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Ultrasound-Based Rectus Femoris and Parasternal Intercostal Muscle Thickness and Weaning Outcomes in Critically Ill Patients

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Abstract

Aim: To investigate the association between ultrasound-derived rectus femoris and parasternal intercostal muscle thickness and weaning outcomes in mechanically ventilated, critically ill patients, as well as their relationship with post-extubation non-invasive mechanical ventilation requirements and 28-day mortality.

Study Design: This prospective observational study included 69 mechanically ventilated adult patients undergoing spontaneous breathing trials in a medical intensive care unit. Demographic characteristics, clinical severity scores (modified Nutrition Risk in the Critically Ill [modified NUTRIC] score, Acute Physiology and Chronic Health Evaluation II [APACHE II], Sequential Organ Failure Assessment [SOFA], and Clinical Frailty Scale [CFS]), and ultrasonographic measurements of rectus femoris and parasternal intercostal muscle thickness were obtained at the 30th minute of the spontaneous breathing trial. Patients were classified into weaning success or failure groups based on the absence or presence of reintubation or death within seven days after extubation.

Results: The mean rectus femoris thickness was 6.93±2.31 mm in the weaning success group and 5.96±2.41 mm in the weaning failure group (p>0.05). Parasternal intercostal muscle thickness was 4.49±1.25 mm and 4.18±1.48 mm in the respective groups (p>0.05). Muscle thickness was not associated with weaning success; however, both rectus femoris and parasternal intercostal muscle thicknesses were significantly lower in non-survivors compared with survivors at 28 days. Reduced rectus femoris thickness was also associated with an increased requirement for post-extubation non-invasive mechanical ventilation. In addition, higher modified NUTRIC scores were associated with both weaning failure and 28-day mortality.

Conclusions: Ultrasound-based muscle thickness alone was not associated with weaning success; however, reduced rectus femoris and parasternal intercostal muscle thickness were associated with 28-day mortality and an increased requirement for post-extubation non-invasive mechanical ventilation. These findings suggest that ultrasound-based muscle assessment may provide useful prognostic insights for risk stratification in critically ill patients. Further multicenter studies are needed to validate standardized cut-off values and enhance clinical applicability.

Keywords: Critical illness; mechanical ventilation; mNUTRIC score; muscle thickness; parasternal intercostal; rectus femoris; sarcopenia; ultrasonography; weaning.

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Introduction

Liberation from mechanical ventilation represents a pivotal transition in the management of critically ill patients; however, failure to achieve successful discontinuation remains common, occurring in nearly one-quarter of cases, depending on the study population and the definitions used.[1,2] Unsuccessful weaning is associated with prolonged intensive care unit (ICU) stay, increased complications, and substantial mortality.[3] Although multiple physiological determinants influence weaning outcomes, respiratory muscle function and overall skeletal muscle integrity are among the most critical factors.[4]

ICU-acquired weakness and sarcopenia develop early during critical illness as a consequence of systemic inflammation, immobility, suboptimal nutrition, and multiorgan dysfunction.[5] These processes contribute to the rapid loss of both peripheral and respiratory muscle mass, frequently resulting in diaphragmatic dysfunction and subsequent difficulty in achieving ventilator independence.[6] Traditional indices such as the rapid shallow breathing index (RSBI) provide only modest predictive accuracy.[7] In contrast, diaphragm ultrasonography, despite its increasing use, remains limited by operator dependency, technical variability, and inconsistent cutoff values across heterogeneous ICU cohorts.[8]

Consequently, attention has shifted toward the evaluation of peripheral and accessory respiratory muscles. The rectus femoris is a major locomotor muscle that is highly susceptible to systemic muscle wasting, whereas the parasternal intercostals contribute directly to inspiratory effort and may reflect respiratory load. Both muscle groups can be assessed reproducibly at the bedside using ultrasonography. Previous research has shown associations between rectus femoris thickness and cross-sectional area and muscle strength, prolonged mechanical ventilation, and mortality.[9,10] Similarly, increased parasternal intercostal activity has been linked to diaphragmatic dysfunction and adverse respiratory outcomes.[11]

Ultrasound-based muscle evaluation provides a practical, repeatable, and radiation-free alternative to imaging modalities such as computed tomography and magnetic resonance imaging, while also offering patient-specific information relevant to clinical decision-making.[12] Beyond quantifying muscle mass, ultrasonography may improve early risk stratification in mechanically ventilated patients.

