Journal of Multidisciplinary Healthcare

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ORIGINAL RESEARCH

Assessing the Diagnostic Efficacy of Handgrip Dynamometry and Diaphragmatic Ultrasound in Intensive Care Unit-Acquired Weakness

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Objective: The aim of this study is to examine the diagnostic significance of using handgrip dynamometry and diaphragmatic ultrasound in intensive care unit-acquired weakness (ICU-AW).

Methods: This study included patients who received mechanical ventilation in the ICU at the Fourth Hospital of Hebei Medical University from July to December 2020. We collected comprehensive demographic data and selected conscious patients for muscle strength and ICU-AW assessments. The evaluation comprised grip strength measurement and bedside ultrasound for diaphragmatic excursion (DE) and thickening fraction (DTF). Results were documented for comparative analysis between patient groups, focusing on the diagnostic efficacy of grip strength, DE, DTF, and their combined application in diagnosing ICU-AW.

Results: A total of 95 patients were initially considered for inclusion in this study. Following the exclusion of 20 patients, a final cohort of 75 patients were enrolled, comprising of 32 patients (42.6%) diagnosed with ICU-AW and 43 patients (57.4%) classified as non-ICU-AW. Comparative analysis revealed that grip strength, DE, and DTF were significantly lower in the ICU-AW group ($P < 0.05$). Subgroup analysis specific to male patients demonstrated a noteworthy decrease in grip strength, DE, and DTF within the ICU-AW group ($P < 0.05$). Receiver operating characteristic curve analysis indicated statistically significant diagnostic value for ICU-AW with grip strength, DE, DTF, and grip strength and diaphragmatic ultrasound ($P < 0.01$). Furthermore, it was observed that the amalgamation of grip strength and diaphragmatic ultrasound significantly enhanced the diagnostic accuracy of ICU-AW in patients who are critically ill.

Conclusion: Grip strength, DE, DTF, and the combined use of grip strength with diaphragm ultrasound demonstrated diagnostic efficacy in ICU-AW. Notably, the integration of grip strength with diaphragm ultrasound exhibited a heightened capacity to enhance the diagnostic value specifically in patients diagnosed who are critically ill with ICU-AW.

Keywords: diaphragmatic excursion, diaphragm thickening fraction, handgrip dynamometer, ICU acquired weakness

Introduction

Intensive care unit-acquired weakness (ICU-AW), recognized as the predominant neuromuscular impairment in patients who are critically ill and admitted to the intensive care unit (ICU), is defined by the manifestation of generalized muscle weakness, encompassing both limb and respiratory muscles, without an apparent cause other than the critical illness.[1,2] Studies have revealed that the incidence of ICU-AW may reach up to 50% among patients admitted to the ICU, with figures escalating to 25–65% in patients who are mechanically ventilated within the first 24 hours.[1,3–6] Furthermore, an association between ICU-AW and heightened morbidity and mortality rates in patients who are critically ill has been reported.[7] Factors contributing to ICU-AW in patients who are critically ill include sepsis, systemic inflammatory response syndrome, multiple organ failure, prolonged immobility, advanced age, and hyperglycemia.[8] The impact of corticosteroids and neuroleptic blocking agents on ICU-AW remains a subject of debate.[2,6] ICU-AW may manifest as

Received: 31 January 2024
Accepted: 30 April 2024
Published: 16 May 2024

critical illness polyneuropathy (CIP), critical illness myopathy (CIM), or disuse amyotrophy. The most prevalent syndrome is critical illness polyneuromyopathy (CIPNM), a combination of CIP and CIM. Clinically, ICU-AW is characterized by symmetrical muscle weakness affecting the limbs and respiratory muscles. Involvement of the diaphragm can lead to prolonged mechanical ventilation and challenges with extubation, whereas facial muscles typically remain unaffected.[9] Reduction in muscular tension and normal to decreased deep tendon reflexes are commonly observed features of ICU-AW.[7]

