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Article

Study of the Relationship Between the Area of the Rectus Femoris Measured by Ultrasound and Psoas Muscle Index (PMI) and Skeletal Muscle Index (SMI) Measured by Opportunistic CT in Oncological Surgical Patients

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Summary: Introduction: The psoas muscle index (PMI) and the skeletal mass index (SMI), as determined by computed tomography (CT), are the reference methods for assessing muscle mass. An alternative method is to measure the area of the rectus femoris muscle using ultrasonography (US). **Objective:** The objective of this study is twofold: firstly, to assess whether ultrasound imaging of the rectus femoris has an adequate correlation with psoas muscle index (PMI) and skeletal mass index (SMI) measurements obtained from computed tomography (CT) scans of oncosurgical patients at the L3 level; and secondly, to establish a cut-off point for diagnosing low muscle mass using this ultrasound technique. **Material and methods:** A retrospective cross-sectional observational study was carried out on oncosurgical patients referred to the nutrition consultation of the General University Hospital of Castellón over a four-year period. Malnutrition was diagnosed according to the GLIM criteria, muscle mass was assessed by ultrasound using a Mindray device, and skeletal muscle index (SMI) and appendicular skeletal muscle mass (PMI) were measured by computed tomography at the third lumbar vertebra (L3). Patients lacking a CT scan or with a CT scan performed more than one month after the ultrasound examination were excluded. **Results:** The study cohort comprised 43 patients (31 males), with a mean age of 64.7 ± 6.72 years, a mean BMI of 23.7 ± 4.31 kg/m², and a mortality rate of 25.6%. Most of the evaluations were conducted post-surgically (65.1%), with a notable prevalence of radical cystectomy and hepatic surgery. A total of 53 ultrasound evaluations were conducted, with an average area of 2.96 cm² [2.47-4.2] and adipose tissue of 0.55 cm [0.1-0.99] *. Additionally, computed tomography (CT) scans were performed to assess skeletal muscle mass (SMM) using the SMI/height method, yielding an average area of 38.4 cm² [31.6- 45.7] The median values for the variables were as follows: 272 [207-390] HU, PMI area of 4.31 m² [3.71-5.94] * and 86 [69-103] * HU density in PMI. All data were expressed as median and interquartile range. The Pearson correlation coefficients between US and SMI/height, SMI/height and PMI/height, and US and PMI/height were 0.70, 0.750, and 0.548, respectively. All these coefficients were statistically significant (p < 0.001). Following the established criteria for low muscle mass for SMI (1) and PMI (2), a ROC curve analysis was conducted on US, with a cutoff point for low muscle mass of 3.6 cm² , AUC 0.770 with 70% and specificity 100%. Respect PMI , the cut-off was 3.29 cm² and the area

under the curve was 0.609, with a sensitivity of 42.55% and a specificity of 100%. **Conclusions:** The results of this study indicate that there is a significant correlation between SMI, PMI, and the area in cm² measured by US in the rectus femoris according to the protocol of García-Almeida et al. (3). The positive correlation between ultrasound and computed tomography (CT) imaging in our sample, which yielded comparable results to those reported by (4), suggests that ultrasonography may serve as a viable alternative to CT for the detection of low muscle mass. This study is the first to establish a cutoff point for ultrasonography in comparison to SMI and PMI. Further studies are required, utilising a semi-automatic method to circumvent measurement bias and encompassing a larger patient cohort, in order to detect cutoff points pre- and post-surgery for cystectomy and hepatic surgery, as well as cutoff points by sex.

Keywords: Muscle ultrasound; body composition; CT imaging; GLIM criteria

Introduction

Malnutrition is a prevalent issue across all levels of healthcare, from primary care to specialised care and geriatric care settings. It primarily affects the elderly. In developed countries, malnutrition has been identified as a significant issue in hospitals since the mid-20th century, yet a comprehensive solution has yet to be established. The condition itself serves to exacerbate malnutrition, thereby creating a vicious cycle that can ultimately result in death.

