 (18.5–38.4)	31.9 (23.7–70)	0.1068	28.0 (18.5–35)	30.5 (22.8–70)	0.0921
Comorbidities							
Hypertension	12 (24)	7 (18.4)	5 (41.7)	0.1292	5 (14.7)	7 (43.8)	0.0363 ^a
Diabetes mellitus	6 (12)	2 (5.3)	4 (33.3)	0.0239 ^a	1 (2.9)	5 (31.3)	0.0098 ^b
Tobacco use	25 (50)	19 (50.0)	6 (50.0)	1.0000	18 (52.9)	7 (43.8)	0.7624
ASA score				0.0139 ^a			0.0011 ^b
II	33 (66)	29 (76.3)	4 (33.3)		28 (82.4)	5 (31.3)	
III	16 (32)	8 (21.1)	8 (66.7)		6 (17.7)	10 (62.5)	
IV	1 (2)	1 (2.6)	0 (0.0)		0 (0.0)	1 (6.3)	
Reconstructive indication				0.1899			0.5966
Primary trauma	39 (78)	31 (81.6)	8 (66.7)		28 (82.4)	11 (68.8)	
Osteomyelitis	6 (12)	3 (7.9)	3 (25.0)		3 (8.8)	3 (18.8)	
Exposed hardware	3 (6)	3 (7.9)			2 (5.9)	1 (6.3)	
Tumor	2 (4)	1 (2.9)	1 (8.3)		1 (2.9)	1 (6.3)	
Perioperative factors							
Prealbumin, mean $\pm$ SD	16.0 $\pm$ 3.6	18.1 $\pm$ 5.8	10.2 $\pm$ 3.4	0.0008 ^c	17.5 $\pm$ 3.6	13.4 $\pm$ 3.4	0.0271 ^a
Albumin, mean $\pm$ SD	6.4 $\pm$ 0.5	5.8 $\pm$ 0.5	4.3 $\pm$ 0.5	0.2289	6.0 $\pm$ 0.5	6.4 $\pm$ 0.6	0.1165
Days to flap, mean $\pm$ SD	12.8 $\pm$ 8.6	12.2 $\pm$ 7.2	11.1 $\pm$ 10.3	0.3245	12.1 $\pm$ 7.4	11.6 $\pm$ 9.2	0.9641
Flap type				0.1406			0.3696
Fasciocutaneous flap	44 (88)	35 (92.1)	9 (75.0)		31 (91.2)	13 (81.3)	
Myocutaneous flap	6 (12)	3 (7.9)	3 (25.0)		3 (8.8)	3 (18.8)	

Abbreviations: ASA, American Society of Anesthesiologists; BMI, body mass index; HUAC, Hounsfield unit average calculation; SD, standard deviation.

^a $p < 0.05$.

^b $p < 0.01$.

^c $p < 0.001$.

relatively young age of our cohort, in addition to the lower rates of comorbidities and optimal serum prealbumin levels seen among patients not classified as sarcopenic. As previously mentioned, both inactivity and trauma itself have been linked to exacerbating sarcopenic changes, and patients undergoing LE reconstruction are unlikely to be particularly mobile postoperatively. Sarcopenia increases fall risk among the elderly^{56,57} and is more prevalent among patients requiring LE orthopaedic surgery compared with nonsurgical patients.⁵⁸ Additionally, sarcopenia might impair postoperative healing as muscle weakness may further limit use of the reconstructed limb, potentially exacerbating muscular atrophy, edema,

and vascular stasis. These factors may have contributed to the relatively high rate of thrombotic complications in our high-risk patient population, many of which had multiple surgeries and long operative times. In conjunction with the immobility and trauma of the extremity itself, the risk of venous stasis and clotting was further increased; most patients developed a venous thrombus in an injured extremity complicated by multiple fractures. One of these patients was found to have a protein S deficiency which also contributed to a flap failure. Two patients developed PE shortly after discharge after stopping anticoagulation; one also presented with concomitant cellulitis of the flap site and a *Clostridium difficile* infection. Given these

Table 3 Complications by sarcopenia classification (N = 50)

Complication	Overall (%) (n = 50)	Traditional HUAC (≤ 20.7)			Ellipse HUAC (≤ 20.6)		
		Nonsarcopenic (%) (n = 38)	Sarcopenic (%) (n = 12)	p-Value	Nonsarcopenic (%) (n = 34)	Sarcopenic (%) (n = 16)	p-Value
Any complication	21 (42)	14 (36.8)	7 (58.3)	0.3145	9 (26.5)	12 (75)	0.0019 ^b
Total flap failure	5 (10)	4 (10.5)	1 (8.3)	1.0000	2 (5.9)	3 (18.8)	0.3109
Partial flap failure	2 (4)	2 (5.3)	0 (0)	1.0000	1 (2.9)	1 (6.3)	0.5420
Venous outflow complication	5 (10)	4 (10.5)	1 (8.3)	1.0000	3 (8.8)	2 (12.5)	0.6498
DVT/PE	7 (14)	3 (7.9)	4 (33.3)	0.0477 ^a	3 (8.8)	4 (25)	0.1903
Dehiscence	4 (8)	3 (7.9)	1 (8.3)	1.0000	1 (2.9)	3 (18.8)	0.0906
Infection	13 (26)	8 (21.1)	5 (41.7)	0.2557	6 (17.7)	7 (43.8)	0.0824
Hardware removal	3 (6)	3 (7.9)	0 (0)	1.0000	2 (5.9)	1 (6.3)	1.0000

Abbreviations: DVT, deep vein thrombus; HUAC, Hounsfield unit average calculation; PE, pulmonary embolism.