Currently, the Medical Research Council (MRC) score is widely used in the ICU as a common diagnostic criterion for assessing muscle strength in the context of ICU-AW. This scoring system evaluates muscle strength in 12 distinct muscle groups, with the summation of individual MRC scores yielding a total score of 60. A diagnosis of ICU-AW is considered when the total MRC score is < 48.[4] Despite its prevalent use, the MRC score faces limitations in the ICU setting due to the protracted duration of scoring and challenges in distinguishing between grade 4 and 5 muscle strength. In contrast, the handgrip dynamometer value has demonstrated satisfactory diagnostic consistency with the MRC score in the identification of ICU-AW. Specifically, the grip strength of the dominant hand, as assessed based on a grip strength test, serves as an initial screening tool for ICU-AW. The established cutoff values for grip strength indicative of ICU-AW are less than 11 kg for males and 7 kg for females.[10] Advancements in critical illness ultrasound have led to an increased recognition of its utility in identifying ICU-AW.[11] Notably, studies have reported significant diaphragmatic atrophy and reduced systolic function within the initial 24 hours of mechanical ventilation, as detected by ultrasound.[12] Diaphragmatic weakness is diagnosed when Diaphragmatic excursion (DE) < 1.4 cm or diaphragm thickening fraction (DTF) < 30%–36%.[13,14] However, a recent study observed a higher incidence of diaphragmatic weakness when compared to ICU-AW, with a limited correlation between the two conditions.[15] The purpose of the research is to make a clear diagnosis of intensive care unit acquired weakness in patients with intensive care unit acquired weakness earlier.

Research Method

Study Participants

Patients who were mechanically ventilated and admitted to the ICU at The Fourth Hospital of Hebei Medical University from July 2020 to December 2020, were included in this study.

Inclusion Criteria

1). Age ≥ 18; 2). Mechanical ventilation for over 24 hours in ICU; 3). Patients with spontaneous respiration, being awake and cooperative (RASS score: −1-0).

Exclusion Criteria

1). Pregnant women; 2). Patients with local or generalized weakness (such as myasthenia gravis, muscular dystrophy, cachexia); 3). Patients with physical defects without the ability to cooperate with the test; 4). Inadequate access to suitable sound windows (subcutaneous emphysema, pneumothorax, partial thoracotomy or laparotomy) for diaphragm assessment; 5). Patients unable to follow orders or consent to registration (with conditions such as delirium or dementia); 6). Patients who undergo neurosurgery following admission; 7). Patients diagnosed with stroke experiencing motor deficits; 8). Patients or their family refuse to participate in this study.

Clinical Data Collection

While hospitalized, the demographic data of patients, admitting disease, medical history, medication use (including hormones, neuroleptic medications, and dietary support), sickness severity, and routine laboratory results were recorded as baseline data. We prospectively recorded the mechanical ventilation time, hospital stay length, success rate of extubation, and patient prognosis, and conducted daily assessments until the patient was either diagnosed as ICU-AW or transferred out of the ICU.

Table 1 MRC Muscle Strength Scale

0 Point	Complete Paralysis, without Muscle Contraction
1 point	Having muscle contraction, but no action
2 points	Parallel movement on the bed, without the ability to defy gravity
3 points	Having the ability to move the limbs and defy gravity, but without the ability to resist the resistance
4 points	Having the ability to move the limbs and resist the resistance, but not completely
5 points	Normal muscle strength

Abbreviation: MRC, Medical Research Council.

MRC Score for Diagnosis of ICU-AW

The same doctor used the MRC score to conduct clinical assessments of the patients. All patients had their strength measured across 12 different muscle groups; each group was given a score between 0 and 5, with the upper extremities (wrist extension, elbow flexion, and shoulder abduction) and lower extremities (foot dorsiflexion, knee extension, and hip flexion) examined separately (Table 1). The MRC score can serve as an indicator for ICU-AW when it falls below 48. The score ranges from 0, indicating quadriplegia, to 60, denoting normal muscle strength.[16]

Measurement with a Handgrip Dynamometer

Following the MRC assessment, the researcher instructed the patients to grip the dynamometer with their dominant hand three consecutive times for further evaluation. To record the maximum value of the grip strength, the patients were asked to sit up straight with their elbows bent at a maximum of 90°[10] (Figure 1). The average of three recorded hand dynamometer measurements was included in the analysis.