The initial definition of malnutrition was defined based on weight loss, low body mass index (BMI), and serum albumin levels (5). However, in 2012, ASPEN (6) published new diagnostic criteria for adult malnutrition, which were primarily focused on identifying patients at nutritional risk and included clinical and body composition data.

In 2015, ESPEN (7) established that for individuals identified as being at risk of malnutrition through screening, the diagnosis of malnutrition should be based on a low BMI (<18.5 kg/m²), or a combination of unintentional weight loss and a low BMI for age or a low fat-free mass index (FFMI) using sex-specific cut-offs.

In 2019, the GLIM criteria (8) were published and have remained current, with updates in 2022 (9, 10).

There is an increasing focus on muscle mass in the assessment of malnutrition, given that BMI is less responsive to early changes and does not provide information about the nature of the body compartments.

A variety of techniques are available for the measurement of muscle mass. Dual-energy X-ray absorptiometry (DEXA), computed tomography (CT), and magnetic resonance imaging (MRI) are regarded as the gold standard (8). In CT scans, muscle mass is typically measured at the level of the third lumbar vertebra. According to Walowski et al (11), the skeletal mass index (SMI) is a superior indicator of total muscle mass compared to the psoas muscle index (PMI).

These methods have inherent limitations, as they are either employed in research contexts or utilize opportunistic CT scans conducted on surgical or oncological patients for other purposes. In recent years, in addition to bioelectrical impedance analysis (10), ultrasonography of the rectus femoris muscle in the middle to distal third of the femur has gained increasing importance for the assessment of muscle mass (3). This is due to the fact that it is a non-radiating, rapid method with a suitable learning curve that can be performed at the bedside.

In this context, the objective of our study is to assess the correlation between the rectus femoris cross-sectional area (RFSA) as measured by US and SMI, as well as PMI measured by opportunistic CT at the level of the third lumbar vertebra in a sample of oncosurgical patients followed up in the nutrition clinic.

MATERIAL AND METHODS

Study Design and Population

This is a retrospective cross-sectional observational study of the records of oncological surgical patients referred to the specialized nutrition clinic from October 2020 to June 2024 at Castellón University Hospital.

The study included patients aged 18 or over who had undergone oncological surgery and had undergone both ultrasound and CT scans. Patients were excluded if there was a time interval of more than one month between the ultrasound and CT scans. Over the course of the study period, 68 oncological patients underwent 108 morpho-functional evaluations.

A total of 43 patients were included in the study (Figure 1), comprising 31 males and 12 females, with a mean age of 64.7 ± 6.72 years, a mean BMI 23.7 ± 4.31 kg/m², and a mortality rate of 25.6%. The majority of evaluations were conducted postoperatively (65.1%), with radical cystectomies and liver surgery being the most prevalent (Tables 1 and 2).

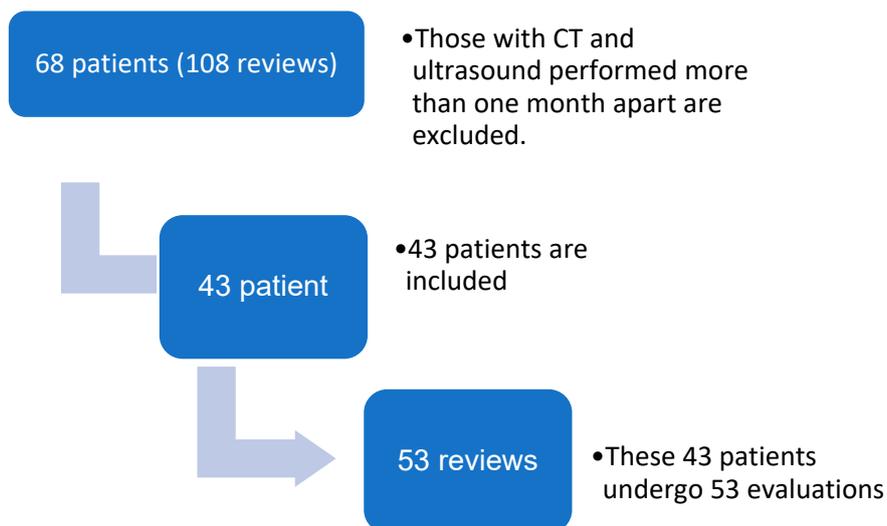


Figure 1. Included patients in the study.

