ORIGINAL ARTICLE

Risk Factors of Decreased Abdominal Expiratory Muscle Thickness in Mechanically Ventilated Critically Ill Patients—The mNUTRIC Score is an Independent Predictor

Vishwas P[1], Vedaghosh Amara[2], Sagar Shanmukhappa Maddani[3], Souvik Chaudhuri[4], Suvajit Podder[5]

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Abstract

Background: The expiratory abdominal skeletal muscles are an important component of the respiratory muscle pump, and their reduced thickness has been associated with difficult weaning. There is no objective score that may help clinicians to predict expiratory abdominal muscle thinning.

Patients and methods: This was a single-center retrospective study on 81 patients undergoing weaning from mechanical ventilation. The thickness of the four abdominal expiratory muscles—rectus abdominis (RA), internal oblique (IO), external oblique (EO), and transversus abdominis (TA) on the day of the first spontaneous breathing trial (SBT), was obtained. The various parameters of the patients with thinner RA, IO, EO, and TA below the determined thickness cut-off values, predicting difficult weaning was analyzed.

Results: Modified nutritional risk in critically ill (mNUTRIC) score was found to be an independent predictor of thinner IO muscle after logistic regression analysis [$p = 0.001$, adjusted OR 2.33, 95% CI (1.394–3.892)]. The mNUTRIC score was also an independent predictor of thinner EO ($p = 0.014$, adjusted OR 1.57) and RA muscle ($p = 0.002$, adjusted OR 1.69). The mNUTRIC cutoff score ≥4 predicted thinner IO (AUC 0.813, $p < 0.001$ sensitivity 71%, specificity 77%) and thinner EO (AUC 0.738, $p < 0.001$, 71% sensitivity, 67% specificity). The mNUTRIC score ≥3 predicted that at least one out of the four abdominal expiratory muscles will be thin (AUC 0.849, $p < 0.001$, 95% CI [0.763–0.935], sensitivity 87.5%, specificity 59%).

Conclusion: The mNUTRIC score is an independent predictor of thinner abdominal expiratory muscles in mechanically ventilated critically ill patients.

Keywords: Abdominal expiratory muscle thickness, Internal oblique muscle, mNUTRIC score.

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Highlights

This study evaluated risk factors of thinner abdominal expiratory muscles, which are an important component of respiratory muscle pump to aid in weaning. The study identified the mNUTRIC score being an independent risk factor for predicting a thin abdominal expiratory muscle.

Introduction

Thinner abdominal expiratory muscles – RA, EO, IO, and TA have been associated with difficult weaning.[1] An adequately thick IO was found to have the highest diagnostic accuracy to predict simple weaning, followed by the EO, RA, and TA.[1] Since up to 53% of mechanically ventilated patients invariably have some degree of diaphragmatic dysfunction (DD) within 24 hours of ventilation, and overall 80% develop DD, the abdominal expiratory muscles assume greater significance in aiding successful weaning.[2–4] The thickness of a muscle correlates to the pressure generated during the contraction phase of the muscle, and thus a thicker muscle may generate a greater force of contraction.[5] Though there are studies on predictors of DD in critically ill patients, there is a scarcity of literature on the risk factors predicting thinner abdominal expiratory muscles.[4,6]

Though sepsis, multiorgan failure, immobilization, and inflammatory processes have been said to be risk factors of DD and skeletal muscle dysfunction in the critically ill, there is no easily computable objective scoring system to help intensivists assess the risk of abdominal expiratory muscle thinning, which forms a significant component of respiratory muscle pump.[6,7]

[1-4]Department of Critical Care Medicine, Kasturba Medical College, Manipal Academy of Higher Education, Manipal, Karnataka, India

[5]Department of Anaesthesiology, Kasturba Medical College, Manipal Academy of Higher Education, Manipal, Karnataka, India

Corresponding Author: Souvik Chaudhuri, Department of Critical Care Medicine, Kasturba Medical College, Manipal Academy of Higher Education, Manipal, Karnataka, India, Phone: +91 9937178620, e-mail: souvikchaudhuri1207@gmail.com

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Aim

To determine the risk factors affecting abdominal expiratory muscle thickness (RA, EO, IO, and TA) measured by ultrasound during the first SBT. The primary objective was to determine the independent predictors for at least one out of the four abdominal expiratory muscles being thinner than the predetermined cutoff predicting difficult weaning. The secondary objective was to determine if a thinner abdominal expiratory muscle (at least one out of four muscles) is associated with more intensive care unit (ICU) days of stay.

Materials and Methods

Study Design and Setting

This was a single-center retrospective study where the medical records were retrieved from April 1st 2022 to August 20th 2022.

Ethics

Prior to initiation of the retrospective study, Institutional Ethics Committee approval was taken (IEC:759/2021) and was registered with Clinical Trials Registry-India (CTRI/2022/03/041278). Since it was a retrospective study, the requirement of consent was waived by the Ethics committee.

