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ORIGINAL ARTICLE

MODIFIED FRAILTY INDEX-5, APACHE II AND SOFA SCORES, AND SERUM ALBUMIN AND LACTATE FOR PREDICTING 28-DAY MORTALITY IN ELDERLY ICU PATIENTS UNDERGOING PERCUTANEOUS TRACHEOSTOMY FOR PROLONGED MECHANICAL VENTILATION: A RETROSPECTIVE COHORT STUDY

Abstract

Introduction: Tracheostomy is commonly performed in elderly intensive care unit patients requiring prolonged ventilatory support to facilitate airway management, ventilator weaning, secretion control, and patient comfort. Because these patients often have prolonged critical illness, comorbidity burden, and reduced physiological reserve, accurate prognostic assessment is important for clinical management and family counseling. This study evaluated the prognostic value of the Modified Frailty Index-5, disease severity scores, albumin, and lactate in elderly patients undergoing tracheostomy.

Materials and Method: Patients aged ≥65 years who underwent elective percutaneous tracheostomy for prolonged mechanical ventilation in a general adult intensive care unit between 2021 and 2025 were retrospectively analyzed. Demographic data, Acute Physiology and Chronic Health Evaluation II (APACHE II), Sequential Organ Failure Assessment (SOFA), Modified Frailty Index-5, and pre-procedural albumin and lactate concentrations were recorded. The outcomes were 28-day mortality and post-procedural complications. Multivariable logistic regression and receiver operating characteristic (ROC) analyses were performed.

Results: A total of 114 patients were analyzed. Twenty-eight-day mortality was 58.8% and post-procedural complications occurred in 13.2% of patients. Non-survivors had significantly higher Modified Frailty Index-5 and SOFA scores and higher lactate concentrations, while albumin concentrations were lower. In multivariable analysis, the Modified Frailty Index-5 score independently predicted mortality and post-procedural complications. Both the SOFA score and serum lactate concentration emerged as independent predictors of mortality.

Conclusion: Frailty assessed by the Modified Frailty Index-5 predicts mortality and post-procedural complications in elderly intensive care unit patients undergoing tracheostomy and may improve clinical risk stratification when integrated with conventional severity scores and pre-procedural lactate and albumin concentrations.

Keywords: Tracheostomy; Frailty; Intensive Care Units; Aged; Mortality.

INTRODUCTION

The rapid aging of the global population has led to a growing proportion of geriatric patients being managed in intensive care units (ICUs). Demographic projections indicate that the population aged 65 years and older will continue to increase in the coming decades, accompanied by a substantial rise in the demand for intensive care services among elderly individuals (1,2). In this population, tracheostomy is commonly performed in individuals who require prolonged mechanical ventilation during critical illness. The procedure facilitates airway management, reduces sedation requirements, supports earlier and more effective weaning from mechanical ventilation, and improves patient comfort (3,4). Nevertheless, geriatric intensive care patients undergoing tracheostomy represent a clinically heterogeneous population, and their prognosis may vary substantially. These patients are often characterized by prolonged critical illness, a high burden of comorbidities, and reduced physiological reserve. Therefore, the potential variability in clinical outcomes among individuals makes risk assessment particularly important. Accurate identification of individual risk is clinically valuable for guiding care planning, tailoring treatment goals more appropriately to patient characteristics, and improving communication with patients' relatives regarding prognosis (1,2,5).

Although chronological age is frequently used as a fundamental parameter in traditional risk assessment models, accumulating evidence suggests that age alone does not adequately reflect physiological reserve, the capacity to respond to stress, or overall clinical prognosis. In this context, frailty has emerged as a clinical syndrome that more accurately represents biological vulnerability in older adults. Frailty represents a significant risk factor for poor clinical results, ranging from elevated mortality rates and extended ICU or hospital stays to persistent functional impairment (5,6). The Modified Frailty Index-5 (mFI-5) represents a concise and practical tool derived from a limited set of comorbidity and functional status variables. Owing to its simplicity and ease of application in clinical settings, the mFI-5 has been shown to provide a reliable prognostic measure for predicting postoperative complications and mortality across different patient populations (7,8).