Based on this rationale, we hypothesized that reduced peripheral and respiratory muscle thickness would be associated with weaning difficulty and adverse short-term outcomes. Accordingly, this study aimed to investigate the association between rectus femoris and parasternal intercostal muscle thickness and weaning success, post-extubation non-invasive mechanical ventilation requirements, and 28-day mortality among critically ill patients receiving mechanical ventilation.

Materials and Methods

Study Design and Patient Population

This prospective observational study included all intubated adults (≥18 years) admitted to the Medical Intensive Care Unit (ICU) of Marmara University School of Medicine between August 2024 and May 2025. In mechanically ventilated patients with an inspired oxygen fraction (FiO_2)<50%, positive end-expiratory pressure (PEEP)≤5 cmH_2O, no vasopressor requirement or norepinephrine<0.2 μg/kg/min, and a rapid shallow breathing index (RSBI)<105, daily spontaneous breathing trials (SBTs) were performed to assess readiness for liberation from mechanical ventilation.

Weaning Protocol

Eligible patients underwent spontaneous breathing trials using either pressure support ventilation with a pressure support of 7 cmH_2O and a positive end-expiratory pressure of 5 cmH_2O, or a T-piece system delivering supplemental oxygen without pressure support. Each spontaneous breathing trial was conducted for 30 minutes. The choice of spontaneous breathing trial modality was left to the discretion of the treating clinician, based on patient characteristics and clinical judgment, as both approaches are routinely used in daily practice and recommended by current weaning guidelines. Patients who fulfilled the predefined spontaneous breathing trial success criteria were extubated and considered weaned.

Successful weaning was defined according to established criteria: extubation without death or reintubation within the subsequent 7 days (regardless of whether post-extubation non-invasive ventilation was applied), or discharge from the ICU without invasive mechanical ventilation within 7 days, whichever occurred first. This standardized definition ensured consistency in outcome assessment and allowed reliable comparison with prior studies.[13]

Patients were categorized into weaning success and weaning failure groups based on the occurrence of reintubation or death within 7 days after extubation.

Post-extubation non-invasive mechanical ventilation (NIMV) was initiated in patients who developed signs of respiratory distress after extubation, including increased work of breathing, tachypnea, hypercapnia, or hypoxemia despite conventional oxygen therapy.

Ultrasound Assessment

Ultrasound measurements of rectus femoris and parasternal intercostal muscle thickness were obtained at the 30th minute of the spontaneous breathing trial. All examinations were performed using an Esaote MyLab™ Seven device by a single intensivist with formal certification in critical care ultrasonography, more than five years of experience, and active involvement in ultrasound training programs, thereby ensuring consistency and minimizing interobserver variability. Measurements were performed with patients in the supine position and with the head of the bed elevated to approximately 30°. For rectus femoris assessment, the lower extremities were positioned in passive extension and neutral rotation. A high-frequency linear transducer (7–13 MHz) was used for all measurements, and care was taken to avoid excessive probe pressure to prevent muscle compression. Measurements were obtained on the right side only for both the rectus femoris and parasternal intercostal muscles to enhance procedural standardization and feasibility in the critical care setting.

All ultrasound measurements were obtained during the spontaneous breathing trial under standardized ventilatory conditions. At the time of ultrasonographic assessment, patients were either breathing through a T-piece without pressure support or receiving pressure support ventilation with a pressure support level of 7 cmH_2O and a positive end-expiratory pressure of 5 cmH_2O, in accordance with the study protocol. All patients met the predefined criteria for spontaneous breathing trials, including an inspired oxygen fraction below 50%.