Sample Size

The 81 adult patients were included in the previous prospective study by the same investigators as this study, titled "Evaluation of abdominal expiratory muscle thickness pattern, diaphragmatic excursion, and lung ultrasound score in critically ill patients and their association with weaning patterns: a prospective observational study." The previous prospective study had ethical clearance (IEC 465/2020) with CTRI registration (CTRI/2020/11/028895) and was conducted from 8th November 2020 to 1st April 2021. *Post-hoc* power calculation was done as follows:[8] the mean and standard deviation (SD) of the independent predictor of at least one out of four abdominal expiratory muscles {modified Nutritional Risk in Critically ill (mNUTRIC) score in our study} was considered between the two groups—group one with at least one out of four abdominal expiratory muscles being thin ($n = 64$), and group two without any one out of four abdominal expiratory muscles being thin ($n = 17$). The mean $\pm$ SD of the mNUTRIC score was 4.52 $\pm$ 1.85 and 2.29 $\pm$ 0.98 cm, respectively.

Post-hoc power $= \Phi\,[-Z_{1-\alpha/2} + \delta / (\sqrt{\sigma_1}^2/n_1 + (\sqrt{\sigma_2}^2/n_2)]$,[8] where Φ = function converting the Z value to a *post-hoc* power, $Z = 1.96$ for 95% confidence interval (CI), Δ = absolute difference between the means of the two groups (4.52–2.29 = 2.23), σ_1 = standard deviation (SD) of group one, σ_2 = SD of group two, n_1 = number pf patients in group one, and n_2 = number pf patients in group two.

The *post-hoc* power was calculated to be 99.9%.

Inclusion Criteria

Patients who were mechanically ventilated in ICU met the following criteria for SBT for the first time for weaning were included: Fraction of inspired oxygen (FiO_2 <0.5), positive end-expiratory pressure (PEEP) ≤5 cm H_2O, partial pressure of oxygen in arterial blood (PaO_2)/FiO_2 >150 mm Hg, respiratory rate <35/minute, tidal volume >5 mL /kg, and minute ventilation <10 L/min. No abnormality in electrolyte parameters, absence of hemodynamic instability, resolution of the initial cause of ventilator requirement, and patients awake with the ability to cough on the day of the first SBT.

Exclusion Criteria

Patients <18 years, patients with chest, distorted chest wall anatomy, patients with any known neuromuscular weakness, patients with any known diaphragmatic disorders, and pregnant women.

Patients and Methods

The data of patients of the previously done prospective observational study were accessed after separate IEC and CTRI approval.[1] The data included the abdominal expiratory muscle thickness on the day of the first SBT in mechanically ventilated patients, as measured by bedside ultrasound. The thickness of the four abdominal expiratory muscles – RA, EO, IO, and TA was noted on the day of the first SBT. For the measurement of RA muscle thickness by ultrasound, the method is to place the linear ultrasound probe in a horizontal fashion about 3 cm above the umbilicus and 3 cm away from the midline (Fig. 1). For the measurement of EO, IO, and TA muscles' thickness by ultrasound, the method is to place the linear ultrasound probe in a horizontal fashion in the anterior axillary line, at the midpoint between the costal margin and the iliac crest, as described by Shi et al. (Fig. 2).[2] Each of the four muscles was classified from the previous study as being thin (below the cutoff thickness determined in the previous prospective study for predicting difficult weaning), or as thick (above the cutoff thickness determined in the previous prospective study for predicting simple weaning).[1] The cutoff values for classifying the abdominal muscles

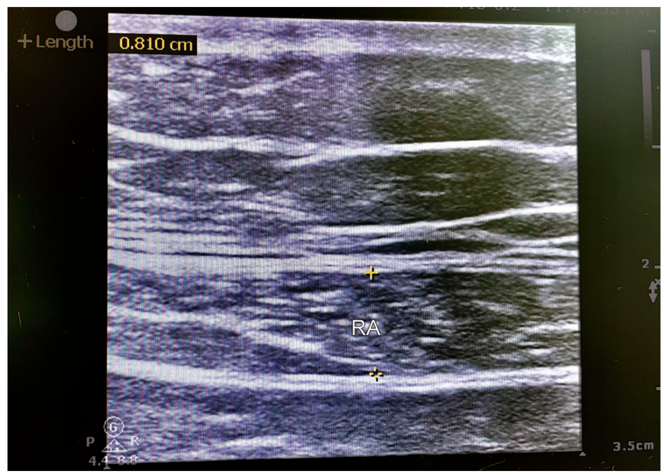

Fig. 1: Ultrasound image in a patient showing the thickness of the rectus abdominis (RA) muscle

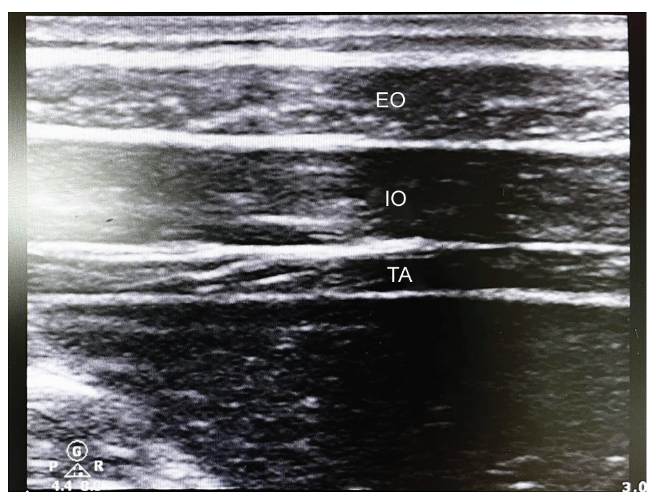

Fig. 2: Ultrasound image in a patient depicting the thickness of the external oblique (EO), internal oblique (IO), and the transversus abdominis (TA) muscle

as thin were IO (<0.492 cm), EO (<0.315 cm), RA (<0.638 cm), and TA (<0.253 cm).[1]