Validated scoring instruments, particularly the Sequential Organ Failure Assessment (SOFA) and Acute Physiology and Chronic Health Evaluation II (APACHE II), are widely used to characterize illness severity in critically ill patients (9,10). However, these scoring systems may not adequately reflect geriatric-specific parameters, including frailty syndromes, nutritional status, and biological reserve (5). Biomarkers reflecting systemic inflammation, nutritional status, and tissue perfusion may improve prognostic assessment in critically ill patients. Serum albumin indicates nutritional reserve and systemic inflammation, whereas lactate reflects tissue hypoperfusion and metabolic stress; both have been associated with increased mortality in critically ill populations (11,12). Evaluating these biomarkers together with established disease severity scores and frailty assessments may therefore provide a more comprehensive and clinically meaningful framework for risk stratification in critically ill elderly patients.

However, studies quantitatively assessing frailty using the mFI-5 in geriatric patients undergoing tracheostomy in the intensive care setting, and evaluating it together with conventional disease severity scores and relevant biomarkers, remain limited. These patients should therefore be regarded as a high-risk group because of their underlying critical illness, prolonged mechanical ventilation, comorbidity burden, and frailty, rather than because of tracheostomy itself. This gap in the literature highlights the need for a practical and multidimensional risk stratification approach that may support clinical management in this vulnerable population.

Accordingly, this study aimed to investigate the prognostic value of frailty, as assessed by the mFI-



5, together with APACHE II and SOFA scores and selected biomarkers, including serum albumin and lactate, for 28-day mortality and post-procedural complications in elderly ICU patients undergoing tracheostomy for prolonged mechanical ventilation. We hypothesized that frailty assessed by the mFI-5 would provide additional prognostic information beyond conventional disease severity scores in predicting mortality and complications in elderly ICU patients undergoing tracheostomy.

MATERIALS AND METHOD

Study Design and Patient Selection

This study was designed as a single-center retrospective observational study using the medical records of patients managed in the general adult ICU of Burdur State Hospital between January 1, 2021, and December 31, 2025, who underwent elective percutaneous tracheostomy during their ICU stay. The study protocol was approved by the Süleyman Demirel University Health Sciences Ethics Committee (Meeting No: 110; Decision No: 21, 2026), and the study was conducted in accordance with the Declaration of Helsinki.

Patients aged 65 years or older were eligible for inclusion if complete demographic, clinical, and laboratory data were available in the hospital's electronic medical record system. Patients who underwent emergency tracheostomy or died during the procedure were excluded. All included patients underwent percutaneous tracheostomy on or after the 14th day of invasive mechanical ventilation due to prolonged ventilatory support requirements.

Percutaneous Tracheostomy Procedure

All tracheostomy procedures were performed at the bedside in the intensive care unit using a percutaneous dilatational technique. Patients were adequately sedated and received neuromuscular blockade before the procedure. Following sterile skin preparation and neck extension, the trachea was punctured between the second and third tracheal rings. A guidewire was inserted and the tract was dilated using the Seldinger technique, after which an appropriately sized tracheostomy cannula was placed. Correct cannula placement was confirmed by clinical assessment and ventilatory parameters.

Demographic and Clinical Variables

Demographic and clinical data were retrospectively obtained from the hospital's electronic medical record system. Age, sex, primary diagnosis for ICU admission, APACHE II score, SOFA score, and Modified Frailty Index-5 (mFI-5) score were recorded. APACHE II was calculated using clinical and laboratory data obtained during the first 24 hours of ICU admission. The SOFA score used in the analyses was calculated using the worst clinical and laboratory values recorded within the 24 hours immediately preceding tracheostomy, to reflect organ dysfunction at a standardized pre-procedural time point rather than serial changes in organ failure during the ICU stay. Laboratory variables measured before tracheostomy included white blood cell count, neutrophil count, lymphocyte count, platelet count, hemoglobin, C-reactive protein, procalcitonin, serum albumin, lactate, and arterial blood gas parameters. Procedure-related complications were also recorded.

