RESPIRATORY CARE Paper in Press. Published on April 17, 2024 as DOI: 10.4187/respcare.11676

Intercostal Muscle Function During Noninvasive Ventilation and Acute Hypercapnic Respiratory Failure

Aslıhan Gürün Kaya, Miraç Öz, Serhat Erol, Fatma Arslan, Aydın Çiledağ, and Akın Kaya

BACKGROUND: Noninvasive ventilation (NIV) is a widely used and well-established treatment modality for respiratory failure. In patients with increased respiratory work of breathing, accessory muscles are commonly activated along with the diaphragm. Whereas diaphragm ultrasound has been utilized to assess outcomes of mechanical ventilation, the data on intercostal muscle ultrasound remain limited. We aimed to investigate the association between intercostal muscle thickening fraction (TF) and NIV failure in critical care patients with hypercapnic respiratory failure. METHODS: Critical care subjects receiving NIV for hypercapnic respiratory failure were enrolled in the study. The intercostal muscle TF was measured on admission day (day 0) and the following day (day 1). NIV failure was defined as the need for invasive mechanical ventilation or death during NIV therapy. RESULTS: A total of 158 subjects were enrolled, and 30 experienced NIV failure. Age, sex, and body mass index (BMI) were similar in the NIV success and failure groups. Acute Physiology And Chronic Health Evaluation II (APACHE II) and the Sequential Organ Failure Assessment (SOFA) scores were higher in the NIV failure group. In terms of causes of respiratory failure, the COPD exacerbation rate was higher in the NIV success group. TF was higher in the NIV failure group on both day 0 and day 1. The increased TF on the ICU admission day, with a cutoff value of 12%, was associated with NIV failure after adjusting for age, sex, BMI, APACHE II, and SOFA. Persistence of a higher TF value on both day 0 and day 1 was also associated with NIV failure risk. CONCLUSIONS: There is a positive relation between intercostal muscle TF measured by ultrasound and NIV failure, even after adjusting for APACHE II and SOFA scores.
Key words: intercostal muscle ultrasound; intercostal muscle thickness fraction; noninvasive ventilation failure; respiratory failure. [Respir Care 0;0(0):1–●. © 2024 Daedalus Enterprises]

Introduction

Noninvasive ventilation (NIV) is a widely utilized and well-established treatment modality for respiratory failure.[1] Guidelines strongly recommend NIV as the primary approach for patients experiencing hypercapnic respiratory failure. However, the success of this therapeutic modality hinges on precise patient selection and adherence to follow-up protocols.[2-4] Effective patient selection involves recognizing contraindications to NIV and identifying those at risk of NIV failure.[4,5]

Identification of patients with increased risk for NIV failure is crucial for best outcomes. Failing to recognize such patients promptly may result in delayed initiation of invasive mechanical ventilation, a delay linked to increased mortality, heightened morbidity, and prolonged hospital length of stay.[3,6,7] Although increased respiratory work load is a known predictor of NIV failure, its objective assessment proves challenging.[8] Consequently, many studies turn to evaluation of diaphragm function via ultrasound as a measurable marker. Reduced diaphragm movement and thickening fraction (TF) during muscle contraction are identified as predictors of increased respiratory load, weaning failure, NIV failure, and mortality.[9,10] Nevertheless, ultrasonic visualization of the diaphragm poses challenges in cases such as obesity and abdominal distention.[11]

Despite the diaphragm being the primary muscle of ventilation, accessory respiratory muscles play a role in generating tidal volume.[9] In generating tidal volume, accessory muscles are commonly activated together with the diaphragm especially in patients with increased respiratory work of breathing. Among these accessory muscles, the intercostal muscles are one of the most crucial for managing chest expansion.[12,13]

A few studies on subjects receiving invasive mechanical ventilation found that increased parasternal intercostal muscle TF, a reproducible technique with a high intraclass correlation coefficient, might indicate diaphragm dysfunction

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and increased respiratory load.[13] However, data on patients receiving NIV support are yet to be determined. This study aimed to establish whether a relationship exists between intercostal muscle TF, measured by ultrasound, and NIV failure.

Methods

We conducted a prospective cohort study involving subjects with hypercapnic respiratory failure receiving NIV in the ICU of Ankara University Faculty of Medicine, Department of Chest Disease between August 1, 2022–January 30, 2023. Informed consent was obtained from subjects or their relatives, and the study protocol was approved by the ethics committee of Ankara University (05-391-22) in accordance with the Declaration of Helsinki.