Rectus Femoris Measurement

A straight line was drawn between the anterior inferior iliac spine (AIIS) and the superior border of the patella. Using a high-frequency linear transducer in B-mode, measurements were obtained at the midpoint of this line. Each measurement was performed three times, and the mean value was recorded.[14]

Parasternal Intercostal Measurement

The probe was positioned at the right second intercostal space, 6–8 cm lateral to the sternal border. With a high-frequency linear transducer held longitudinally in B-mode, parasternal thickness was measured at the thickest point of the mid-portion of the muscle. Each measurement was repeated three times, and the average value was used for analysis.[15]

Sample Size and Power Analysis

Prior to data collection, an a priori power analysis was performed using G*Power (version 3.1.9.7). The calculation was based on the primary comparison between patients with weaning success and weaning failure in terms of rectus femoris muscle thickness. Assuming a two-sided α of 0.05, 80% power, and a moderate effect size (Cohen's d=0.5), the required sample size was estimated to be 55 participants, assuming approximately equal group allocation. In the absence of well-established reference values for this population, a moderate effect size was selected a priori as a pragmatic assumption for sample size estimation. To account for potential exclusions and missing data, a higher enrollment target was planned. The final analyzable cohort consisted of 69 patients, exceeding the minimum requirement and maintaining at least 80% statistical power for the primary comparison.

Variables Assessed

The following parameters were collected: demographic variables (age, sex), comorbidities, body mass index (BMI), Sequential Organ Failure Assessment (SOFA) and Acute Physiology and Chronic Health Evaluation II (APACHE II) scores assessed at ICU admission and at the time of weaning; modified Nutrition Risk in the Critically Ill (modified NUTRIC) score and Clinical Frailty Scale (CFS) assessed at ICU admission; Charlson Comorbidity Index; reason for ICU admission; rectus femoris and parasternal intercostal muscle thickness; serum albumin level at hospital admission; ICU length of stay; 28-day mortality; requirement for post-extubation NIMV or high-flow nasal cannula (HFNC); and weaning outcome.

Severity and nutritional risk scores were calculated according to previously validated definitions.[16,17,19]

Sepsis was defined as sepsis present at ICU admission, in accordance with the Sepsis-3 criteria, i.e., suspected or documented infection accompanied by an acute increase of ≥2 points in the SOFA score.[18]

Frailty was assessed using the CFS, a 9-point scale that evaluates baseline functional status prior to acute illness, with higher scores indicating greater frailty, as originally described by Rockwood et al.[20]

The primary outcome of the study was weaning success or failure. Secondary outcomes included post-extubation non-invasive ventilation requirement and 28-day mortality.

Twenty-eight-day mortality was defined as death from any cause occurring within 28 days following extubation. Mortality data were obtained from the hospital electronic medical record system and, when applicable, verified using the national death registry.

Eligibility Criteria

Patients were eligible for inclusion if they were admitted to the Medical Intensive Care Unit of Marmara University School of Medicine, were aged ≥18 years, and had received invasive mechanical ventilation for at least 24 hours. Patients were excluded if they had been intubated for more than 24 hours prior to ICU admission, experienced self-extubation, received neuromuscular blocking agents during the ICU stay, declined participation, had a history of endotracheal intubation within the preceding 6 months, or had a tracheostomy in place before or performed during the study period. The process of patient screening, enrollment, and exclusion is summarized in the flow diagram presented in Figure 1.

Ethics Approval

This study was approved by the Marmara University School of Medicine Clinical Research Ethics Committee (Approval Number: 09.2024.749; Date: 19.07.2024). Written informed consent was obtained from the legally authorized representatives of all included patients. The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki.

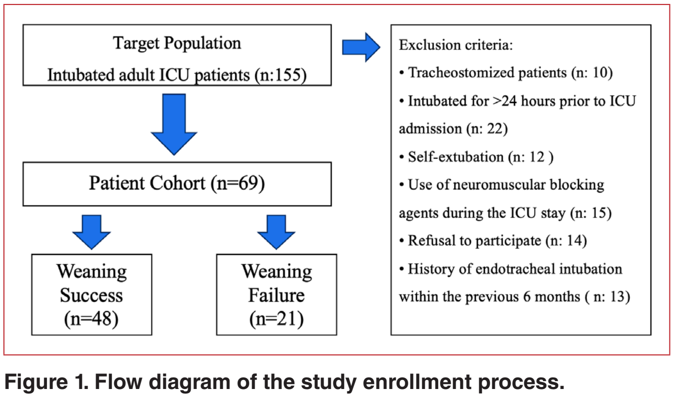

Figure 1. Flow diagram of the study enrollment process.