Frailty Assessment

Assessment of frailty was performed using the Modified Frailty Index-5 (mFI-5), which was derived from comorbidity and functional status data documented in the patients' medical records. The mFI-5 score was determined according to the presence of five clinical variables: diabetes mellitus, insulin dependent or non-insulin dependent; hypertension requiring pharmacological treatment; history of chronic obstructive pulmonary disease (COPD); congestive heart failure, previously diagnosed or requiring treatment within the preceding 30 days; and functional dependence, defined as partial or complete dependence in activities of daily living (7). Each variable was assigned a value of 1 if present and 0 if absent, giving an mFI-5 score between 0 and 5.

Outcome Measures

The primary outcome of the study was defined as 28-day mortality following tracheostomy. Secondary outcomes included post-procedural complications, including minor bleeding, major bleeding, stomal infection, subcutaneous emphysema, pneumothorax, and tube displacement. In addition, patients were stratified according to their mFI-5 score into two groups: frail (mFI-5 ≥ 3) and non-frail (mFI-5 < 3), and clinical outcomes were compared between these groups.

Statistical Analysis

Statistical evaluation was carried out using IBM SPSS Statistics software, version 22.0; IBM Corp., Armonk, NY, USA. Continuous variables are presented as medians together with interquartile ranges (25th–75th percentiles). Categorical data are summarized as counts and corresponding percentages. For comparisons between groups, non-parametric testing was applied for continuous variables using the Mann–Whitney U test. Categorical variables were analyzed with the chi-square test, and Fisher's exact test was preferred when the expected frequencies were insufficient. To explore variables independently associated with mortality and post-procedural complications, multivariable logistic regression models adjusted for age and sex were constructed. The strength of associations was expressed using odds ratios (ORs) along with 95% confidence intervals (CIs). To prevent potential overestimation and assess multicollinearity among variables with shared parameters (e.g., age, APACHE II, SOFA, and lactate), collinearity diagnostics were performed. Variance Inflation Factor (VIF) values for all independent variables included in the multivariable models were <1.5, indicating no significant multicollinearity. The predictive performance of mFI-5, APACHE II, and SOFA scores for mortality was further examined through ROC curve analysis. In this context, the area under the curve (AUC) was calculated, and diagnostic performance metrics—including sensitivity, specificity, positive predictive value, and negative predictive value—were derived. The optimal cut-off value for the mFI-5 score was also determined based on this analysis. All statistical tests were two-sided, and a p-value below 0.05 was accepted as statistically significant.

RESULTS

Over the study period, 148 patients who underwent tracheostomy in the ICU were screened for eligibility. Of these, 114 patients fulfilling the predefined inclusion criteria were retained for the final analysis, whereas 34 patients were excluded based on the predetermined exclusion criteria. The patient screening, inclusion, and exclusion process is illustrated in detail in the flow diagram presented in Figure 1. The median age of the patients in the final analysis cohort was 75.5 years (IQR 66–83.8). Of the 114 patients, 64 (56.1%) were male and 50 (43.9%) were female.

Comparison of clinical and laboratory data based on survival status revealed that several factors varied significantly between survivors and non-survivors. The mFI-5 score was significantly higher in the non-survivor group compared to survivors (median 3.0 [IQR 2.0–4.0] vs. 2.0 [IQR 1.0–3.0], p < 0.001). Likewise, those who did not survive were older than those who did (median 76.5 [66.8–84.0] vs. 68.5 [65.0–78.2] years, p = 0.039). The pre-

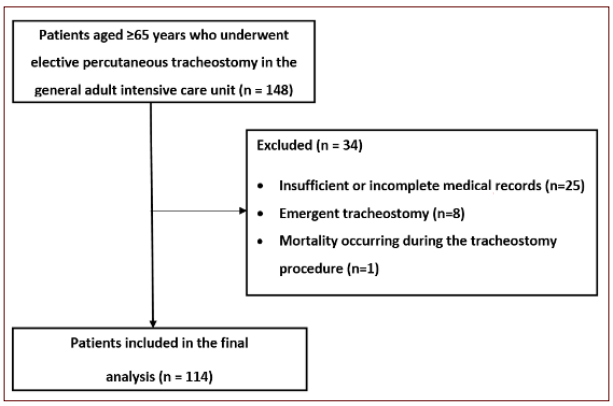


Figure 1. Flowchart of patient selection and eligibility process.