Table 1. valuation type.

Frequencies of type			
type	Counts	% of Total	Cumulative %
pre-surgical	15	34.9 %	34.9 %
post-surgical	28	65.1 %	100.0 %

Table 2. type of pathology.

Frequencies of pathology			
pathology	Counts	% of Total	Cumulative %
gastric	2	4.7 %	4.7 %
pancreas	2	4.7 %	9.3 %
cystectomy	12	27.9 %	37.2 %
liver	24	55.8 %	93.0 %
colon	1	2.3 %	95.3 %
head and neck	2	4.7 %	100.0 %

Study Variables The following variables were subjected to assessment

- **Malnutrition:** The assessment was conducted following the GLIM criteria (8), which entail the application of both phenotypic criteria (weight loss) and etiological criteria. The resulting classification was as follows: normonutrition, moderate malnutrition, and severe malnutrition.
- **Muscle mass and quality:** Ultrasonography was employed to assess the area in cm², adipose tissue depth in the rectus femoris ultrasound, and echogenicity using a Mindray ultrasound, following the methodology outlined by García-Almeida et al. (3).
- **Muscle mass at the L3 level:** The psoas index and skeletal mass index were employed to ascertain the aforementioned measurements, while myosteatosis was evaluated utilising Centricity Universal Viewer v7.0 SP1 0.3 (a radiology image management system at Castellón General Hospital). The system is manual, with measurements taken manually. All CT scans were performed with contrast.
- **Dynapenia:** Assessed using a JAMAR dynamometer, with dynapenia defined as a value below the 10th percentile based on Pizarra's cut-off points (12).

Objectives:

- **Primary:**
 - To compare the results of rectus femoris ultrasound in oncosurgical patients with skeletal mass index measured at L3 on CT, assessing the correlation between area in cm² and SMI.
 - To compare the results of rectus femoris ultrasound in oncosurgical patients with PMI measured at L3 on CT, assessing the correlation between area in cm² and PMI.
 - To analyse the most suitable cut-off, point for detecting low muscle mass using US, based on SMI cut-off points (1) (< 43 cm² in males with BMI < 25, <53 cm² if BMI > 25, and < 41 cm² in females regardless of BMI) and PMI cut-off points (2) (< 6.36 cm² for males and 3.92 cm² for females). The cut-off points proposed by Lisa Martin (13) were employed instead of those put forth by Carla Prado (1) due to the fact that the mean BMI of our sample was 23.7 ± 4.31 kg/m², and Prado et al.'s study was conducted in patients with BMI > 30 kg/m². In regard to PMI, the cut-off points proposed by Hamaguchi et al. (2) were employed in lieu of those put forth by Ufuk et al. (15), given that the findings documented in the latter article are not consistent with those delineated in the attached table.

- **Secondary:**

The objective is to assess the myosteatosis of PMI and SMI, as measured in Hounsfield units on contrast-enhanced CT using Centricity Universal Viewer v7.0 SP1 0.3, and to compare it with adipose tissue depth, as measured by rectus femoris muscle ultrasonography and rectus femoris muscle echogenicity.

Furthermore, the aim is to analyse the most suitable cut-off point for detecting sarcopenia using ultrasound and hand grip strength, in comparison to SMI and PMI.