All subjects age ≥ 18 years, receiving NIV therapy as initial respiratory support for hypercapnic respiratory failure, were enrolled in the study. Hypercapnic respiratory failure was defined as an increased P_{aCO_2} (≥ 45 mm Hg) and a pH below 7.35 on arterial blood gas analysis.[4] Exclusion criteria encompassed patients with chest-wall deformities; surgery or skin lesions hindering performing standard ultrasound techniques; as well as those with neuromuscular disease; diaphragm paralysis; peri-diaphragmatic pathologies affecting diaphragm movements such as pleural effusion, ascites, upper abdominal pathologies; and a history of lung volume reduction intervention. Management of hypercapnic respiratory failure and NIV therapy followed our ICU-specific algorithm based on American Thoracic Society/European Respiratory Society clinical practice and British Thoracic Society guidelines.[3,4]

For each subject, age, sex, body mass index (BMI), comorbidities, the reason for respiratory failure, Sequential Organ Failure Assessment (SOFA) score and Acute Physiology and Chronic Health Evaluation II (APACHE II) score, arterial blood gases analysis, and P_{aO_2}/F_{IO_2} on admission were recorded.

Parasternal intercostal muscle thickness was measured by ultrasound using a high-frequency linear transducer (HFL38, 6–13 MHz, Fujifilm Sonosite, Bothell, Washington) in M-mode in the sagittal plane between the second and the third ribs with a Sonosite M-Turbo (Fujifilm Sonosite). The subjects underwent an ultrasound procedure while lying in a 20° head-up position. The TF was calculated as the difference of thickness between the end of the inspiration (T_{ins}) and expiration (T_{exp}), divided by the thickness of expiration ($[T_{ins} - T_{exp}]/T_{exp}$). Measurements were taken on the day of ICU admission (day 0) and the following day (day 1) during spontaneous breathing. Ultrasonographic images of parasternal intercostal muscles are illustrated in Figure 1. The study subjects were followed up for information on their treatment outcomes, NIV failure status, and length of ICU stay. NIV failure was defined as the need for invasive mechanical ventilation or death under NIV therapy.

The sample size calculation utilized data from a study by Dres et al,[13] considering an expected ratio of 20% in NIV failure/NIV success. A sample of 150 subjects (with at least 30 NIV failures) was deemed necessary to achieve 80% power with an alpha level of 5% as calculated using the G*Power 3.1.9.6 (Heinrich-Heine-Universität Düsseldorf, Germany). Continuous data were presented as means ± SD or medians [interquartile range 25–75], whereas categorical data were expressed as numbers (%). The group associations were examined using the chi-square test for categorical data, and independent samples *t* test or a Mann-Whitney U test was used to comparing continuous data between the 2 groups. Receiver operating characteristic (ROC) curve analysis was performed to identify the optimal cutoff value of the TF in predicting NIV failure. Multivariable binary logistic regression was conducted to identify associated risk factors for primary outcome after adjusting for confounders. Data entry and analysis were performed using IBM SPSS Statistics (version 22.0, IBM, Armonk, New York)

QUICK LOOK

Current knowledge

Increased respiratory work load is the predictor of noninvasive mechanical ventilation failure. Ultrasonographic assessment of respiratory muscles becomes an important technique that objectively evaluates respiratory work load. Current data show that decreased diaphragm contractility and increased intercostal muscle contractility are associated with a poor prognosis for patients with invasive mechanical ventilation.

What this paper contributes to our knowledge

An increased thickening fraction (TF) of intercostal muscle at initiation and during follow-up can be associated with noninvasive ventilation (NIV) failure risk. Prompt recognition of patients with an elevated intercostal TF may allow for early intervention in escalating respiratory support. Further studies are required to investigate the effect of intercostal muscle ultrasound on NIV success.

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The authors have disclosed no conflicts of interest.