Data Collection

The age, gender, Acute Physiology and Chronic Health Evaluation II (APACHE II) score, Sequential Organ Failure Assessment (SOFA) score, mNUTRIC score, and left ventricle ejection fraction (LVEF) of patients on the day of ICU admission were noted. The lung ultrasound score (LUS) on the day of the first SBT and days of ventilator support prior to the first SBT were also noted. The serum sodium, potassium, albumin, urea, creatinine, and urea–creatinine ratio on the day of ICU admission (day 1) and serum sodium, potassium, urea, and creatinine on the third day of ICU admission (day 3) were noted. The presence of sepsis or septic shock on ICU admission, hemodialysis (HD) prior to the day of SBT, corticosteroid use prior to SBT, ventilator-associated pneumonia (VAP), and presence of multidrug-resistant (MDR) infection were noted. Days of ICU stay and survival at 28 days of hospitalization were also noted.

Statistical Analysis

Statistical software IBM SPSS (Statistical Package for the Social Sciences) software (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, version 26.0 Armonk, NY: IBM) was used. The mean and SD were calculated for the study's quantitative variables with a parametric distribution. For the quantitative variables with a nonparametric distribution, the median and interquartile range (IQR) were calculated. Qualitative variables were expressed as numbers and percentages. Independent Student *t*-test was used for parametrically distributed continuous variables between the groups of thick and thin abdominal expiratory muscles, whereas Mann–Whitney *U*-test was used for non-parametrically distributed continuous variables between the two groups. Pearson Chi-square test was used for differences in nominal variables between the two groups. For the variables that were found to be significantly different between the thick and thin groups of each of the respective muscles, RA, EO, IO, and TA, the univariate analysis was then done to predict reduced muscle thickness. The variables with *p*-value <0.15 in the univariate analysis were taken in order to include as many confounders as possible, for the multivariable logistic regression to predict reduced muscle thickness. In the multivariable logistic regression, only one variable with the highest OR in the univariate analysis out of the independent variables like age, APACHE II score, SOFA score, and mNUTRIC score that are otherwise correlated, was considered. This was to avoid the problem of multicolinearity in regression when related variables like age, APACHE II score, and SOFA score which are already included in the mNUTRIC score are taken for regression analysis. Further analysis was done to find independent predictors of at least one of the four abdominal expiratory muscles being thin using univariate and multivariable logistic regression. Bootstrapping multivariable logistic regression was done using 1000 samples for validating the findings, using bias-corrected accelerated method. For the independent predictor (continuous variable) that reliably predicted a thin muscle (RA, EO, IO, or TA), the receiver operating characteristic curve (ROC) was plotted to show the area under the curve (AUC) along with sensitivity, specificity, and 95% CI and cutoff scores. The cutoff scores in decimals were rounded-off to the next whole number for a practical approach. Except for the univariate analysis, in all other analyses, a *p*-value of <0.05 was considered as significant.

Results

The mean ± SD and the median (IQR) of the variables in the study in the 81 patients are depicted (Table 1). The number of patients with thin IO was 55/81 (68%), with thin EO was 48/81(59.25%), with thin RA was 47/81(58%), and with thin TA was 48/81(59.25%). There were 64/81 (79%) patients with at least one of the four abdominal expiratory muscles being thin. Regarding IO, there was a significant difference between thicker and thin IO in terms of age, APACHE II score, SOFA score, mNUTRIC score, days of ventilation prior to SBT, urea on day one of ICU admission, presence of sepsis, septic shock, VAP, and corticosteroid use (Table 2). The ROC curve among continuous variables revealed the highest AUC of mNUTRIC score 0.813, *p* <0.001, sensitivity 71%, specificity 77%, 95% CI [0.719–0.906], and cutoff score 4 to predict thinner IO (Fig. 3). However, on univariate and multivariable logistic regression to

Table 1: Values of the variables in the study patients (*n* = 81)

Variables	*Mean ± SD*
Age (years)	55.70 ± 15.91
Gender	52 (64.2%)
APACHE II score	15.43 ± 6.63
SOFA score	6.22 ± 3.53
LUS	8.93 ± 5.11
mNUTRIC score	4.05 ± 1.92
EF (%)	59.47 ± 7.6
Days of ventilation before SBT	5.26 ± 3.08
IO thickness (cm)	0.46 ± 0.18
EO thickness (cm)	0.32 ± 0.10
RA thickness (cm)	0.62 ± 0.18
TA thickness (cm)	0.24 ± 0.07
Serum sodium (day 1) mEq/L	134.58 ± 8.90
Serum potassium (day 1) mEq/L	4.49 ± 0.87
Serum albumin (day 1) g/dL	3.32 ± 0.87
Serum sodium (day 3) mEq/L	135.58 ± 6.23
Serum potassium (day 3) mEq/L	4.32 ± 0.73
Variables	*Median (IQR)*
Serum urea (day 1) mg/dL	39 (24.5–72)
Serum creatinine (day 1) mg/dL	1.07 (0.70–1.73)
Serum urea (day 3) mg/dL	44 (31–83.50)
Serum creatinine (day 3) mg/dL	0.94 (0.65–2.07)
Urea–creatinine ratio (day 1)	31.57 (22.2–53.78)
Length of ICU stay (days)	7 (5–11.5)
Variables	*Frequency*
Sepsis *n* (%)	42 (51.9%)
Septic shock *n* (%)	25 (30.9%)
Hemodialysis *n* (%)	17 (21%)
VAP *n* (%)	18 (22%)
MDR *n* (%)	21 (25.9%)
Corticosteroid use *n* (%)	21 (25.9%)