Statistical Analysis:

The statistical analysis was conducted using the JAMOVI program (version 2.3.28). The regression analysis (correlation matrix) was employed with a positive hypothesis if the result was > 0.5 and the result was considered statistically significant if p<0.005. To identify the optimal cut-off, point that exhibited the highest sensitivity and specificity, binomial logistic regression prediction was utilized to construct ROC curves and AUC.

Results

Primary objectives: A total of 43 patients were included in the analysis, comprising 31 males (12 females) with a mean age of 64.7 ± 6.72 years and a mean BMI of 23.7 ± 4.31 kg/m², with a mortality rate of 25.6%. Of the 43 patients, 53 assessments were conducted, comprising 31 post-surgical assessments (21 pre-surgical) with a preponderance of radical cystectomies (34.6%) and hepatic surgeries (51.9%). Malnutrition was classified in accordance with the GLIM criteria (8) (measured based on a phenotypic criterion (weight loss) and an etiological criterion. The resulting classifications were norm nutrition, moderate malnutrition, and severe malnutrition. The results are presented in Figure 2.

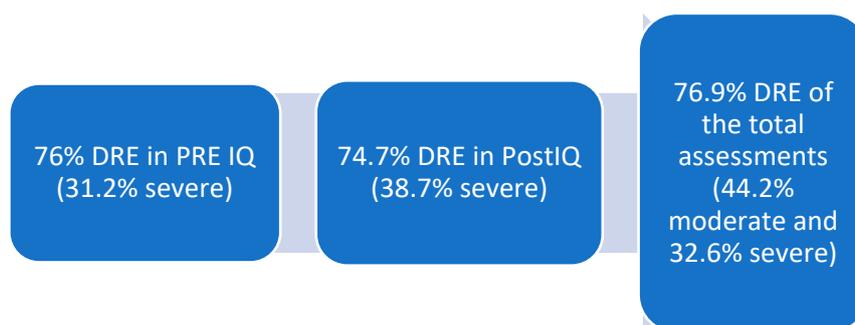


Figure 2. According to GLIM criteria in 53 assessments.

Ultrasound measurements

- Area: 2.96 cm² [2.47-4.2] *
- Adipose tissue depth: 0.55 cm [0.1-0.99] *

CT measurements

- SMI/height: 38.4 cm² [31.6-45.7], HU density: 272 [207-390]
 - PMI/height: 4.31 m² [3.71- 5.94], HU density in PMI: 86 [69-103]
- median-interquartile range

Table 3. Morpho-functional characteristics of the 53 assessments.

Descriptives										
	SEX	AGE	adipose tissue depth (mm)	BMI	SMI	SMI /height	PMI	PMI/height	hu SMI	HU PMI
N	43	43	43	43	43	43	43	43	42	42
Missing	0	0	0	0	0	0	0	0	1	1
Mean	1.28	64.7	0.605	23.5	102	36.3	12.3	4.39	288	85.3
Median	1	65	0.530	23.5	100	35.1	11.4	4.04	270	87.0
Standard deviation	0.454	6.72	0.484	4.41	26.1	7.45	3.76	1.11	135	24.3
IQR	1.00	10.0	0.855	6.40	40.5	11.8	6.65	1.96	167	35.0
Minimum	1	54	0.100	16.3	60.0	24.1	5.99	2.31	-142	37
Maximum	2	88	1.71	35.0	150	50.1	18.8	6.28	606	135
25th percentile	1.00	59.5	0.100	20.1	80.0	29.9	9.46	3.63	218	66.8
50th percentile	1.00	65.0	0.530	23.5	100	35.1	11.4	4.04	270	87.0
75th percentile	2.00	69.5	0.955	26.5	121	41.8	16.1	5.58	385	102

Note: The CT measurement method was manual, and all CT scans were performed with contrast.

Pearson's correlation coefficients were 0.700, 0.702, and 0.504 for US vs. SMI/height, SMI/height vs. PMI/height, and US vs. PMI (calculated by height), respectively. All correlations were statistically significant (see Table 4)

Table 4. Pearson correlation of ultrasound with SMI and PMI/height.