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DOI: 10.4187/respcare.11676

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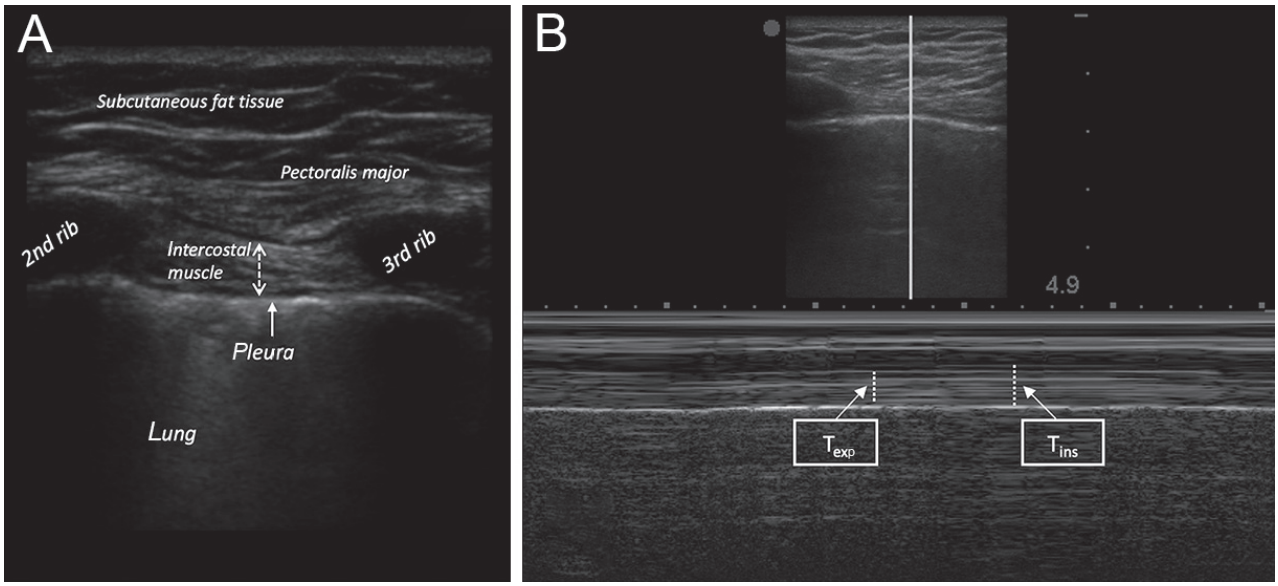


Fig. 1. Typical ultrasonographic image of parasternal intercostal muscle by sagittal plane of linear probe at the parasternal second intercostal space. A: The parasternal intercostal muscle consisted of 2 linear hyperechoic membranes with a medial part exhibiting muscle echotexture (shown by a dotted-arrowed line); B: The thickness of the intercostal muscle in the parasternal region on frozen images using M-mode at both end expiration and end inspiration. T_{exp} = end expiration; T_{ins} = end inspiration.

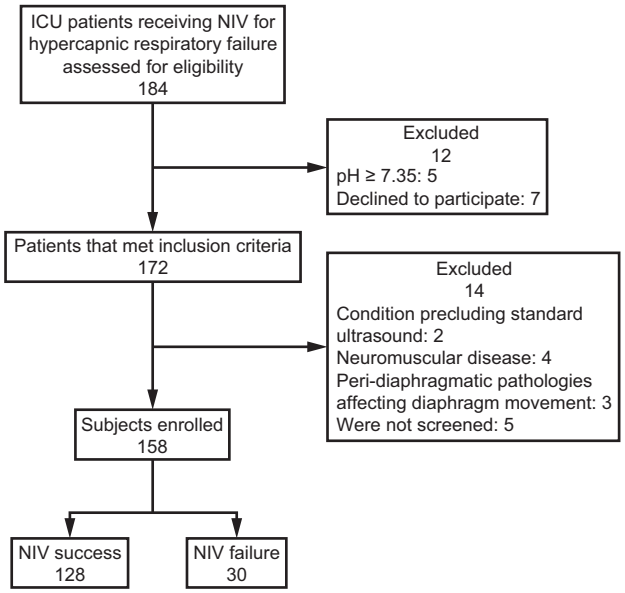


Fig. 2. Flow chart. NIV = noninvasive ventilation.

with the statistical significance level set at $P < .05$ for all tests.

Results

We assessed a total of 184 patients who underwent NIV therapy for eligibility, and 158 were included in the study. During the follow-up of the 158 study subjects, 29 required invasive mechanical ventilation; and one experienced sudden cardiac arrest under NIV, resulting in death. Therefore, NIV failure was observed in 30 (18.9%) subjects. The flow diagram of the study design is depicted in Figure 2. Age, sex, and BMI were comparable between the 2 groups. COPD was the most prevalent comorbid disease, and COPD exacerbation was the primary cause of respiratory failure in the entire group. Demographic and baseline clinical features of the 2 subject groups are presented in Table 1.