APACHE II, Acute Physiology and Chronic Health Evaluation II score; EF, ejection fraction; EO, external oblique; IO, internal oblique; LUS, lung ultrasound score; MDR, multidrug resistant; mNUTRIC score, modified Nutritional Risk in Critically ill score; RA, rectus abdominis; SBT, Spontaneous breathing trial; SOFA score, Sequential Organ Failure Assessment score; TA, transversus abdominis; VAP, ventilator-associated pneumonia

Table 2: Difference in variables between the thin and thick IO muscle patients

Variables	*IO thin (<0.492 cm) n = 55*	*IO thick (≥0.492 cm) n = 26*	*p-value*	*Statistical test*
Age	61.04 ± 14.02	44.42 ± 13.79	**<0.001**	Independent Student *t*
APACHE II score	17 ± 6.79	12.12 ± 4.91	**0.002**	Independent Student *t*
SOFA score	6.78 ± 3.36	5.04 ± 3.65	**0.03**	Independent Student *t*
LUS	9.36 ± 5.02	8 ± 5.25	0.26	Independent Student *t*
mNUTRIC score	4.71 ± 1.83	2.65 ± 1.29	**<0.001**	Independent Student *t*
EF (%)	59.45 ± 7.55	59.5 ± 7.8	0.98	Independent Student *t*
Days of ventilation prior to SBT	5.82 ± 3.29	4.08 ± 2.23	**0.017**	Independent Student *t*
Serum sodium (day 1)	134.05 ± 10.14	135.69 ± 5.47	0.44	Independent Student *t*
Serum potassium (day 1)	4.49 ± 0.89	4.51 ± 0.83	0.92	Independent Student *t*
Serum albumin (day 1)	3.29 ± 0.94	3.41 ± 0.71	0.59	Independent Student *t*
Serum urea (day 1)	47 (28–78)	30 (21–50.5)	**0.039**	Mann–Whitney *U*
Serum creatinine (day 1)	1.2 (0.77–2.07)	0.87 (0.62–1.39)	0.12	Mann–Whitney *U*
Urea–creatinine ratio (day 1)	32.37 (20.77–54.16)	30.93 (25.5–48.44)	0.86	Mann–Whitney *U*
Serum sodium (day 3)	135.3 ± 6.94	136.12 ± 4.42	0.59	Independent Student *t*
Serum potassium (day 3)	4.37 ± 0.71	4.24 ± 0.77	0.46	Independent Student *t*
Serum urea (day 3)	48 (34–84)	35 (25.25–62.75)	0.09	Mann–Whitney *U*
Serum creatinine (day 3)	1.20 (0.68–2.25)	0.84 (0.60–1.49)	0.29	Mann–Whitney *U*
Male gender	34 (69.2%)	18 (61.2%)	0.52	Chi-square
Sepsis	34 (61.8%)	8 (30.8%)	**0.009**	Chi-square
Septic shock	22 (40%)	3 (11.5%)	**0.010**	Chi-square
Hemodialysis	11 (20%)	7 (26.9%)	0.316	Chi-square
VAP	16 (29.6%)	2 (7.7%)	**0.028**	Chi-square
MDR	17 (30.9%)	4 (15.4%)	0.137	Chi-square
Corticosteroid use	19 (34.5%)	2 (7.7%)	**0.01**	Chi-square

IO, internal oblique

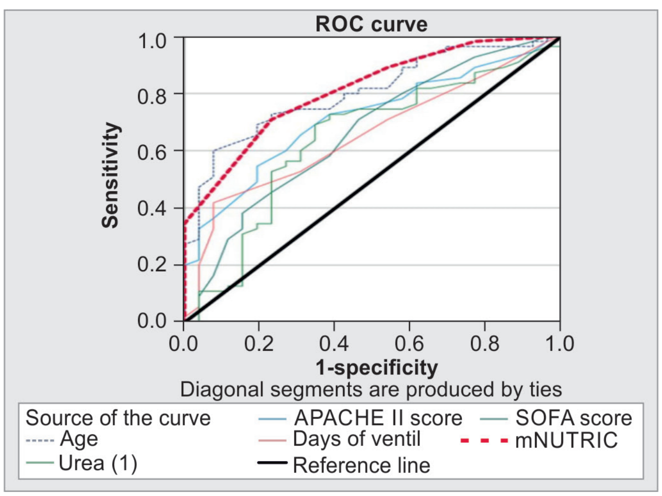

Fig. 3: The AUC of variables predicting thin IO, the mNUTRIC score has the highest AUC 0.813, p <0.001, sensitivity 71%, specificity 77%, 95% CI [0.719–0.906], and cut-off score 4 to predict thin IO (AUC, area under the curve; CI, confidence interval; IO, internal oblique; mNUTRIC, modified nutritional risk in critically ill)