Bedside Ultrasound Assessment of Diaphragmatic Function

1) DTF measurement: The patients were placed on an elevated bed with a head elevation of 20–40°. A 4–12 MHz linear array transducer was used for diaphragm ultrasound assessment. M-mode ultrasound was utilized to continuously observe the right side of the diaphragm imaging from the 8th to the 10th rib. The measured end-inspiratory and end-expiratory diaphragm thicknesses (DTi and DTe, respectively) were obtained from the frozen image. To determine the DTF, which is depicted in Figure 2 as DTF(%)=(DTi-DTe)/DTe×100%, each patient was monitored for three to five breathing cycles.[17] 2) DE measurement: With the head of the patient raised 20–40°, a 3–5 MHz convex array ultrasonic probe was

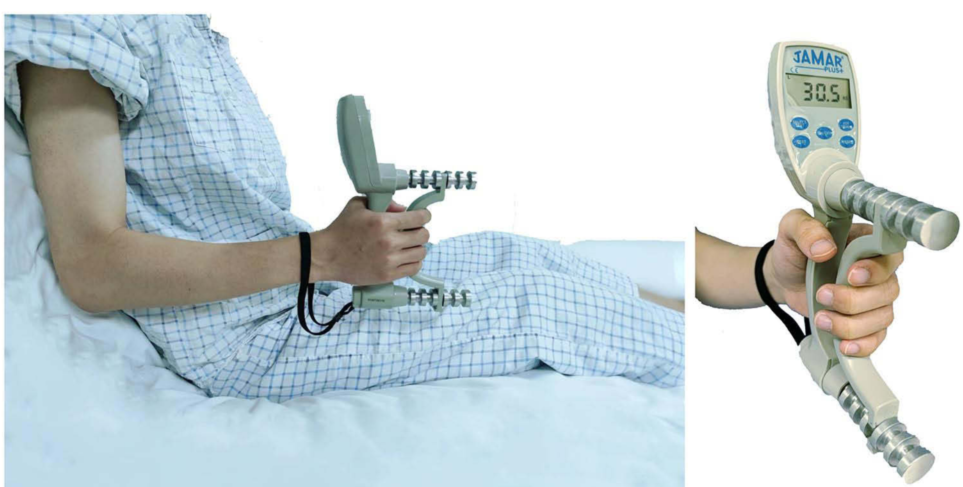

Figure 1 Handgrip dynamometer to assess muscle strength.