^a $p < 0.05$.

^b $p < 0.01$.

Table 4 Logistic regression analysis of risk factors with postoperative morbidity (N = 50)

Risk factor	R-squared ^c	p-Value ^d
Sarcopenia (ellipse)	25.99%	0.0011 ^b
Age (continuous)	22.76%	0.0023 ^b
Age ≥ 50	17.48%	0.0083 ^b
HUAC (ellipse; continuous)	17.20%	0.0089 ^b
ASA score	16.10%	0.0413 ^a
Prealbumin (continuous)	15.39%	0.0289 ^a
Diabetes mellitus	11.52%	0.0262 ^a
Albumin (continuous)	11.52%	0.0361 ^a
HUAC (traditional; continuous)	8.82%	0.0656
BMI (continuous)	8.75%	0.0667
Extreme obesity (BMI ≥ 35)	8.74%	0.0669
Reconstructive indication	8.21%	0.3692
Race	7.58%	0.2345
Sex	7.41%	0.0922
Tobacco use	5.45%	0.1504
Hypertension	4.53%	0.1907
Sarcopenia (traditional)	4.53%	0.1907
Obesity (BMI ≥ 30)	0.52%	0.6610
Flap type	0.48%	0.6738

Abbreviations: ASA, American Society of Anesthesiologists; BMI, body mass index; HUAC, Hounsfield unit average calculation.

^a $p < 0.05$.

^b $p < 0.01$.

^cAdjusted generalized coefficient of determination.

^dLikelihood-ratio test.

considerations, further expounding on the impact of sarcopenia in LE reconstruction may be especially important for optimizing patient outcomes.

Sarcopenia can be difficult to detect clinically, particularly in those with larger body habitus.³⁷ While different methods have been used to quantify sarcopenia throughout the literature, one common methodology is skeletal muscle index (SMI). Unlike HUAC, SMI involves quantification of total skeletal muscle mass at a single axial CT lumbar section.^{34,35} Despite being a more comprehensive quantification of skeletal muscle, there are several significant technical limitations to SMI as a methodology, limiting its use in standard clinical practice. For example, one limitation of the radiology suite at our institution (Philips ISP) is its inability to set the HU thresholds used to exclude intramuscular adipose necessary for SMI calculation. The price of proprietary imaging software commonly utilized for quantification of SMI such as OsiriX (Pirxmeo SARL; Bernex, Geneva, Switzerland) may preclude use outside of academic medical and research centers. Several authors have measured SMI using ImageJ, a free public domain software. However, manual tracing of each muscle to calculate SMI is tedious and particularly difficult without a stylus.⁵⁹ Given these limitations, we elected to assess sarcopenia through the HUAC score, which has been validated and suggested to outperform other methods by multiple studies.^{19,29,60,61}

In contrast to SMI, HUAC does not require software exclusion of intramuscular fat as this is reflected in the HU values utilized by the calculation. Perhaps more importantly, obtaining the HUAC is considerably simpler and rapid. The psoas muscle is easily identified on CT imaging lateral to the vertebral bodies. In healthy, nonsarcopenic patients, the cross-section is prominent and roughly elliptical in shape without substantial irregularity in curvature or indentations; in comparison to tracing the thin, layered musculature of the anterior abdominal wall, outlining the psoas is much simpler. Because preoperative CT angiography (CTA) is increasingly utilized to map perforator and recipient vessel course during free flap reconstruction, HUAC can be easily obtained for assessment prior to surgery.

Despite its relative ease compared with SMI, the traditional HUAC has its own limitations. If sarcopenia is to be widely

accepted clinically as a useful prognostic tool, its quantification must be simple, easy to acquire, and accessible outside the radiology suite. The ellipse method takes only seconds and is noticeably faster than using lines with the traditional method. It can be performed directly from the health record at the time of preoperative evaluation. Only four easily measured values (bilateral psoas HU and area) are needed for risk assessment. To our knowledge, no one has reported using an ellipse or circle tool to estimate psoas HUAC.