Statistical Analysis

All statistical analyses, data management, visualization, and reporting were performed using R software (version 4.4.2; R Foundation for Statistical Computing, Vienna, Austria). The R6 package was used to create reusable object-oriented structures that supported modular and flexible analytical workflows, rstatix facilitated the streamlined execution of statistical tests, and flextable was used to generate publication-ready summary tables formatted according to journal standards.

Numerical variables were first assessed for normality using the Shapiro–Wilk test, after which appropriate statistical methods were selected based on distributional characteristics. For normally distributed variables, comparisons between two groups were performed using the independent-samples t-test, and one-way analysis of variance (ANOVA) was used for comparisons involving more than two groups. For non-normally distributed variables, the Wilcoxon rank-sum test was used for two-group comparisons, and the Kruskal–Wallis test was used for comparisons involving more than two groups.

Categorical variables were analyzed using Pearson's chi-square test when expected cell counts were ≥5; otherwise, Fisher's exact test was applied.

Correlation analyses were conducted to evaluate associations between continuous variables. Pearson's correlation coefficient was used for normally distributed variables with linear relationships, whereas Spearman's rank correlation coefficient or Kendall's tau was preferred for non-normal distributions, monotonic associations, or small sample sizes (<30).

RESULTS

A total of 69 patients were included in the analysis, of whom 41 (59.4%) were male, with a median age of 73 years (IQR: 66–79). The most common comorbidities were hypertension (49.3%), diabetes mellitus (37.7%), and chronic obstructive pulmonary disease (COPD) (26.1%). Pulmonary causes constituted the leading reason for ICU admission (62.3%) and included acute exacerbation of COPD, community-acquired pneumonia, hospital-acquired pneumonia, acute respiratory distress syndrome, and other acute respiratory conditions. Postoperative conditions accounted for 17.4% of admissions, while cardiovascular diseases represented 10.1%. COPD was recorded both as a comorbidity and, when applicable, as the primary reason for ICU admission, and was additionally reported as a separate category because of its clinical relevance and high prevalence in the study population. The median ICU length of stay was 13 days (IQR: 8–23). Baseline demographic, clinical, and ultrasonographic characteristics stratified by weaning outcome are summarized in Table 1.

Following spontaneous breathing trials and subsequent extubation, patients were monitored for 7 days. During this period, 21 patients (30.4%) experienced weaning failure, whereas 48 patients (69.6%) were successfully weaned. At 28 days following extubation, 24 patients (34.8%) had died, while 45 patients (65.2%) remained alive. Twenty-eight-day mortality was assessed as a secondary outcome and was defined independently of weaning success or failure.

The mean rectus femoris muscle thickness in the overall cohort was 6.63±2.37 mm. Rectus femoris thickness did not differ significantly between patients with successful and failed weaning (6.93±2.31 mm vs. 5.96±2.41 mm, respectively; p=0.116). Similarly, parasternal intercostal muscle thickness was comparable between the weaning success and failure groups (4.49±1.25 mm vs. 4.18±1.48 mm, respectively; p=0.369). These findings indicate that static measurements of peripheral and accessory respiratory muscle thickness were not associated with short-term weaning outcomes (Table 1).

In contrast, both rectus femoris and parasternal intercostal muscle thickness were significantly lower in non-survivors compared with survivors at 28 days. Mean parasternal intercostal muscle thickness was 4.65±1.35 mm in survivors and 3.92±1.13 mm in non-survivors (p=0.027). Likewise, rectus femoris muscle thickness was significantly reduced in non-survivors compared with survivors (5.50±1.62 mm vs. 7.24±2.49 mm, respectively; p=0.003). These results are presented in Table 2.