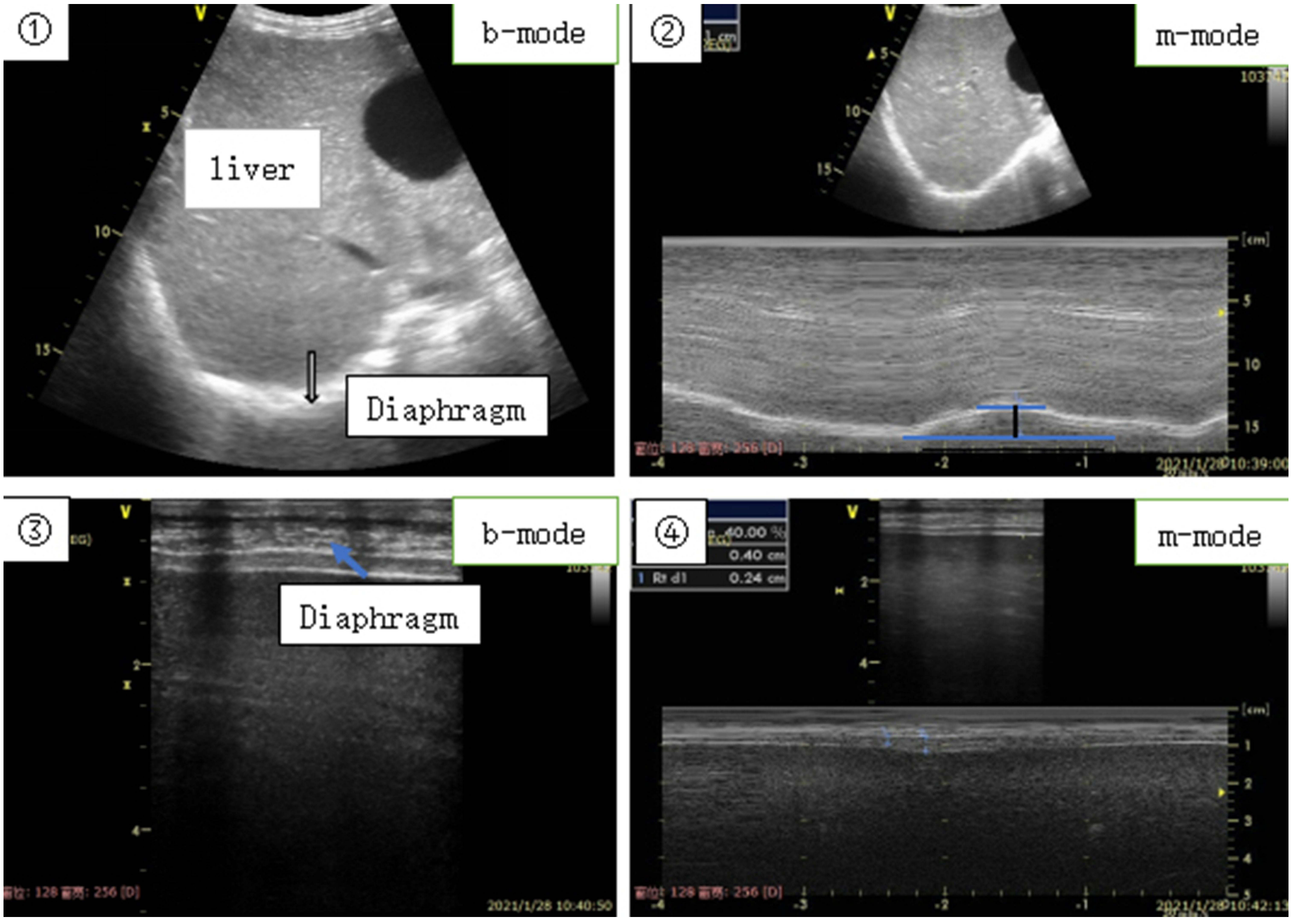

Figure 2 Diaphragm ultrasound measurement.

Notes: ① and ② are the measurement of the movement of the diaphragm. ① Find the diaphragm to be measured in the 2D mode, select the M mode, align the sample line perpendicular to the diaphragm, and measure the movement of the diaphragm (DE). ② The vertical distance between the two blue lines is the movement of the diaphragm. ③ and ④ are the measurement of the diaphragm thickening rate, select the M mode, place the sampling line perpendicular to the diaphragm, measure the end-inspiratory diaphragm thickness (DTi) and the end-expiratory diaphragm thickness (DTe), the diaphragm thickening rate = (DTi -DTe)/DTe×100%.

positioned at the point where the midclavicular line or anterior axillary line met the lower edge of the costal arch. The liver was used as an acoustic window, and the probe was pointed toward both the head and back, ensuring that the ultrasound reached and was perpendicular to the middle and posterior 1/3 of the diaphragm. We measured the diaphragmatic excursion by utilizing M-ultrasound, a technique based on two-dimensional images. Diaphragmatic excursion is defined as the distance from the end of inhalation to the baseline and from the end of exhalation to the baseline, divided by the sum of these two measurements (Figure 2).[18] Until they were either diagnosed as ICU-AW or transferred out of the ICU, patients who did not fulfill diagnostic criteria based on the MRC score were subject to daily arousal assessments using the MRC scoring system, a handgrip dynamometer, and critical diaphragm ultrasound.

Ethics

The Ethics Committee of the Fourth Hospital of Hebei Medical University gave their approval, ensuring that the study complied with all ethical standards (Approval No.: 2019150).

Sample Size Estimation

In the study's initial phase, a pilot experiment involving 20 cases was conducted, with 10 ICU-AW and 10 non-ICU-AW patients diagnosed based on the MRC score criteria. Sample size determination relied on the hand dynamometer index, with an α level of 0.05 and a statistical power (1-β) of 0.80. Mean and standard deviation values for the ICU-AW group were 12.48 and 8.75, respectively, and for the non-ICU-AW group were 20.05 and 12.44, respectively. Employing a 1:1 sample size ratio between the groups and STATA software for analysis, it was calculated that a minimum of 32 patients per group was necessary to achieve adequate statistical power in validating the research outcomes.