Table 1. Demographic, Clinical, Laboratory, and Post-Procedural Characteristics of the Study Population According to 28-Day Mortality

Characteristics	Survivors (n=47)	Non-survivors (n=67)	All (n=114)	P value
Demographic data				
Age, years	68.5 (65.0–78.2)	76.5 (66.8–84.0)	75.5 (66.0–83.8)	0.039
Male, n (%)	23 (48.9%)	41 (61.2%)	64 (56.1%)	—
Female, n (%)	24 (51.1%)	26 (38.8%)	50 (43.9%)	—
Clinical scores				
APACHE II score	21 (19–24)	22 (21–25)	22 (19–25)	0.076
SOFA score	5 (5–6)	6 (6–8)	6 (5–7)	<0.001
mFI-5 score	2 (1–3)	3 (2–4)	3 (2–4)	<0.001
Laboratory tests				
WBC, $\times 10^3/\mu L$	10.2 (7.7–12.9)	12.0 (8.0–16.2)	10.9 (7.9–15.0)	0.114
Neutrophil, $\times 10^3/\mu L$	8.1 (5.6–10.6)	10.3 (6.3–13.9)	9.1 (6.0–13.0)	0.061
Hemoglobin, g/dL	8.8 (7.7–10.3)	9.2 (8.0–10.5)	8.9 (8.0–10.5)	0.293
Lymphocyte, $\times 10^3/\mu L$	1.1 (0.8–1.5)	1.1 (0.8–1.5)	1.1 (0.8–1.5)	0.924
Platelet, $\times 10^3/\mu L$	245 (174–346)	214 (154–304)	235 (157–328)	0.168
Albumin, g/L	24.0 (21.0–26.0)	22.0 (20.0–25.0)	22.5 (20.0–25.0)	0.047
CRP, mg/L	87 (52–116)	102 (57–160)	96 (55–148)	0.100
Procalcitonin, ng/mL	0.25 (0.12–0.53)	0.43 (0.21–0.95)	0.34 (0.16–0.73)	0.010
Lactate, mmol/L	1.27 (1.10 – 1.50)	1.66 (1.30 – 2.09)	1.47 (1.20 – 1.92)	< 0.001
Arterial blood gas analysis				
pH	7.50 (7.46–7.53)	7.50 (7.42–7.56)	7.50 (7.43–7.54)	0.936
$PaCO_2$, mmHg	37.0 (33.5–44.0)	39.0 (31.0–46.5)	38.0 (33.0–45.8)	0.906
PaO_2, mmHg	87.0 (75.5–101.5)	92.0 (78.5–119.0)	88.0 (76.2–115.0)	0.525
HCO_3, mEq/L	28.0 (25.0–32.0)	28.0 (25.0–32.0)	28.0 (25.0–32.0)	0.917
PaO_2/FiO_2	210 (174–260)	192 (159–246)	200 (164–252)	0.147
Primary diagnosis for ICU admission				0.418
Respiratory / pulmonary causes	9 (19.1%)	18 (26.9%)	27 (23.7%)	—
Neurological / neuromuscular causes	11 (23.4%)	14 (20.9%)	25 (21.9%)	—
Cardiovascular causes	10 (21.3%)	11 (16.4%)	21 (18.4%)	—
Sepsis / infectious causes	9 (19.1%)	7 (10.4%)	16 (14.0%)	—
Postoperative / surgical causes	3 (6.4%)	10 (14.9%)	13 (11.4%)	—
Renal / metabolic causes	4 (8.5%)	3 (4.5%)	7 (6.1%)	—
Other	1 (2.1%)	4 (6.0%)	5 (4.4%)	—
Post-procedural complications				
Any complication	2 (4.3%)	13 (19.4%)	15 (13.2%)	0.038
Minor bleeding	1 (2.1%)	3 (4.5%)	4 (3.5%)	—
Stomal infection	0 (0.0%)	4 (6.0%)	4 (3.5%)	—
Subcutaneous emphysema	1 (2.1%)	2 (3.0%)	3 (2.6%)	—
Pneumothorax	0 (0.0%)	2 (3.0%)	2 (1.8%)	—
Major bleeding	0 (0.0%)	1 (1.5%)	1 (0.9%)	—
Tube displacement	0 (0.0%)	1 (1.5%)	1 (0.9%)	—