		AREA ECO	smi	SMI /ALT	PMI	PMI /ALT	DINAM
AREA ECO	Pearson's r	—					
	p-value	—					
	Spearman's rho	—					
	p-value	—					
	N	—					
smi	Pearson's r	0.620	—				
	p-value	< .001	—				
	Spearman's rho	0.596	—				
	p-value	< .001	—				
	N	52	—				
SMI /ALT	Pearson's r	0.700	0.931	—			
	p-value	< .001	< .001	—			
	Spearman's rho	0.699	0.926	—			
	p-value	< .001	< .001	—			
	N	52	52	—			
PMI	Pearson's r	0.548	0.787	0.752	—		
	p-value	< .001	< .001	< .001	—		
	Spearman's rho	0.473	0.790	0.708	—		
	p-value	< .001	< .001	< .001	—		
	N	52	52	52	—		
PMI /ALT	Pearson's r	0.567	0.700	0.750	0.969	—	
	p-value	< .001	< .001	< .001	< .001	—	
	Spearman's rho	0.502	0.702	0.704	0.950	—	
	p-value	< .001	< .001	< .001	< .001	—	
	N	52	52	52	52	—	

To ascertain the optimal cut-off points for low muscle mass, ROC curve analysis was conducted on US data, based on the established low muscle mass thresholds for SMI (1) and PMI (2). Cut-off points for low muscle mass were determined as 3.6 cm² for SMI/height (AUC 0.770, sensitivity 70%, specificity 100%) and 3.29 cm² for PMI/height (AUC 0.609, sensitivity 42.55%, specificity 100%) (see Figures 3 and 4 for ROC curves and Tables 5 and 6 for AUC values)

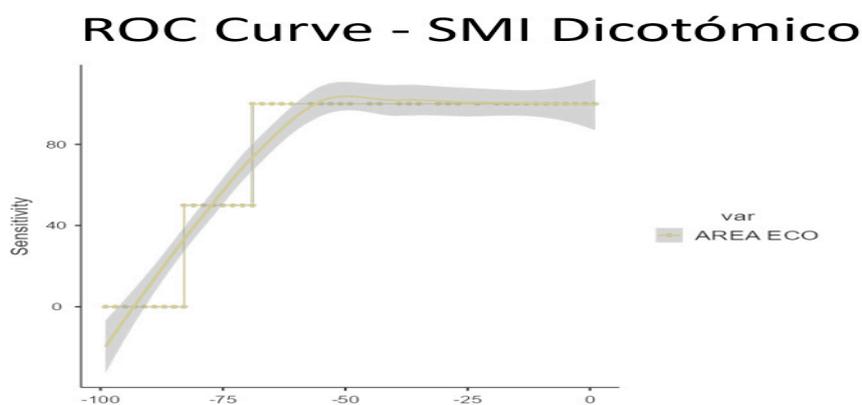


Figure 3. ROC curves for SMI.

Table 5. AUC for RCFSA compared to SMI.

Scale: AREA ECO							
Cutpoint	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Youden's index	AUC	Metric Score
3.26	100%	66%	10.53%	100%	0.660	0.770	0.660
3.29	100%	68%	11.11%	100%	0.680	0.770	0.680
3.6	100%	70%	11.76%	100%	0.700	0.770	0.700