The minimum threshold to define sarcopenia varies considerably between studies, methods, sex, and different populations.^{1,3,29–32,34,36} However, the thresholds we obtained via ROC analysis were comparable to HUAC values previously reported in the plastic surgery literature,^{19,29} while also roughly paralleling use of the bottom quartile to define sarcopenia by some authors.²⁹ Notably, there was a high concordance with sarcopenia and other factors such as age, sex, and diabetes. While we lacked the sample size to perform a large multivariate analysis to elucidate an independent role in predicting risk, this should not diminish sarcopenia's competency as a useful prognostic factor. As sarcopenia is essentially a high-risk state mediated by multiple risk factors that is not inherently independent of said factors, its total cumulative effect may be more relevant than comparisons to any individual factor. Of the risk factors examined, sarcopenia as defined by the ellipse classification yielded the greatest predictive power for a complication over any other observed single risk factor. Our findings concur with the strong consensus on sarcopenia's value as a prognostic indicator.^{1,3,29–32,34,36,37,62} Both the ellipse and traditional methods were concordant and accurate, predicting complications with an accuracy of 70 and 60%, respectively.

Despite being less detailed, one potential explanation for the increased specificity among the ellipse method may be because it excludes sections where the psoas cannot be encircled without incorporating other structures. As the muscle atrophies and becomes infiltrated with fat, it becomes more irregularly shaped on axial CT. As such, the ellipse method may be more specific in identifying poor "muscle quality" based on axial morphology. It has been reported that observable characteristics of muscle remain insufficiently defined for use in clinical practice.^{3,44} To our knowledge, there are no studies examining the effect of sarcopenia on the cross-sectional morphology of the psoas muscle. Future studies might investigate whether sarcopenic patients with visibly abnormal psoas architecture are at higher risk for postoperative complications and overall morbidity.

Our analysis suggests that utilizing the ellipse tool to measure psoas HUAC is a simple, accessible, and valid proxy for morbidity prognosis in patients undergoing LE reconstruction that should be integrated into risk stratification models. However, there remains a paucity of specific recommendations following preoperative diagnosis of sarcopenia; discussions regarding the modifiable nature of sarcopenia acutely remain inconclusive.^{30,31} As much of LE reconstruction is related to primary trauma, surgical planning may not allow for substantial delays for nutritional and physiological optimization despite knowledge of operative risk.

However, several working groups and nutrition societies have found preoperative nutritional supplementation to produce significant reductions in postsurgical morbidity among gastrointestinal and oncologic patients within only 7 to 10 days.^{63–68} Although some guidelines define an optimal period of supplementation to be at least 2 weeks for the most malnourished patients, one study demonstrated a 50% reduction in overall complication rates in as little as 7 days of nutritional support.⁶⁵ Considering that our mean time from presentation to flap coverage was 12.8 days, there certainly still exists a window for introducing nutritional support among sarcopenic patients possessing acute reconstructive needs. Additionally, oncologic patients may have a greater opportunity to undergo nutritional optimization in advance of surgery. Both oncologic patients in our cohort were seen in clinic several weeks prior to admission and received CTA imaging several days prior to free flap reconstruction. Theoretically, oncologic patients preoperatively identified as sarcopenic could begin early supplementation. Future studies examining the timeframe and impact of preoperative and postoperative nutritional therapy among sarcopenic patients undergoing free flap surgeries would be worthwhile in our quest to optimize reconstructive outcomes and reduce overall hospital length of stay and financial burden.

Finally, the effect of sarcopenia on pure muscle or myocutaneous flap quality remains unexplored.³¹ While most flaps received by our study patients were fasciocutaneous antero-lateral thigh flaps, five received myocutaneous vastus lateralis flaps and one a tensor fascia lata flap. As the risk of flap complications is significantly higher among free flaps, we did not examine locoregional muscle flaps such as the gastrocnemius or soleus that are commonly utilized for LE reconstruction. Theoretically, muscle flaps in sarcopenic patients might be smaller and may provide less bulk and coverage capabilities. Flap type was not associated with complication risk in our cohort. Still, future studies might investigate the direct impact of sarcopenia on muscle flap volume.

Our study suffers from limitations, including the standard retrospective biases. This study is susceptible to the risk of confirmation bias, but scans were analyzed blinded to outcomes. Despite observable differences between sarcopenic and nonsarcopenic cohorts, statistical significance among individual complications may not have been met due to insufficient statistical power. Further studies with larger sample sizes, evaluations of inter-rater variability, and comparisons to other methods such as SMI are warranted. Finally, it is important to reiterate that our thresholds were determined by the unique properties of our patient cohort and are not stratified by sex. We await a multipopulation meta-analysis to define a unified cutoff that maximally encompasses patients of all backgrounds.

Conclusion

Our clinical findings suggest that sarcopenia is associated with substantially greater preoperative and postoperative morbidity in the setting of LE reconstruction. The novel

ellipse HUAC method is a simplified and accurate measure of sarcopenia that can easily be performed in the clinical setting and is accessible to physicians of all specialties. It reliably predicts postoperative complications and can potentially be integrated into surgical risk stratification models. Although patients undergoing LE reconstruction in the setting of trauma or osteomyelitis may not always possess an adequate window for nutritional and physiologic optimization, an effort should be made nonetheless, and patients closely monitored for postoperative morbidity.

Conflict of Interest

None declared.

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