Continuous data are expressed as median (interquartile range [IQR]). Categorical data are expressed as number (%). WBC, white blood cell count; CRP, C-reactive protein; APACHE II, Acute Physiology and Chronic Health Evaluation II; SOFA, Sequential Organ Failure Assessment; mFI-5, Modified Frailty Index-5; ICU, intensive care unit; FiO_2, fraction of inspired oxygen; $PaCO_2$, arterial partial pressure of carbon dioxide; PaO_2, arterial partial pressure of oxygen; HCO_3^-, bicarbonate

procedural SOFA score, calculated within the 24 hours before tracheostomy, was significantly higher in non-survivors than in survivors (median 6.0 [IQR 6.0–8.0] vs. 5.0 [IQR 5.0–6.0], p < 0.001), while the median SOFA score in the overall cohort was 6.0 (IQR 5.0–7.0).

Biochemical parameters were evaluated in relation to survival status. Serum lactate concentrations were higher in non-survivors than in survivors (median 1.66 [1.30–2.09] vs. 1.27 [1.10–1.50] mmol/L, p < 0.001). In contrast, serum albumin concentrations were lower in non-survivors (median 22.0 [20.0–25.0] vs. 24.0 [21.0–26.0], p = 0.047). The APACHE II score did not differ significantly between the two groups (p = 0.076). A detailed comparison of clinical and laboratory variables according to survival status is provided in Table 1.

In the multivariable logistic regression model adjusted for age and sex, the mFI-5 score was independently associated with mortality. A one-point increment in the mFI-5 score corresponded to a 2.53-fold increase in the odds of death (OR: 2.528; 95% CI: 1.534–4.164; p < 0.001). The SOFA score also demonstrated an independent association with mortality risk (OR: 2.869; 95% CI: 1.579–5.214; p = 0.001). Furthermore, higher serum lactate concentrations were significantly linked to increased mortality (OR: 4.794; 95% CI: 1.569–14.645; p = 0.006). Conversely, no statistically significant relationship with mortality was observed for age, sex, serum albumin, or APACHE II score.

A separate multivariable logistic regression analysis was conducted to evaluate factors associated with post-procedural complications. In this model, the mFI-5 score remained an independent predictor of post-procedural complications, with each one-point increase associated with a 1.96-fold rise in complication risk (OR: 1.959; 95% CI: 1.105–3.474; p = 0.021). The APACHE II score was likewise independently associated with the development of complications (OR: 1.266; 95% CI: 1.014–1.581; p = 0.037). In contrast, age, sex, albumin concentration, SOFA score, and lactate concentration did not show a statistically significant association with complications. Detailed findings from these analyses are summarized in Table 2.

The ability of the evaluated scoring systems to predict 28-day mortality was assessed using ROC

Table 2. Multivariable logistic regression analysis for predictors of mortality and post-procedural complications

Variables	Mortality OR (95% CI)	p value	Complications OR (95% CI)	p value
Age (per 1-year increase)	1.008 (0.949–1.072)	0.788	1.057 (0.976–1.146)	0.172
Sex (male)	1.411 (0.533–3.736)	0.488	2.269 (0.565–9.108)	0.248
Albumin (g/L)	1.023 (0.886–1.182)	0.758	1.203 (0.986–1.468)	0.069
APACHE II score	0.965 (0.835–1.115)	0.630	1.266 (1.014–1.581)	0.037*
SOFA score	2.869 (1.579–5.214)	0.001*	0.735 (0.392–1.380)	0.338
mFI-5 score	2.528 (1.534–4.164)	<0.001*	1.959 (1.105–3.474)	0.021*
Lactate (mmol/L)	4.794 (1.569–14.645)	0.006*	2.133 (0.494–9.207)	0.310

ORs and 95% CIs are presented. *p < 0.05 indicates statistical significance.

Abbreviations: OR, odds ratio; CI, confidence interval; APACHE II, Acute Physiology and Chronic Health Evaluation II; mFI-5, Modified Frailty Index-5; SOFA, Sequential Organ Failure Assessment.

curve analysis. Among these scores, the SOFA score yielded the highest discriminatory performance, with an AUC of 0.752. The mFI-5 score followed closely, demonstrating a comparable level of predictive accuracy (AUC: 0.735). In comparison, the APACHE II score showed a weaker performance in distinguishing between outcomes (AUC: 0.598). The ROC curves illustrating these differences are shown in Figure 2.