The parasternal intercostal muscle ultrasound was performed on all 158 study subjects on the admission day (day 0) and the subsequent day (day 1). Univariate analysis revealed that the thickness at the end of the inspiration and TF were higher in the NIV failure group on both day 0 and day 1. The ultrasound findings of the parasternal intercostal muscle are summarized in Table 2.

The ROC curve analysis for TF on day 0 (Fig. 3A) and day 1 (Fig. 3B) predicting NIV failure yielded values of 0.86 (95% CI 0.79–0.93, $P < .001$) and 0.81 (95% CI 0.73–0.89, $P < .001$), respectively. The optimal cutoff points for TF values were determined as 0.12 (with a sensitivity of 80% and specificity of 74%) for day 0 and 0.14 (with a sensitivity 80% and specificity of 71%) for day 1 in predicting NIV failure.

Given that a significant proportion of the study group and those with NIV success were diagnosed with COPD, additional ROC curve analysis for TF on day 0 and day 1 was conducted specifically for the subgroup of subjects diagnosed with COPD. The area-under-the-curve values were found to be 0.85 (95% CI 0.77–0.93, $P < .001$) for TF on day 0 and 0.89 (95% CI 0.82–0.96, $P < .001$) for TF on day 1. In this subgroup, the cutoff value of TF was

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Table 1. Comparison of Baseline Features of Study Group by Univariate Analysis

	All ($N = 158$)	NIV Success ($n = 128$)	NIV Failure ($n = 30$)	P
Age, y	79.0 [69.0–83.0]	78.50 [69.00–84.00]	79.00 [69.00–81.25]	.58
Male sex	90 (57)	69 (53.9)	21 (70)	.11
BMI, kg/m^2	28.84 ± 2.94	28.79 ± 3.04	29.02 ± 2.48	.70
APACHE II score	17 [13–22]	16 [12–18]	27 [24–32]	< .001
SOFA score	5 [4–6]	4 [4–5]	8 [6–9]	< .001
Reason of respiratory failure				
COPD exacerbation	120 (75.9)	106 (82.8)	14 (46.7)	< .001
Cardiogenic pulmonary edema	53 (33.5)	41 (32)	12 (40)	.40
Pneumonia	58 (36.7)	45 (35.2)	13 (43.3)	.40
Exacerbation of ILD	7 (4.4)	4 (3.1)	3 (10.0)	.13
Comorbid disease				
COPD	130 (82.3)	116 (90.6)	14 (46.7)	< .001
Hypertension	76 (48.1)	61 (47.7)	15 (50.0)	.82
Diabetes mellitus	42 (26.8)	30 (23.6)	12 (40.0)	.07
Asthma	8 (5.1)	7 (5.5)	1 (3.3)	> .99
Cardiovascular disease	26 (16.5)	13 (10.2)	13 (43.3)	< .001
Chronic renal failure	22 (13.9)	16 (12.5)	6 (20.0)	.38
Chronic liver disease	18 (11.4)	13(10.2)	5 (16.7)	.34
Malignancy*	12 (7.6)	10 (7.8)	2 (6.7)	> .99
Other†	18 (11.4)	14 (10.9)	4 (13.3)	.75
Arterial blood gases at admission				
pH	7.30 [7.26–7.33]	7.31 [7.27–7.33]	7.26 [7.25–7.30]	< .001
P_{aCO_2}, mm Hg	64 [58–72]	63 [57–69]	68 [60–80]	.02
P_{aO_2}, mm Hg	57 ± 6	57 ± 6	56 ± 5	.37
P_{aO_2}/F_{IO_2}	188 [174–216]	195 ± 29	189 ± 32	.31
HCO_3, mmol/L	27 [25–31]	28 [26–31]	26 [23–28]	.001

Data are presented as n (%), median [interquartile range 25–75], or mean ± SD.
*Lung carcinoma, colon adenocarcinoma, renal cell carcinoma, lymphoma, and metastatic solid organ tumors.
†Inflammatory bowel disease, thyroid functional disease, dementia, peptic ulcer, peripheral vascular disease, and Behçet disease.
NIV = noninvasive ventilation
BMI = body mass index
APACHE II = Acute Physiology and Chronic Health Evaluation II
SOFA = Sequential Organ Failure Assessment
ILD = interstitial lung disease
HCO_3 = bicarbonate

determined as 0.12 for day 0, demonstrating a sensitivity of 78% and specificity of 75%, while TF with a cutoff value of 0.14 for day 1 showed a sensitivity of 85% and specificity of 73%.