Table 1. Baseline demographic, clinical, and ultrasonographic characteristics of the study population according to weaning outcome

	All patients (n=69)	Weaning success (n=48)	Weaning failure (n=21)	p
Demographic and baseline clinical characteristics				
Age, years, median (IQR)	73 (66–79)	72 (65–78)	75 (67–81)	0.258
Male sex, n (%)	41 (59.4)	27 (56.3)	14 (66.7)	0.41
BMI, mean±SD	24.7±4.2	24.6±4.1	24.9±4.3	0.43
Reasons for ICU admission, n (%)				
Pulmonary cause of ICU admission	43 (62.3)	30 (62.5)	13 (61.9)	0.85
Sepsis at ICU admission	12 (17.4)	7 (14.6)	5 (23.8)	0.36
Comorbidities, n (%)				
Malignancy	16 (23.2)	9 (18.8)	7 (33.3)	0.18
Chronic obstructive pulmonary disease (COPD)	18 (26.1)	12 (25.0)	6 (28.6)	0.72
Chronic kidney disease	11 (15.9)	7 (14.6)	4 (19.0)	0.63
Severity, frailty, and nutritional risk scores				
SOFA score, median (IQR)	6 (3–8)	5 (3–6.25)	8 (6–10)	0.006
APACHE II score, median (IQR)	12 (9–20)	12 (7–16.25)	19 (12–30)	0.006
Modified NUTRIC score, median (IQR)	4 (3–6)	4 (3–5)	6 (5–7)	<0.001
Clinical Frailty Scale score, median (IQR)	6 (4–7)	5 (3–7)	6 (4–7)	0.19
Charlson Comorbidity Index, median (IQR)	6 (4–8)	6 (3.75–8)	6 (4–8)	0.53
ICU course and ultrasonographic measurements				
ICU length of stay, days, mean±SD	15.9±9.6	15.3±8.9	16.9±10.7	0.60
Rectus femoris thickness, mm, mean±SD	6.63±2.37	6.93±2.31	5.96±2.41	0.116
Parasternal intercostal thickness, mm, mean±SD	4.40±1.32	4.49±1.25	4.18±1.48	0.369

BMI: body mass index; SOFA: Sequential Organ Failure Assessment; APACHE II: Acute Physiology and Chronic Health Evaluation II; COPD: Chronic obstructive pulmonary disease; NUTRIC: Nutrition Risk in the Critically Ill; ICU: intensive care unit.

Table 2. Relationship between muscle thickness and 28-day mortality

	All patients (n=69)	Survivors (n=45)	Non-survivors (n=24)	p
Parasternal intercostal muscle thickness, mm, mean±SD	4.40±1.32	4.65±1.35	3.92±1.13	0.027
Rectus femoris muscle thickness, mm, mean±SD	6.63±2.37	7.24±2.49	5.50±1.62	0.003

RF: rectus femoris; PI: parasternal intercostal.

Correlation analyses further characterized the relationships between muscle thickness and clinical variables. Parasternal intercostal muscle thickness demonstrated a weak positive correlation with body mass index (ϱ=0.328, p=0.006) and weak negative correlations with frailty score (ϱ=–0.287, p=0.017) and 28-day mortality (ϱ=–0.261, p=0.031). No significant association was observed between parasternal intercostal muscle thickness and the modified NUTRIC score. Rectus femoris muscle thickness showed a moderate positive correlation with body mass index (ϱ=0.418, p<0.001) and a moderate negative correlation with frailty score (ϱ=–0.392, p=0.001). In addition, rectus femoris thickness demonstrated a weak negative correlation with 28-day mortality (ϱ=–0.334, p=0.005). No significant correlations were observed between rectus femoris thickness and ICU length of stay, hospital length of stay, SOFA score, APACHE II score, or Charlson Comorbidity Index. Correlation analyses are summarized in Table 3.

Post-extubation non-invasive mechanical ventilation was required in a subset of patients following weaning. Rectus femoris muscle thickness was significantly lower in patients who required post-extubation NIMV compared with those who did not (5.60±2.11 mm vs. 6.97±2.37 mm, respectively; p=0.037). In contrast, parasternal intercostal muscle thickness did not differ significantly between patients who required NIMV and those who did not (4.23±0.87 mm vs. 4.45±1.44 mm, respectively; p=0.566). These findings are shown in Table 4. High-flow nasal cannula was used as post-extubation respiratory support in a limited number of patients; however, due to the small sample size, these patients were not analyzed as a separate subgroup.