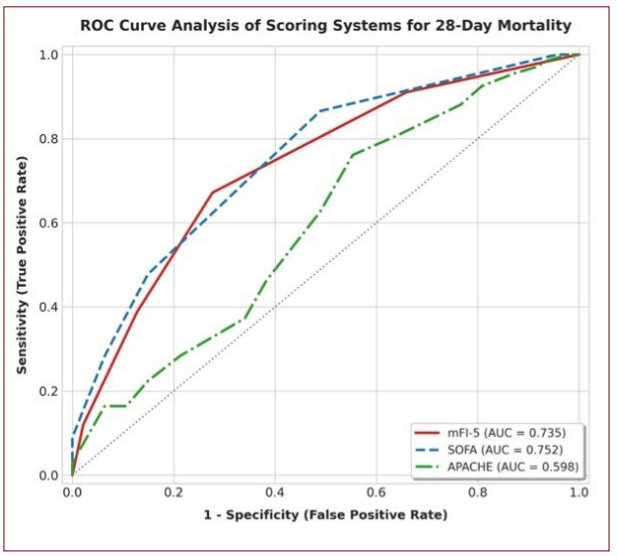


Figure 2. Receiver operating characteristic curves of the mFI-5, SOFA, and APACHE II scores for predicting 28-day mortality in intensive care unit patients.

Further analysis was conducted to identify the optimal threshold for the mFI-5 score. The most appropriate cut-off value was determined as 3. At this threshold (≥ 3), the sensitivity and specificity for mortality prediction were 67.2% and 72.3%, respectively. The corresponding positive predictive value was 77.6% while the negative predictive value was 60.7%.

Patients were categorized according to the predefined mFI-5 threshold of 3. Those with scores ≥ 3 were classified as frail, whereas patients with scores below 3 were considered non-frail. The median age differed between the groups, with higher values observed in the frail cohort (79.5 [72–86] vs. 71.5 [65–82] years, p = 0.030). No statistically significant difference was identified regarding sex distribution (p = 0.706).

In contrast, post-procedural complications occurred more frequently in frail patients compared to non-frail individuals (22.4% vs. 3.6%, p = 0.004). Mortality rates were also markedly higher in the frail group (77.6% vs. 39.3%, p < 0.001). A detailed comparison of clinical features and outcomes based on frailty status is provided in Table 3.

Overall, frail patients had significantly higher rates of mortality and post-procedural complications compared with non-frail patients.

Table 3. Comparison of clinical characteristics and outcomes according to mFI-5 frailty status.

Variables	Non-frail (n = 56) (mFI-5 < 3)	Frail (n = 58) (mFI-5 ≥ 3)	p value
Age, years	71.5 (65-82)	79.5 (72-86)	0.030*†
Sex (male), n (%)	30 (53.6)	34 (58.6)	0.706‡
Sex (female), n (%)	26 (46.4)	24 (41.4)	
Post-procedural complications, n (%)	2 (3.6)	13 (22.4)	0.004*§
28-day mortality, n (%)	22 (39.3)	45 (77.6)	<0.001*§

Data are presented as median (interquartile range) for continuous variables and n (%) for categorical variables, as appropriate. *p < 0.05 indicates statistical significance.

† Mann–Whitney U test; ‡ Chi-square test; § Fisher's exact test. mFI-5, Modified Frailty Index-5.

DISCUSSION

In the present study, the prognostic impact of the Modified Frailty Index-5 (mFI-5), along with established disease severity scores (APACHE II and SOFA) and selected biomarkers (albumin and lactate), was analyzed in patients aged ≥ 65 years undergoing tracheostomy in the ICU. Our findings indicate that frailty, as assessed by the mFI-5, is an important prognostic factor in this patient population. A one-point increase in the mFI-5 score corresponded to an approximately 2.53-fold higher risk of mortality, indicating that frailty serves as a relevant predictor of clinical outcomes beyond chronological age and conventional severity scores.