Three distinct models were constructed, and binary logistic regression was applied to control for potential confounders. The analysis revealed an increased TF on day 0 (TF ≥ 0.12) was consistently associated with the risk of NIV failure across all models (Table 3).

To assess the combined effects of TF on both day 0 and day 1, study subjects were categorized into 4 subgroups: low TF on both day 0 and day 1, low TF on day 0 and increased TF on day 1, increased TF on day 0 and low on day 1, and increased TF both in day 0 and day 1. Logistic regression analysis demonstrated that subjects with an increased TF on both day 0 and day 1 were associated with increased risk of NIV failure, even after adjusting for APACHE II and SOFA scores (Table 4). The odds plots visualization of the model is given in Figure 4.

Discussion

The present study shows a positive relationship between intercostal muscle TF, as measured by ultrasound, and the occurrence of NIV failure. The increased TF on the day of ICU admission, with a defined cutoff value of 12%, is linked to NIV failure in critical care subject with hypercapnic respiratory failure. Furthermore, those subjects who have persistently higher value TF (≥ 14%) after 24 h face a 5.5-fold greater risk of NIV failure after adjusting for APACHE II and SOFA scores.

In a study by Chen et al,[14] an NIV failure rate of 49.5% was reported in adult ICUs. Besides, a multi-center study on subjects with COPD exacerbations indicated the NIV failure rate of 22.9%. Notably, the authors denoted NIV

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Table 2. Comparison of Intercostal Muscle Measurements and ICU Length of Stay of Study Groups by Univariate Analysis

	All ($N = 158$)	NIV Success ($n = 128$)	NIV Failure ($n = 30$)	*P*
Intercostal muscle ultrasound, day 0				
End-inspiratory thickness, cm	0.58 [0.53–0.63]	0.58 [0.53–0.62]	0.63 [0.56–0.66]	.004
End-expiratory thickness cm	0.52 [0.49–0.58]	0.52 [0.49–0.58]	0.52 [0.48–0.57]	.72
TF0, %	9.09 [4.91–15.23]	7.2 [3.9–13.6]	18.2 [11.9–24.2]	< .001
Intercostal muscle ultrasound (day 1)				
End-inspiratory thickness, cm	0.59 [0.54–0.65]	0.59 [0.53–0.64]	0.63 [0.57–0.69]	.002
End-expiratory thickness, cm	0.52 [0.48–0.57]	0.53 [0.48–0.58]	0.51 [0.47–0.56]	.68
TF1, %,	11.6 [8.05–17.57]	10.5 [7.2–14.9]	23.4 [15.5–26.9]	< .001
ICU length of stay, d	5.00 [3.75–6.00]	4 [3–5]	10.50 [5.75–13.25]	< .001

Data are presented as median [interquartile range 25–75].
NIV = noninvasive ventilation
TF0 = thickening fraction on day 0
TF1 = thickening fraction on day 1