Table 3. Correlation between muscle thickness and clinical parameters

Parameter	Parasternal intercostal thickness (r)	p	Rectus femoris thickness (r)	p
ICU length of stay, days	-0.102	0.404	-0.105	0.388
SOFA score	0.027	0.825	-0.065	0.594
Charlson Comorbidity Index	-0.213	0.079	-0.146	0.231
Body mass index	0.328	0.006	0.418	<0.001
Modified NUTRIC score	-0.167	0.169	-0.230	0.057
APACHE II score at weaning	0.029	0.811	-0.177	0.145
APACHE II score at admission	0.021	0.845	-0.026	0.830
Clinical Frailty Scale score	-0.287	0.017	-0.392	0.001
28-day mortality	-0.261	0.031	-0.334	0.005

SOFA: Sequential Organ Failure Assessment; BMI: body mass index; APACHE II: Acute Physiology and Chronic Health Evaluation II; ICU: intensive care unit , mNUTRIC: modified Nutrition Risk in the Critically Ill score; RF: rectus femoris; PI: parasternal intercostal.

Table 4. Relationship between muscle thickness measurements and post-weaning NIMV requirement

	All patients (n=69)	No NIMV requirement (n=52)	NIMV requirement (n=17)	p
Parasternal intercostal muscle thickness, mm, mean±SD	4.40±1.32	4.45±1.44	4.23±0.87	0.566
Rectus femoris muscle thickness, mm, mean±SD	6.63±2.37	6.97±2.37	5.60±2.11	0.037

RF: rectus femoris; PI: parasternal intercostal; NIMV: non-invasive mechanical ventilation.

Discussion

In this prospective observational study, we investigated whether ultrasound-derived measurements of rectus femoris and parasternal intercostal muscle thickness were associated with weaning outcomes and short-term prognosis in mechanically ventilated, critically ill patients. Our results demonstrate that, while static muscle thickness measurements were not predictive of weaning success, reduced rectus femoris thickness was significantly associated with both an increased requirement for post-extubation NIMV and higher 28-day mortality. These findings suggest that peripheral and accessory respiratory muscle depletion, detectable through bedside ultrasonography, reflects global physiological vulnerability rather than immediate weaning performance.

Weaning failure remains a multifactorial clinical challenge, affecting approximately one-quarter of critically ill patients despite the implementation of structured weaning protocols.[1–3,13] Among the physiological determinants of weaning outcomes, respiratory muscle dysfunction, particularly ventilator-induced diaphragmatic atrophy, is well recognized.[4,6,8] However, diaphragm ultrasonography is limited by operator dependency, technical variability, and the absence of universally accepted cutoff values.[8] These limitations have led to increasing interest in alternative ultrasound-based indices that may better reflect overall muscle health and physiological reserve.

ICU-acquired weakness and sarcopenia develop rapidly during critical illness as a consequence of systemic inflammation, immobility, and inadequate nutritional intake.[5,10] Muscle mass loss may exceed 20% within the first week of ICU admission.[10] This loss affects both locomotor and respiratory muscles and contributes to impaired ventilatory mechanics and persistent respiratory insufficiency.[9–11] The rectus femoris, as a large and metabolically active locomotor muscle, has been proposed as a reliable surrogate marker of global muscle wasting.[14] In contrast, the parasternal intercostal muscles contribute directly to inspiratory effort and may become increasingly recruited when diaphragmatic function is compromised.[11,15]

In our cohort, neither rectus femoris nor parasternal intercostal muscle thickness discriminated between successful and failed weaning. This finding is consistent with previous studies demonstrating that single, static muscle measurements have limited predictive value for extubation readiness.[21,22] Weaning and extubation outcomes are influenced by multiple factors beyond muscle mass, including airway protection, secretion clearance, cardiovascular reserve, and the occurrence of unexpected post-extubation complications, none of which are captured by static ultrasound measurements alone.