ROC analysis showed that SOFA and mFI-5 had higher discriminatory performance for predicting 28-day mortality than APACHE II in this cohort. This finding may be related to the specific clinical phase represented by patients undergoing tracheostomy after prolonged mechanical ventilation. While APACHE II reflects illness severity at ICU admission, mortality after tracheostomy may be more strongly influenced by the patient's current organ dysfunction and accumulated physiological vulnerability at the time of the procedure. Therefore, the pre-procedural SOFA score and mFI-5 may better capture short-term mortality risk in this elderly, chronically critically ill population. This does not diminish the established prognostic role of APACHE II, but suggests that its discriminatory ability may be relatively limited in this selected tracheostomy cohort.

Although chronological age is an important clinical variable, it does not fully reflect physiological reserve or biological vulnerability in critically ill elderly patients. Consistent with previous studies showing that frailty is more closely associated with ICU outcomes, clinical morbidity, and mortality than age alone (1,5,6,13–16), age did not remain independently associated with mortality in our multivariable analysis. In contrast, the mFI-5 score independently predicted both mortality and post-procedural complications. These findings suggest that frailty captures clinically relevant vulnerability beyond chronological age, including functional dependence, comorbidity burden, and reduced physiological reserve. Traditional frailty indices typically incorporate numerous clinical variables, which may limit their clinical applicability in time-constrained and dynamic settings such as intensive care units (8,17). To overcome this limitation, the Modified Frailty Index-5 (mFI-5), based on five core clinical parameters, was developed (7). This index has been proposed as a shorter and more practical version of the previously described 11-variable Modified Frailty Index (mFI-11). Subramaniam et al. (7) identified a high degree of correlation between mFI-5 and mFI-11, with a correlation coefficient exceeding 0.9, and found that the mFI-5 performs similarly in predicting mortality and postoperative complications.

In our cohort, this increased vulnerability was also reflected in the higher frequency of tracheostomy-related post-procedural complications among frail patients compared with non-frail patients (22.4% vs. 3.6%). These events included minor bleeding, stomal infection, subcutaneous emphysema, pneumothorax, major bleeding, and tube displacement. This finding suggests that frailty may be associated not only with mortality but also with increased susceptibility to tracheostomy-related post-procedural complications in critically ill elderly patients. However, because the primary endpoint was 28-day all-cause mortality, the association between frailty and mortality should be interpreted as a marker of overall physiological vulnerability rather than as evidence that procedure-related complications directly caused death.

Evidence from prior studies supports this pattern. In spinal surgery populations, Kweh et al. (8) identified the mFI-5 as a determinant of both major complications and mortality. Likewise, Patel et al. (18) observed that increasing mFI-5 scores correspond to a higher probability of reoperation and hospital readmission following lumbar fusion.



Taken together, these observations suggest that the mFI-5 may function as a practical risk stratification tool not only in elective surgical populations but also in critically ill patients undergoing invasive procedures such as tracheostomy. Importantly, in our cohort, frailty assessed by the mFI-5 predicted both mortality and post-procedural complications, whereas the SOFA score was associated only with mortality. This finding indicates that frailty reflects not only acute physiological derangement but also the patient's overall vulnerability to procedure-related morbidity.

Although SOFA primarily reflects acute organ dysfunction and APACHE II incorporates acute physiological variables together with selected chronic health information, neither score directly quantifies geriatric frailty, functional dependence, or long-term reductions in physiological reserve (5,9,10,19). Therefore, the lower discriminatory performance of APACHE II in this cohort should not be interpreted as a contradiction of its established prognostic role, but rather as suggesting that its chronic health component may not fully capture frailty-related vulnerability in elderly patients undergoing tracheostomy. In line with this concept, the VIP2 study demonstrated that frailty independently predicted 30-day mortality in ICU patients aged over 80 years and provided prognostic information beyond organ failure assessment (20). Similarly, our findings suggest that the mFI-5 may complement conventional ICU severity scores by incorporating comorbidity burden and functional dependence in elderly patients undergoing tracheostomy.