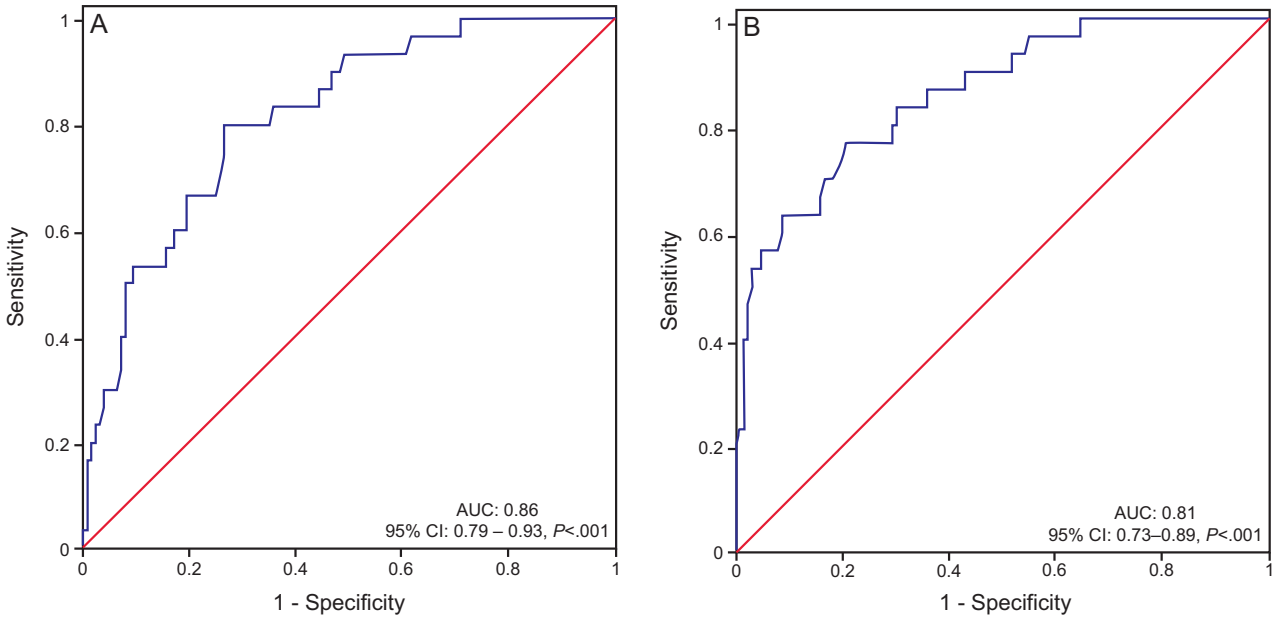


Fig. 3. The receiver operating characteristic curve for TF of parasternal intercostal muscles on day 0 (A) and day 1 (B).

failure rates varied across centers, with the highest rate observed in the ICUs (50%) and a lower in general wards (13.6%).[15] Variable rates of NIV failure have been reported across different ICUs and over various years. Those variable rates may stem from diverse patient characteristics, discrepancies in devices, sets and masks used for NIV applications, the level of ICU care provided, and whether NIV treatment is administered in wards to patients with moderate to good clinical conditions. In our study, the overall NIV failure rate was 18.9%. However, subgroup analysis revealed the highest efficacy of NIV treatment in the COPD exacerbation group, with a rate of 46.7%. The higher NIV failure rate could be explained by the proactive use of NIV therapy for subjects with mild-moderate hypercapnic respiratory failure in wards. Only patients with severe hypercapnic respiratory failure who had an increased risk for NIV failure were admitted to ICU in our clinic. Additionally, in this study, the NIV failure rate in the subjects with pneumonia group was 43.3%. The development of hypercapnia in this group, which mainly progresses with hypoxemic respiratory failure, is a sign of increased respiratory work load and distress and is also associated with increased invasive mechanical ventilation requirements.

Generally, advanced age is considered a risk factor for treatment failure in many diseases due to the progressive loss of physiological integrity, leading to impaired function and increased vulnerability to diseases.[16] Our study group consisted of relatively older subjects with a median

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Table 3. Multivariate Analysis of Thickening Fraction on Day 0 to Predict Noninvasive Ventilation Failure After Adjusting Age, Sex, and Body Mass Index (Model 1); Acute Physiology and Chronic Health Evaluation II and Sequential Organ Failure Assessment Score (Model 2); and Acute Physiology and Chronic Health Evaluation II, Sequential Organ Failure Assessment Score, and Body Mass Index (Model 3)

Variables	Model 1		Model 2		Model 3	
	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
TF0, ≥ 0.12	10.30 (3.91–27.11)	< .001	5.03 (1.20–21.05)	.030	4.59 (1.10–19.03)	.030
Age	1.01 (0.85–1.20)	.91				
Male sex	2.46 (0.93–6.45)	.060				
BMI	1.01 (0.85–1.20)	.88			0.17 (0.91–1.66)	.17
APACHE-II			1.33 (1.14–1.56)	< .001	1.37 (1.15–1.64)	< .001
SOFA score			1.76 (1.16–2.66)	.008	1.79 (1.19–2.68)	.005
−2 Log likelihood	123.59		56.65		54.70	
Cox and Snell R^2	0.17		0.46		0.46	
Nagelkerke R^2	0.28		0.74		0.75	

OR = odds ratio
TF = thickening fraction
BMI = body mass index
APACHE II = Acute Physiology and Chronic Health Evaluation II
SOFA = Sequential Organ Failure Assessment

Table 4. Multivariate Analysis of Groups Based on Change in Thickening Fraction to Predict Noninvasive Ventilation Failure

Variables	OR (95% CI)	*P*
TF0 −/TF1 −	1	
TF0 −/TF1 +	1.92 (0.20–19.48)	.56
TF0 +/TF1 −	7.87 (0.67–92.45)	.10
TF0 +/TF1 +	5.59 (1.04–29.85)	.044
APACHE II	1.33 (1.13–1.57)	.001
SOFA score	1.71 (1.11–2.62)	.01
−2 Log likelihood	55.96	
Cox and Snell R^2	0.45	
Nagelkerke R^2	0.73	