ROC Curve - Psoas Index Dicotómico

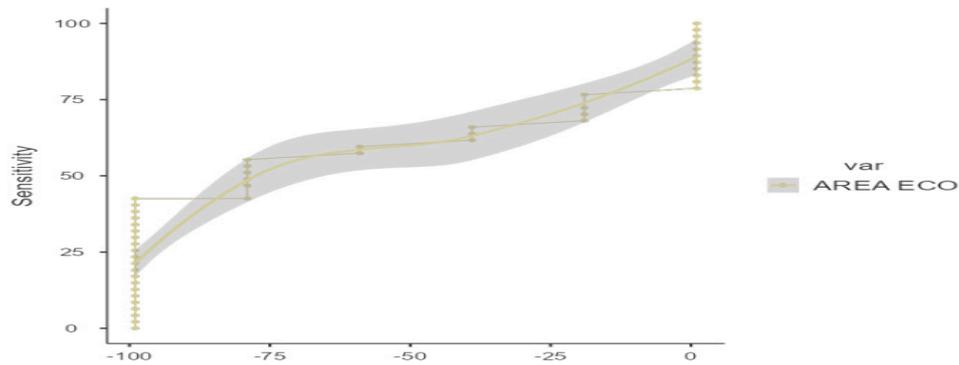


Figure 4. ROC curves for PMI.

Table 6. AUC for RCFSA compared to PMI.

Results							
Scale: AREA ECO							
Cutpoint	Sensitivit y (%)	Specificit y (%)	PPV (%)	NPV (%)	Youden's index	AUC	Metric Score
3.23	42.55 %	100%	100%	15.62 %	0.426	0.609	1.43
3.26	40.43 %	100%	100%	15.15 %	0.404	0.609	1.40
3.29	38.3 %	100%	100%	14.71 %	0.383	0.609	1.38

Secondary Objectives:

DYNAMOMETRY

With regard to dynamometry, only 32 out of 53 assessments were performed. The mean grip strength was 26.4 kg (19.7-36.3*), with 43.8% of the sample showing dynapenia (< p10) based on Pizarra's reference values (12). Meanwhile, the frequency of sarcopenia (14 out of 53 assessments: 26.7% of the sample) was 45.5% and 42.4%, respectively, according to the low muscle mass cut-offs for PMI and SMI.

A ROC curve analysis was performed on US, with a cut-off point for sarcopenia based on SMI of 3.23 cm², AUC 0.637, sensitivity 63.17%, and specificity 78.57% (Figure 5 and Table 7) and 3.12 cm² for PMI, AUC 0.543, sensitivity 55.56%, and specificity 66.67% (Figure 6 and Table 8)

Table 7. AUC for sarcopenia according to SMI.

Results

Scale: AREA ECO

Cutpoint	Sensitivit y (%)	Specificit y (%)	PPV (%)	NPV (%)	Youden's index	AUC	Metric Score
3.12	63.16 %	78.57 %	80%	61.11 %	0.417	0.637	1.42

ROC Curve - SMI para Sarcopenia

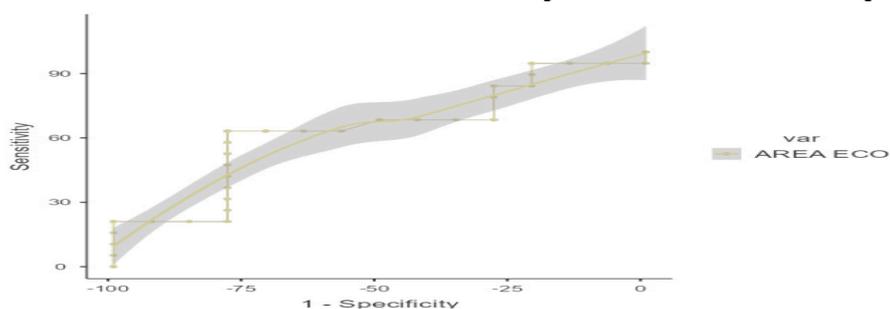


Figure 5. ROC curves for SMI and sarcopenia.