adjust for confounders, only days of ventilator support before the first SBT (p = 0.032, adjusted OR 1.362) and the mNUTRIC score were found to be independent predictors of a thinner IO (p = 0.001, adjusted OR 2.329) (Table 3). For the predictors of EO being thin, only the mNUTRIC score (p = 0.014, adjusted OR 1.566, 95%CI [1.095–2.239]) was found to be an independent predictor after univariate and multivariable analysis (Table 4). The ROC curve showed an AUC of 0.738, $p < 0.001$, 71% sensitivity, 67% specificity, 95% CI [0.626–0.850], and a cutoff score ≥4 to predict a thin EO (Fig. 4). The mNUTRIC score was again found to be the independent predictor of RA muscle being thin, after univariate and multivariable logistic regression (p = 0.002, adjusted OR 1.691, 95% CI [1.205–2.375]) (Table 5). The ROC curve showed an AUC of 0.773, p < 0.001, 74.5% sensitivity, 71.6% specificity, 95% CI [0.668–0.878], and cutoff score ≥4 for the mNUTRIC score to predict a thin RA muscle (Fig. 5). However, only the serum potassium level on the day of ICU admission was found to be an independent predictor of thinner TA muscle after univariate and multivariable regression (p = 0.002, adjusted OR 0.325, 95% CI [0.158–0.668]) (Table 6). Analysis was done to predict at least one of the four abdominal expiratory muscles being thinner than the cutoff of the four abdominal expiratory muscles, which thus predicted difficult weaning. The mean and SD of the mNUTRIC score in at least one of the four abdominal expiratory muscles being thin group (n = 64) was 4.52 ± 1.85, whereas the mNUTRIC score was 2.29 ± 0.98 in the group of patients with none of the muscles being thin (n = 17). The mNUTRIC score was the only independent predictor after regression analysis to predict that at least one out of the four abdominal expiratory muscles will be thin (p = 0.006, adjusted OR 2.699, 95% CI [1.344–5.462]) (Table 7).

Bootstrap multivariable regression analysis with 1000 samples also showed that mNUTRIC was an independent predictor of at least

Table 3: Univariate and multivariable logistic regression for variables predicting thin IO muscle ($n = 55$) among the 81 patients (thickness of IO <0.492 cm)

Univariate analysis				*Multivariable logistic regression*		
Variables	*p-value*	*OR*	*95% CI*	*p-value*	*Adjusted OR*	*95% CI*
Age	0.001	1.079	1.039–1.121			
APACHE II score	0.003	1.142	1.046–1.247			
SOFA score	0.042	1.173	1.006–1.368			
Days of ventilator before SBT	0.022	1.272	1.036–1.561	**0.032**	**1.362**	**1.028–1.806**
mNUTRIC score	<0.001	2.28	1.513–3.436	**0.001**	**2.329**	**1.394–3.892**
Serum urea (day 1)	0.288	1.006	0.995–1.018	0.163	0.988	0.972–1.005
Sepsis	0.011	3.64	1.347–9.85	0.22	3.092	0.506–18.908
Septic shock	0.015	5.11	1.367–19.105	0.743	0.724	0.105–4.998
VAP	0.041	5.05	1.066–23.955	0.45	2.125	0.301–15.021
Corticosteroid use	0.109	6.33	1.35–29.716	0.086	5.042	0.793–32.044

IO, internal oblique. The values depicted in bold represent the significant p values, the adjusted odd's ratio and the 95% confidence interval of the variables which were found to be statistically significant after the multivariable logistic regression

Table 4: Univariate and multivariable logistic regression of the variables for predicting thin EO muscle ($n = 48$) among the 81 patients (thickness of EO <0.315 cm)

Univariate analysis				*Multivariable logistic regression*		
Variables	*p-value*	*OR*	*95% CI*	*p-value*	*Adjusted OR*	*95% CI*
mNUTRIC score	**<0.001**	**1.675**	**1.239–2.264**	**0.014**	**1.566**	**1.095–2.239**
APACHE II score	0.006	1.12	1.033–1.212			
SOFA score	0.002	1.286	1.094–1.512			
Serum albumin (day 1)	0.034	0.528	0.292–0.953	0.709	0.870	0.42–1.803
Sepsis	0.002	4.60	1.771–11.949	0.113	3.198	0.76–13.452
Septic shock	0.045	2.948	1.025–8.484	0.726	0.766	0.172–3.404

EO, external oblique. The values depicted in bold represent the significant p values, the adjusted odd's ratio and the 95% confidence interval of the variables which were found to be statistically significant after the multivariable logistic regression