Using the ROC-derived threshold of ≥3, the mFI-5 demonstrated a sensitivity of 67.2%, specificity of 72.3%, positive predictive value of 77.6%, and negative predictive value of 60.7% for 28-day mortality. These findings suggest that the mFI-5 should be interpreted as a complementary risk stratification tool rather than a standalone screening instrument. In elderly ICU patients being considered for tracheostomy after prolonged mechanical ventilation, early assessment of frailty should be regarded as an important component of pre-procedural risk evaluation. Frailty identified by the mFI-5 may help clinicians recognize patients at higher risk of mortality and post-procedural complications. Rather than serving as an isolated determinant of whether tracheostomy should be performed, this information should be interpreted together with organ dysfunction, biomarkers, and the overall clinical context to support more realistic prognostic assessment, closer post-procedural monitoring in frail patients, and clearer communication with patients' families regarding expected outcomes.

Analysis of biomarkers revealed that higher serum lactate concentrations were independently associated with mortality, whereas albumin concentrations were lower in non-survivors compared with survivors. These findings underscore the contribution of physiological reserve and tissue perfusion to clinical outcomes. Hypoalbuminemia serves as a marker of physiological reserve, inflammatory stress, and nutritional status; its presence has been linked to higher ICU mortality, extended ventilation periods, and a greater susceptibility to infections (11). Lactate, on the other hand, is a well-established indicator of tissue hypoxia and metabolic stress and has been closely linked to mortality in critically ill patients (12). Taken together, these findings suggest that evaluating the mFI-5 score together with biomarkers such as albumin and lactate may contribute to risk stratification by simultaneously reflecting physiological reserve and the severity of acute illness in geriatric ICU patients.

Tracheostomy is a commonly performed intervention within the ICU for patients undergoing long-term mechanical ventilation. The procedure may facilitate airway management, reduce sedation requirements, and support weaning from mechanical ventilation. Nevertheless, mortality following tracheostomy remains considerable in elderly patients, highlighting the importance of careful patient selection. Previous studies conducted in critically ill populations have reported

substantial mortality rates after tracheostomy, particularly among patients with advanced age and a high burden of comorbidities (4,21-23). In this context, mortality risk appears to be associated not only with chronological age but also with comorbidity burden and underlying physiological vulnerability. Consistent with this perspective, Yakar et al. (23) demonstrated that in elderly patients undergoing tracheostomy, mortality was more strongly associated with comorbidity burden than with chronological age alone.

The relatively high mortality observed in our study further supports the notion that elderly ICU patients requiring tracheostomy often represent a clinically fragile population characterized by limited physiological reserve and increased susceptibility to organ dysfunction. Importantly, this finding should not be interpreted as evidence that tracheostomy itself increases mortality. Rather, it indicates that patients requiring tracheostomy after prolonged mechanical ventilation already represent a high-risk group with substantial frailty, comorbidity burden, and organ dysfunction. Therefore, decisions regarding tracheostomy should not rely solely on the duration of mechanical ventilation but should also incorporate a comprehensive evaluation of the patient's physiological reserve, comorbidity burden, and degree of frailty.

This study has several limitations. First, it was retrospective and single-center, with a relatively limited sample size. Second, the SOFA score was assessed at a single pre-procedural time point to reflect the physiological status before tracheostomy; therefore, serial daily SOFA scores or delta-SOFA changes were not evaluated. Third, because of the retrospective design, specific causes of death and detailed variables related to treatment protocols could not be evaluated separately; therefore, the analyses were based on 28-day all-cause mortality.

In conclusion, frailty assessed using the mFI-5 emerged as a strong and clinically relevant predictor of mortality and post-procedural complications in older patients who underwent tracheostomy in the ICU. Compared with chronological age, the mFI-5 provided meaningful prognostic information and complemented traditional ICU severity scores in identifying high-risk patients. In addition, the combined evaluation of frailty with biological markers reflecting physiological reserve and tissue perfusion—such as albumin and lactate—may further enhance risk stratification in this vulnerable population. The present findings support the incorporation of frailty assessment into routine clinical evaluation when considering tracheostomy in elderly ICU patients. A comprehensive approach that includes frailty status should not be interpreted as a reason to withhold an otherwise clinically indicated tracheostomy, but rather as a means to improve pre-procedural risk assessment, guide closer post-procedural monitoring in frail patients, and support more informed discussions with patients and their relatives regarding expected outcomes and treatment goals. Ultimately, recognizing frailty as a central determinant of prognosis may contribute to more individualized, realistic, and ethically grounded decision-making in the management of critically ill elderly patients.

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