OR = odds ratio
TF = thickening fraction
APACHE II = Acute Physiology and Chronic Health Evaluation II
SOFA = Sequential Organ Failure Assessment
TF0 (+) = TF in admission day ≥ 0.12
TF0 (−) = TF in admission day < 0.12
TF1 (+) = TF after 24 h ≥ 0.14
TF1 (−) = TF after 24 h < 0.14

age of 79. Additionally, the ages of the study subjects were similar between the NIV failure and success groups. A recent study by Chung et al[17] demonstrated an increased prevalence of hypercapnic respiratory failure with age. Furthermore, a multi-center study by Uğurlu et al[18] reported more frequent use of NIV in elderly subjects than in younger individuals in critical care, with similar NIV success rates across different age groups. These findings align with our results.

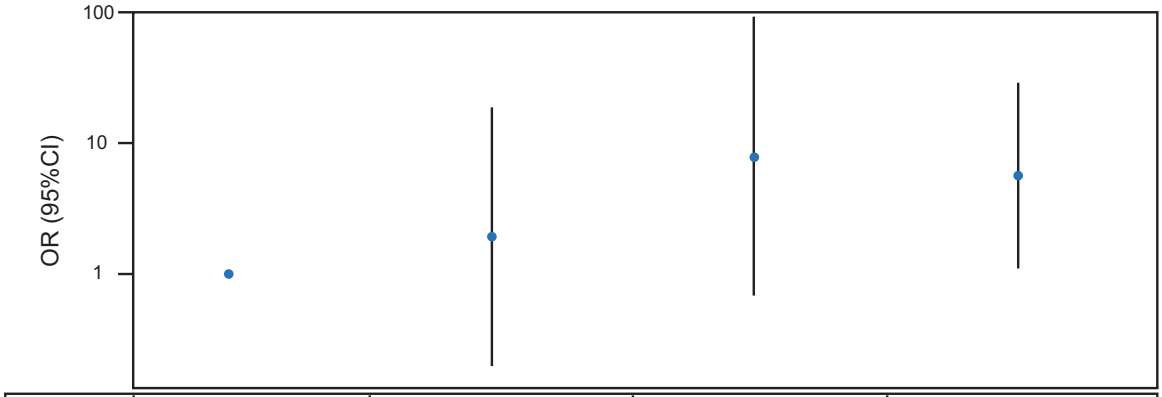
Another study by Chung et al[19] indicated that obstructive lung disease, congestive heart failure, and lower respiratory tract infection are the most common reasons for hypercapnic respiratory failure, and obstructive lung disease and cardiac failure are associated with low mortality risk. In our study, COPD was the most common comorbid condition. As anticipated, COPD exacerbation was the most common underlying reason for hypercapnic respiratory failure. The rate of COPD exacerbation was lower in cases with NIV failure, as NIV therapy has been proven effective in the treatment of COPD exacerbation and in preventing intubation.[4]

Disease severity is crucial for treatment outcomes in critical care patients, and the APACHE II and SOFA are widely used scoring systems in critical care units.[20] Confalonieri et al[15] demonstrated that an increased APACHE score predicts NIV failure in subjects with COPD exacerbation. The SOFA score is also associated with NIV failure in critical care patients.[21,22] Consistent with these findings, subjects with NIV failure in our study population exhibited higher APACHE II and SOFA scores than those in the NIV success group.

Respiratory muscle function, assessed through ultrasound and electromyographic techniques, has been explored as a predictor of respiratory load and pump failure in previous studies.[8,9,23] A recent meta-analysis of 19 cohort studies showed that increased diaphragm TF and decreased diaphragm excursion are associated with weaning success from the ventilator; notably, diaphragmatic TF exhibited a more accurate relationship in this context.[24] However, visualizing the diaphragm can be challenging, particularly in patients with obesity, abdominal distention, or abdominal pain. Monitoring diaphragm thickening at the end of deep inspiration may also face obstacles due to the potential interference of the lung moving into the ultrasonic view.[11,25] Additionally, due to the larger muscle size, it is easier to

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	TF0–/TF1– (n: 84)	TF0–/TF1+ (n: 18)	TF0+/TF1– (n: 12)	TF0+/TF1+ (n: 44)
• LnOR	1.0	1.92	7.87	5.59
LRL		0.20	0.67	1.04
URL		19.48	92.45	29.85