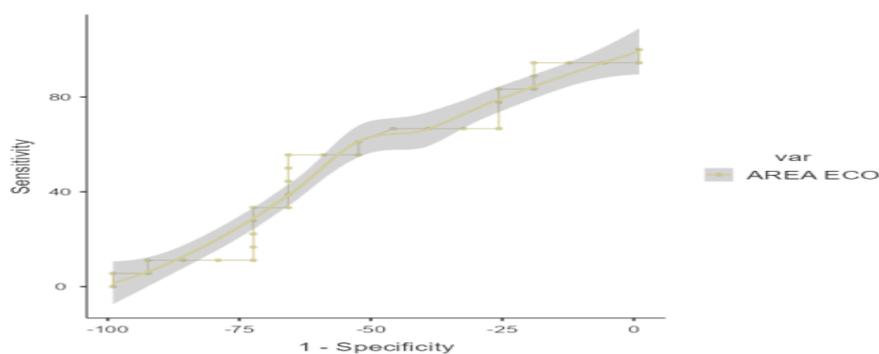


Figure 6. ROC curves for SMI and sarcopenia.

Table 8. AUC for sarcopenia according to PMI.

Results							
Scale: AREA ECO							
Cutpoint	Sensitivit y (%)	Specificit y (%)	PPV (%)	NPV (%)	Youden's index	AUC	Metric Score
3.12	55.56 %	66.67 %	66.67 %	55.56 %	0.222	0.543	1.22

MYOSTEATOSIS

Finally, the Pearson correlation between ultrasound-measured muscle adipose tissue (mioesteatosis) and the HU density of PMI and SMI was -0.133 (p 0.351) and -0.358 (p 0.020), respectively, and did not change after adjustment for BMI or height. The Pearson correlation between BMI and the depth of adipose tissue measured by ultrasound in the rectus femoris was 0.503 (p<0.001) (Table 9).

Table 9.

Correlation Matrix		adipose tissue depth (mm)	hu SMI	HU PMI	echogenicity	BMI
adipose tissue depth (mm)	Pearson's r	—				
	df	—				
	p-value	—				
	95% CI Upper	—				
	95% CI Lower	—				
	N	—				
hu SMI	Pearson's r	-0.234	—			
	df	40	—			
	p-value	0.135	—			
	95% CI Upper	0.075	—			
	95% CI Lower	-0.502	—			
	N	42	—			
HU PMI	Pearson's r	0.109	0.521 ***	—		
	df	40	40	—		
	p-value	0.494	< .001	—		
	95% CI Upper	0.399	0.712	—		
	95% CI Lower	-0.202	0.258	—		
	N	42	42	—		
echogenicity	Pearson's r	0.229	-0.099	0.093	—	
	df	41	40	40	—	
	p-value	0.140	0.531	0.558	—	
	95% CI Upper	0.495	0.211	0.386	—	
	95% CI Lower	-0.077	-0.391	-0.217	—	
	N	43	42	42	—	
BMI	Pearson's r	0.503 ***	-0.358 *	-0.027	0.119	—
	df	41	40	40	41	—
	p-value	< .001	0.020	0.867	0.448	—
	95% CI Upper	0.698	-0.061	0.280	0.405	—
	95% CI Lower	0.238	-0.597	-0.328	-0.188	—
	N	43	42	42	43	—

Note. * p < .05, ** p < .01, *** p < .001

Discussion

There is an increasing emphasis on the use of morpho-functional assessment to provide a comprehensive nutritional assessment. This global assessment is essential to complete the overall diagnosis of a patient and to enable personalised therapy. Traditionally, DEXA (especially in research), CT, and MRI have been considered the gold standards for assessing muscle mass; however, (16) these techniques have drawbacks such as difficulty in follow-up and patient exposure to radiation.

In recent years, strong correlations have been described between phase angle and bioelectrical impedance analysis (BIA)-derived body cell mass (BCM) and the rectus femoris cross-sectional area (RFCSA) (17, 18, 19). However, few studies have investigated the correlation between SMI measured at the third lumbar vertebra and RFCSA.