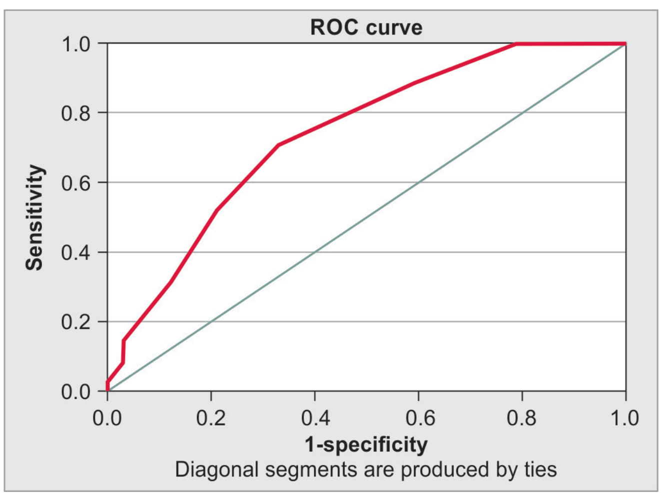

Fig. 4: ROC shows that the mNUTRIC score has the AUC 0.738, $p < 0.001$, cut-off score ≥4, sensitivity 71%, specificity 67%, and 95% CI [0.626–0.850] to predict thin EO (AUC, area under the curve; CI, confidence interval; EO, external oblique; mNUTRIC, modified nutritional risk in critically ill)

one of the four abdominal muscles being thin ($B = 0.993$, $p = 0.004$, 95% CI bias-corrected accelerated 0.375–3.403).

The ROC curve showed that the mNUTRIC score ≥3 predicted that at least one of the four muscles (RA, EO, IO, or TA) will be thin with AUC 0.849, $p < 0.001$, 95% CI [0.763–0.935] (Fig. 6). The relationship map showing that mNUTRIC score ≥3 are related strongly to at least one of the four abdominal expiratory muscles being thin is depicted (Fig. 7). There were 63 patients with an mNUTRIC score of ≥3 in our study, and 18 patients with an mNUTRIC score of < 3. In the mNUTRIC score ≥3, up to 56/63 (89%) patients had at least one of the four abdominal muscles thin, whereas, in patients with mNUTRIC score <3, only 8/18 (44.44%) had at least one of the four abdominal muscles thin (p <0.001, Chi-square test). There was a significant difference between the median (IQR) days of ICU stay in patients having at least one abdominal expiratory muscle thin ($n = 68$) and those not having any of the abdominal expiratory muscles thin ($n = 17$), [7 (5.25–12) days in at least one muscle being thin versus 5 (4–8) in not even one muscle being thin, $p = 0.038$, Mann–Whitney U test].

Discussion

During critical illness, there is a decrease of 1–2% in muscle thickness each day.[9] The cause of this may be due to sepsis and inflammation, immobilization, muscle disuse during ventilation, altered metabolism with catabolic processes, and use of corticosteroids and muscle relaxants.[7,9] Clinicians should identify patients who are having this reduction in muscle thickness, often measured easily by bedside ultrasound, and take remedial measures to assist recovery.[10] Very few studies have underlined the importance of adequate nutrition on muscle function and muscle thickness in the critically ill, and have rather focussed on the final outcomes of poor nutrition like the length of ICU stay and mortality.[7] A study showed

Table 5: Univariate and multivariable logistic regression of variables predicting thin RA muscle ($n = 47$) out of 81 patients (thickness of RA <0.638 cm)

Univariate analysis				*Multivariable logistic regression*		
Variables	*p-value*	*OR*	*95% CI*	*p-value*	*Adjusted OR*	*95% CI*
Age	<0.001	1.060	1.025–1.096			
APACHE II score	<0.001	1.155	1.061–1.259			
SOFA score	0.031	1.168	1.014–1.345			
mNUTRIC score	**<0.001**	**1.838**	**1.332–2.536**	**0.002**	**1.691**	**1.205–2.375**
Sepsis	0.003	4.051	1.585–10.352	0.188	2.046	0.706–5.933

RA, rectus abdominis. The values depicted in bold represent the significant *p* values, the adjusted odd's ratio and the 95% confidence interval of the variables which were found to be statistically significant after the multivariable logistic regression

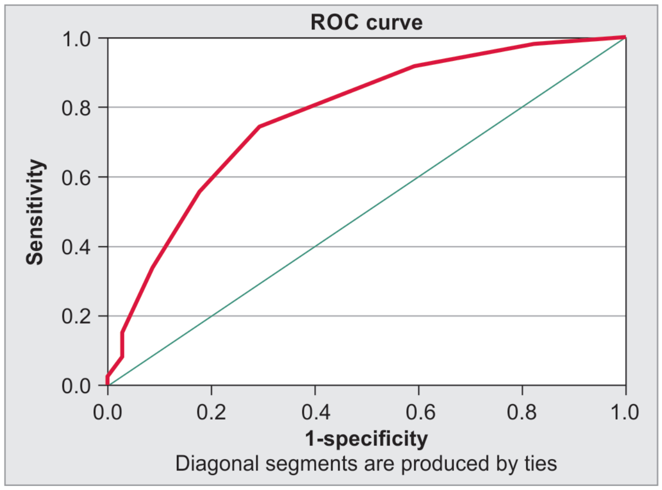

Fig. 5: The ROC curve showed the mNUTRIC score has an AUC of 0.773, $p < 0.001$, 74.5% sensitivity, 71.6% specificity, 95% CI [0.668–0.878], and cutoff score ≥4 to predict a thin RA muscle (AUC, area under the curve; CI, confidence interval; RA, rectus abdominis, mNUTRIC, modified nutritional risk in critically ill)

Table 6: Univariate and multivariable logistic regression predicting thin TA muscle ($n = 48$) out of 81 patients (thickness of TA <0.253 cm)