Fig. 4. Odd ratio plots of the model investigating the combined effects of thickening fraction (TF)0 and TF1. TF0 (+) indicates increased TF on day 0 (≥ 0.12). TF0 (–) indicates low TF on day 0 (< 0.12). TF1 (+) indicates increased TF on day 1 (≥ 0.14). TF1 (–) indicates low TF on day 1 (< 0.14). OR = odds ratio; TF = thickening fraction; LnOR = natural logarithm–transformed odds ratio; LRL = lower reference limit; URL = upper reference limit.

track thickness changes in the intercostal muscles than in the diaphragm muscle.[12]

In studies focusing on intercostal muscle by ultrasound, a relatively rare area of investigation, an inverse correlation between the TF of the diaphragm and intercostal muscles has been observed.[9] Dres et al[13] showed that increased parasternal intercostal muscle TF was associated with a higher level of ventilator assistance and failure of spontaneous breathing trials in subjects receiving invasive mechanical ventilation. In the context of NIV treatment, Helmy et al[13] performed a study in subjects with COVID-19, and showed that increased parasternal intercostal muscle TF was associated with NIV failure with a cutoff value of 9%.[26] In line with these findings, the present study indicates that TF of intercostal muscle was significantly higher in subjects with NIV failure, and increased TF was associated with NIV failure. This association remained unchanged even after multivariate analysis, adjusting for age, sex, BMI, and APACHE II and SOFA scores. Additionally, ROC curve analysis also demonstrated the good performance of TF on day 0 and day 1 for predicting NIV failure in both the entire study group and subgroup with COPD.

In our study, we measured the intercostal muscle TF both on admission day and after 24 h. Subsequent analysis aimed to explore the combined effects of changes in TF within this 24-h period revealed that subjects with increased TF both on day 0 and day 1 faced a higher risk for NIV failure. The reduction of respiratory muscle load and the improved capacity of pump function are crucial advantages of NIV support in patients.[7,27] A decrease in dyspnea severity, breathing frequency, and the use of the accessory respiratory muscles during inspection signify an improvement in ventilation, reflecting the diminished severity of work of breathing.[28] The persistence of increased TF in intercostal muscles may indicate ongoing respiratory load, indicating that NIV treatment is not achieving the desired response.

To the best of our knowledge, this is the first study examining parasternal intercostal muscles through ultrasound and their association with the risk of NIV failure in critical care subjects with hypercapnic respiratory failure. Various factors, including disease severity, age, and BMI, may influence treatment outcomes during an ICU stay. The inclusion of these potential confounders in the analysis is a strength of our study.

This study, however, is subject to several limitations. The single-center nature of the study may restrict the generalizability of the results to other settings. On the other hand, the single-center design contributes to the consistency in managing patients with hypercapnic respiratory failure. Intercostal muscle ultrasonography is a procedure dependent on the practitioner's skill. In this study, inter-observer variability was avoided by performing the ultrasound procedure by the same certified clinician, and the average of 3 repeated measurements was recorded to mitigate intra-observer variability. Another limitation is the wide confidence intervals in the multivariable model, attributed to the relatively small sample size in our research.

Conclusions

We found a favorable association between baseline intercostal muscle TF and NIV failure in critical care subjects with hypercapnic respiratory failure. Subjects with increased TF on both the admission day and the subsequent day

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RESPIRATORY CARE Paper in Press. Published on April 17, 2024 as DOI: 10.4187/respcare.11676

exhibited a significantly higher susceptibility to NIV failure. Intercostal muscle TF can serve as a valuable standalone parameter, particularly when ultrasonic imaging of the diaphragm is unfeasible. It can be utilized alongside diaphragm TF/excursion, established parameters, to play a crucial role in determining prognosis and devising treatment plans for patients experiencing respiratory failure. The early identification of individuals at risk of NIV failure can be facilitated through the use of ultrasonography. This noninvasive and readily applicable technique can be conveniently employed at the patient's bedside.

ACKNOWLEDGMENT

We would like to thank Demir, Ahmet Uğur MD, professor; Karakurt, Zuhal MD, professor; and all faculty members of Methods in Epidemiologic, Clinical and Operations Research (MECOR) Turkey Program, the training course organized by American Thoracic Society and Turkish Thoracic Society for building epidemiologic the infrastructure of the study.

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