Paris et al. (20) compared SMI at L3 in 149 ICU patients and found a correlation of 0.45 ($p < 0.001$). Unlike our study, they used a semi-automated CT method (SliceOmatic 4.3 image analysis software) and measured rectus femoris thickness instead of RFCSA. Lambell et al. (21) included 50 ICU patients and, similar to Paris et al., compared SMI at L3 with muscle thickness, and found a correlation of 0.75 ($p < 0.001$). They also measured the sum of muscle thickness in the upper middle part of the arm and bilateral thighs. Finally, Fiorella Palmas et al. (22) included 147 patients with colorectal cancer and found a correlation of 0.67 ($p < 0.005$) between rectus femoris area and SMI measured using a semi-automated method, also using a semi-automated method for the interpretation of ultrasound images.

These results are consistent with those presented in this study, as the Pearson correlation was 0.70 between US and SMI/height, 0.750 between SMI/height and PMI/height, and 0.548 between US and PMI (calculated by height), all of which were statistically significant ($p < 0.001$).

According to the established values for low muscle mass for SMI (1) and PMI (2), a ROC curve analysis was performed on US, with a cut-off point for low muscle mass of 3.6 cm², AUC 0.770, sensitivity 70%, and specificity 100%, and 3.29 cm², AUC 0.609, sensitivity 42.55%, and specificity 100%, respectively. However, unlike the study by Palmas et al. (4), our study is the first to establish a cut-off point for ultrasonography compared to SMI and PMI based on ROC curves with a good AUC.

Regarding sarcopenia, the main results indicate that the ROC curve of the "dichotomous SMI for sarcopenia" showed a high specificity value of 100% with a cut-off point of 3.23, highlighting its ability to correctly identify patients without sarcopenia; while the "Psoas index for sarcopenia" showed moderate sensitivity and specificity values with a cut-off point of 3.12, reflecting a lower diagnostic capacity compared to other indices for sarcopenia.

Regarding intramuscular fat mass, in the present study there is a lack of correlation between myosteosis measured in HU density on CT compared to adipose tissue depth measured by rectus femoris ultrasonography (PMI r -0.040 and SMI r -0.133) and rectus femoris muscle echogenicity (r -0.075 and r 0.118 for SMI and PMI, respectively). This may be due to the method used (with Centricity Universal Viewer v7.0 SP1 0.3), which is a manual method and therefore the HU density varies depending on the amount of contrast used, as can be seen in the two figures (Figure 7. HU density PMI 70 / Figure 8. HU density -52).



Figure 7. CT cross section at L3. HU density PMI 70.



Figure 8. Cross section in L3 Density HU PMI -52.

This is in contrast to semi-automated methods (4) where the use or non-use of contrast does not affect the results.

The weaknesses of this study are important, as the use of a manual freehand method can lead to significant intra-observer measurement bias. In addition, the sample size is too small to assess differences between pre-surgical and post-surgical patients, by sex, and by pathology. For the assessment of myosteosis, a semi-automated or automated method is needed where the measurement of myosteosis is not affected by contrast.

Conclusion

Conclusions: There is a strong correlation between SMI, PMI, and the cross-sectional area in cm^2 measured by US in the rectus femoris according to the protocol of García-Almeida et al. (3). The good correlation between US and CT in our sample, with results similar to those published by Soria-Utrilla V et al. (4), suggests that ultrasonography may be a good alternative to CT for detecting low muscle mass. Our study is the first to establish a cut-off point for ultrasonography in comparison with SMI and PMI.

Further studies are needed with a semi-automated method are needed to avoid measurement bias and with a larger number of patients to establish pre-surgical and post-surgical cut-off points for cystectomy and hepatic surgery, as well as cut-off points by sex.

These new data would improve the prehabilitation of oncosurgical patients (hepatic surgery and radical cystectomy) with low muscle mass and dynapenia, as both US and dynamometry can be performed at the bedside on the same day. The pre-surgical cut-off point in patients undergoing radical cystectomy would also allow for a comparison of the number of complications according to the Dindo-Clavien classification in prehabilitated sarcopenic patients with retrospective series in which prehabilitation was performed (23, 24, 25).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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