The very low mean rectus femoris thickness observed in our study population (6.63 mm), which is substantially below the sarcopenia screening thresholds reported in prior studies (typically 11–16 mm depending on age and sex), likely reflects the advanced age and substantial disease burden of our cohort.[14–21] Furthermore, thickness-based assessments may underestimate the true extent of muscle atrophy compared with cross-sectional area measurements and may not fully reflect functional impairment or contractile capacity.[23,24] These methodological considerations may partly explain why static muscle thickness failed to differentiate weaning success from failure.

Similarly, static parasternal intercostal muscle thickness was not associated with weaning outcomes or post-extubation NIMV requirement in our cohort. Previous investigations suggest that dynamic parasternal measurements, particularly the thickening fraction, are more closely linked to respiratory load and adverse outcomes than static thickness alone.[15,25] The parasternal muscles are small, anatomically constrained by rib shadowing, and lack validated reference values, all of which may limit the sensitivity of static measurements. Dynamic indices may therefore offer superior prognostic value and warrant further investigation.[26]

In contrast to weaning outcomes, both rectus femoris and parasternal intercostal muscle thickness demonstrated significant inverse associations with 28-day mortality. These findings align with extensive literature identifying skeletal muscle mass as a robust predictor of mortality in critically ill patients.[10,14,23] Muscle depletion reflects global catabolism, systemic inflammation, and metabolic exhaustion, which collectively reduce physiological reserve and impair the ability to adapt to acute stressors.[26] In this context, ultrasound-based muscle assessment may serve as a practical bedside tool for the early identification of high-risk patients, particularly older adults who are more susceptible to sarcopenia-related adverse outcomes.

A clinically meaningful finding of our study was the association between reduced rectus femoris thickness and an increased post-extubation NIMV requirement.

Non-invasive mechanical ventilation has been shown to reduce the risk of post-extubation respiratory failure in selected patients.[27,28] This is particularly relevant for those with advanced age, comorbidities, high illness severity, or respiratory muscle impairment.[29,30] In our cohort, diminished rectus femoris thickness may reflect generalized muscle weakness, reduced cough effectiveness, and limited respiratory reserve, thereby explaining the increased reliance on NIMV following extubation.

To further explore this observation, we performed a secondary analysis in which post-extubation NIMV requirement was reclassified as a form of weaning difficulty. This approach revealed stronger associations between muscle weakness and adverse outcomes, suggesting that NIMV requirement may represent an intermediate phenotype between successful weaning and overt weaning failure. Although the Weaning according to a New Definition (WIND) classification does not define NIMV use as weaning failure unless reintubation or death occurs within seven days,[13] accumulating evidence indicates that patients requiring NIMV after extubation remain at increased risk of clinical deterioration.[31,32] Future studies should evaluate whether incorporating post-extubation NIMV requirement into weaning outcome definitions improves prognostic stratification and clinical decision-making.

Limitations

This study has several limitations. It was conducted at a single center, which may limit the generalizability of the findings. Ultrasound assessments were performed at a single time point and did not include dynamic measurements such as diaphragm or parasternal intercostal thickening fractions. In addition, receiver operating characteristic analyses and cutoff values were not determined, as the study was not designed to derive or validate diagnostic thresholds. Given the relatively small sample size and limited number of outcome events, such analyses would carry a substantial risk of overfitting and have limited external validity. Finally, the duration of invasive mechanical ventilation was not systematically recorded and therefore could not be included in the analysis.

Conclusion

Although rectus femoris and parasternal intercostal muscle thickness did not predict weaning success, reduced rectus femoris thickness was associated with an increased requirement for post-extubation non-invasive mechanical ventilation, and both muscle groups demonstrated significant negative associations with 28-day mortality. These findings suggest that ultrasound-based skeletal muscle assessment may provide valuable prognostic information in critically ill patients beyond conventional weaning outcomes. Incorporating post-extubation non-invasive mechanical ventilation requirement into the evaluation of weaning outcomes may improve risk stratification. Future multicenter studies are warranted to validate these findings and establish standardized cutoff values and dynamic muscle indices to enhance clinical applicability.

Ethics Committee Approval: Ethics committee approval was obtained from Marmara University School of Medicine Clinical Research Ethics Committee (Approval Number: 09.2024.749; Date: 19.07.2024).

Informed Consent: Written informed consent was obtained from the legally authorized representatives of all included patients.

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