Univariate analysis				*Multivariable logistic regression*		
Variables	*p-value*	*OR*	*95% CI*	*p-value*	*Adjusted OR*	*95% CI*
Age	0.016	1.037	1.007–1.069			
mNUTRIC score	0.018	1.368	1.054–1.775	0.283	1.196	0.863–1.657
Serum potassium (day 1)	**0.028**	**0.539**	**0.311–0.934**	**0.002**	**0.325**	**0.158–0.668**
Sepsis	0.022	2.917	1.164–7.311	0.184	2.353	0.66–8.318
Septic shock	0.014	4.00	1.317–12.15	0.061	4.180	0.935–18.692

TA, transversus abdominis. The values depicted in bold represent the significant *p* values, the adjusted odd's ratio and the 95% confidence interval of the variables which were found to be statistically significant after the multivariable logistic regression

Table 7: Univariate and multivariable logistic regression to predict at least one out of the four abdominal expiratory muscles (Either IO, EO, RA or TA) will be thin ($n = 64$)

	Univariate analysis			*Multivariable logistic regression*		
Variables	*p-value*	*OR*	*95%CI*	*p-value*	*Adjusted OR*	*95% CI*
Age	0.002	1.052	1.021–1.100			
APACHE II score	0.001	1.211	1.078–1.360			
SOFA score	0.003	1.486	1.149–1.923			
LUS	0.047	1.133	1.001–1.281	0.767	1.028	0.855–1.236
mNUTRIC score	**<0.001**	**2.716**	**1.590–4.641**	**0.006**	**2.699**	**1.334–5.462**
Serum urea (day 1)	0.049	1.023	1.000–1.046	0.198	0.976	0.940–1.013
Serum urea (day 3)	0.021	1.027	1.004–1.051	0.103	1.024	0.995–1.053
Sepsis	0.002	12.50	2.62–59.47	0.073	10.354	0.805–133.24
Septic shock	0.033	9.60	1.196–77.05	0.672	0.516	0.024–11.014
Corticosteroid use	0.063	7.27	0.901–58.69	0.176	6.317	0.437–91.311

EO, external oblique; IO, internal oblique; RA, rectus abdominis; TA, transversus abdominis. The values depicted in bold represent the significant *p* values, the adjusted odd's ratio and the 95% confidence interval of the variables which were found to be statistically significant after the multivariable logistic regression

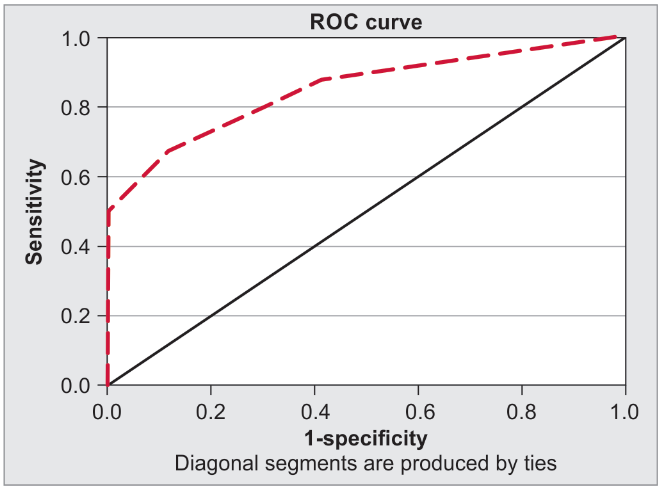

Fig. 6: The ROC depicting the AUC of the mNUTRIC score predicting at least one out of the four abdominal expiratory muscles being thin in the patients with AUC 0.849, $p < 0.001$, and 95% CI [0.763–0.935] (AUC, area under the curve; CI, confidence interval; mNUTRIC, modified nutritional risk in critically ill) mNUTRIC cut off score ≥3

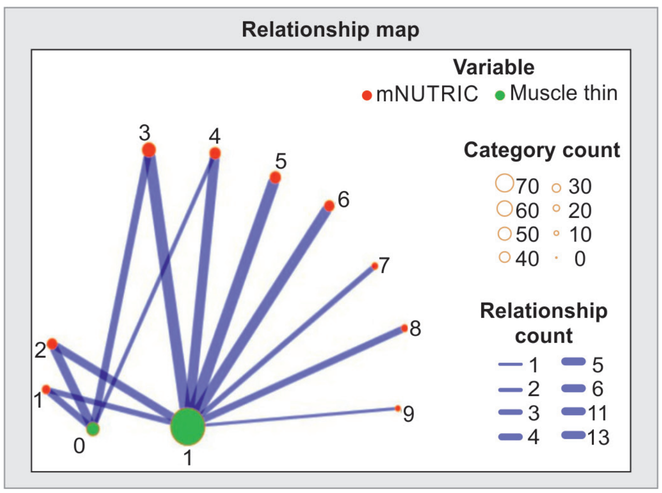

Fig. 7: The relationship map depicting that if at least one out of the four abdominal expiratory muscles is thin, then it is related to mNUTRIC score ≥3, whereas if none of the four abdominal expiratory muscles are thin, it is related to lower mNUTRIC scores (mNUTRIC, modified nutritional risk in critically ill). The big green circle with numeric score 1: At least one out of the four abdominal expiratory muscles are thin. The small green circle with numeric score 0: None of the four abdominal expiratory muscles are thin. Blue relationship lines: Depict the strength of the relationship between the thin or thick abdominal expiratory muscle (at least one out of four) and the mNUTRIC score. Red circles: Depict the mNUTRIC score

that there was an increase in muscle strength with an increase in nutrition (amino acid intake).[11] Thus, adequate nutrition was shown to predict muscle strength.[11] However, it is important to identify which critically ill patient may have thinner muscles, especially, the often neglected abdominal expiratory muscles, which are important in weaning success.[1,2] It is this category of patients who are most likely to benefit from adequate nutritional therapy.

Weakness of abdominal expiratory muscles leads to poor cough, and ineffective clearance of secretions from airways, and increases the risk for re-intubation.[2] Muscle wasting in critically ill is common in those with multi-organ dysfunction (MODS), and occurs more rapidly within one week of critical illness.[9] Apart from MODS and severity of disease, reduced protein intake and advanced age with comorbidities also play a role in muscle loss in the critically ill.[10,12] The components of age, the severity of illness (APACHE II score), organ dysfunction (SOFA score), inflammation (IL-6), and comorbidities – all of which may contribute to reduced skeletal muscle thickness are encompassed in the NUTRIC score, along with days from hospital to ICU admission.[13] In the conceptual model by Heyland et al., the NUTRIC score conceptualized acute and chronic starvation, acute and chronic inflammation along with reduction of lean body mass, and severity of illness.[13] Thus, these factors may play a role in revealing patients with a reduction in abdominal expiratory skeletal muscle thickness.

We found that the mNUTRIC score was the only variable that independently predicted a thinner IO, EO, RA, or at least one of the four muscles of abdominal muscles being thin (which are crucial for successful weaning). The cutoff mNUTRIC score to predict specifically thin IO, EO, and RA was ≥4. However, the cutoff mNUTRIC score to predict that at least anyone out of the four abdominal expiratory muscles will be thin was ≥3. For example, if we specifically want to predict whether the mNUTRIC score can predict a thin IO, the cutoff score ≥4 will be utilized. Though the predictors of skeletal muscle loss or diaphragmatic weakness in critically ill have been studied before, like higher urea–creatinine ratio indicating inflammation, sepsis, poor nutrition, prolonged ventilation, acute respiratory failure, disuse atrophy, and use of sedatives, there are hardly any studies on the important expiratory muscle pump-the abdominal muscles specifically.[2,14,15]

Also, the causes of respiratory muscle weakness in the critically ill have been said to be so multifactorial and varied that there is no objective score that may aid the intensivist in predicting who will have respiratory muscle weakness.[16] We tried to evaluate the risk factors of expiratory muscle weakness, and found that the mNUTRIC score can be objectively used to predict reduced expiratory muscle thickness.

The evaluation of muscle thickness (especially respiratory pump) is very significant because muscle loss affects outcomes in the critically ill in terms of mortality.[17] The study by Ju et al. showed that muscle loss is an independent predictor of mortality in critically ill cirrhotic patients.[17] In another study that analyzed the thickness of abdominal skeletal muscles – RA, IO, EO, and TA using computerized tomographic image analysis, concluded that cross-sectional area of the muscles at the third lumbar vertebra also correlated well to the whole-body skeletal muscle mass.[18] Loss of this skeletal muscle mass leads to longer ICU days.[18] The authors also concluded that the loss of skeletal muscle mass leads to higher mortality in elderly critically ill patients, after regression analysis adjusted for age, gender, and injury severity score.[18] This is because the skeletal muscles (including the abdominal skeletal muscles) perform other important functions, apart from being part of the expiratory pump, like immune function, optimal utilization of glucose, and protein synthesis.[18] Loss of skeletal muscle mass may also impair signaling by cytokines and insulin.[18] Skeletal muscle loss has been said to be associated with the risk of nosocomial infections.[18] Thus, it is important for intensivists to measure skeletal muscle depth or thickness in mechanically ventilated patients. The measurement of abdominal expiratory muscles is beneficial because it performs the metabolic functions of other skeletal muscles, and also performs the function of being the powerful expiratory component of the respiratory pump when diaphragmatic dysfunction is present.

The strengths of the study are that we have analyzed the risk factors of reduced thickness of all four abdominal expiratory muscles that help in weaning, and have accounted for confounders like age, gender, and sepsis by performing multivariable logistic regression. We have done multivariable bootstrap regression of 1000 samples to ensure validity, and have given a cutoff value of the mNUTRIC score that was found to be the independent predictor of reduced abdominal muscle thickness.

There were a few limitations of the study. It was a single-center retrospective study, with a small sample size. Also, we had the data of the muscle thickness at only one time-point, on the day of the first SBT. Thus, we could not evaluate the change in muscle thickness. We also did not have the thickening fraction of the individual abdominal expiratory muscles and how the nutritional intake during the ICU stay affected the muscle thickness.

Conclusion

There was 2.7 times higher risk of thinning of one of the four abdominal expiratory muscles with the mNUTRIC score ≥3. We recommend validating our results in a large prospective cohort of critically ill patients.

Orcid

Vishwas P https://orcid.org/0000-0002-6149-9509
Vedaghosh Amara https://orcid.org/0000-0001-5296-2138
Sagar Shanmukhappa Maddani https://orcid.org/0000-0001-5296-2138
Souvik Chaudhuri https://orcid.org/0000-0001-8392-2366
Suvajit Podder https://orcid.org/0000-0002-6852-5781

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