Statistical Method

The statistical analysis was conducted using SPSS 26.0 software. Normally distributed measurement data are presented as mean ± standard deviation ($\bar{x} \pm s$), and group comparisons were performed using the *t*-test. Non-normally distributed measurement data are expressed as the median (interquartile range) [median (IQR)], with between-group comparisons conducted using the Mann–Whitney rank sum test. Categorical data are presented as frequency (percentage), and inter-group comparisons of component ratios were assessed using the chi-squared test. Diagnostic testing used the receiver operating characteristic (ROC) curve, with the area under the ROC curve (AUC) and a 95% confidence interval (CI) employed to assess the predictive value of handgrip dynamometry and diaphragmatic ultrasound for ICU-AW. Optimal thresholds, sensitivity, and specificity were calculated, and AUC comparisons were made across different indexes. Multifactorial logistic regression analysis was used to identify risk factors for complications associated with ICU-AW in patients who were mechanically ventilated within the ICU. A significance level of $P < 0.05$ was considered indicative of statistical significance.

Results

Patient Enrollment and Baseline Medical Data

Throughout the course of the study, a total of 278 patients who required mechanical ventilation were admitted to the ICU at The Fourth Hospital of Hebei Medical University. Based on the predefined inclusion and exclusion criteria, 95 patients who were mechanically ventilated were initially included. Following the exclusion of 20 cases due to insufficient data, a final cohort comprising of 75 cases was ultimately considered. Among these, 35 cases were diagnosed with ICU-AW, reflecting an incidence of 46.6% (refer to Figure 3). From the findings, there were no statistically significant differences in terms of age, gender, and BMI between the ICU-AW and non-ICU-AW groups. However, the incidence of sepsis was notably higher in the ICU-AW group when compared to the non-ICU-AW group ($P < 0.05$), and the levels of lactic acid were also elevated in the ICU-AW group ($P = 0.03$). Regarding disease severity, the Acute Physiology and Chronic Health Evaluation II (APACHE II) score and Sequential Organ Failure Assessment (SOFA) score in the ICU-AW group exhibited higher values than those in the non-ICU-AW group, although these differences did not reach statistical significance. Analysis of prognostic indicators demonstrated prolonged durations of mechanical ventilation and ICU stay in the ICU-AW group when compared to the non-ICU-AW group ($P < 0.01$). While the success rates of extubation and improvement were slightly lower in the ICU-AW group, these differences were not statistically significant between the two groups. The prognostic indicators collectively indicated a relatively poorer prognosis for patients in the ICU-AW group (refer to Table 2). There were statistical differences between the ICU-AW group and the non-ICU-AW group in MRC scores, grip strength, DTF, and DE.

Diagnostic Value of Handgrip Dynamometer and Diaphragm Ultrasound in ICU-AW

In the analysis of differences between the ICU-AW and non-ICU-AW groups, statistical significance was observed in MRC scores, grip strength, DTF, and DE ($P < 0.05$). The results of the ROC curve analysis demonstrated that grip strength, DE, DTF, and the combination of grip strength with diaphragm ultrasound exhibited significant diagnostic values in ICU-AW ($P < 0.01$; refer to Figure 4). Among all included patients, the AUC for grip strength was 0.889, with a 95% CI of (0.808–0.969). Setting the cutoff value at grip strength < 9.1 kg resulted in a sensitivity of 0.742 and specificity of 0.907 for predicting ICU-AW. DE demonstrated an AUC of 0.706 (95% CI: 0.589-–0.822), with a cutoff value of DE < 2.23 cm yielding a sensitivity of 0.871 and specificity of 0.488. The AUC for DTF was 0.700 (95% CI: 0.574–0.827), and when using a cutoff value of DTF < 28%, the sensitivity was 0.71, and the specificity was 0.744. Combining grip strength < 9.1 kg and DTF < 28%, the AUC reached 0.950 (95% CI: 0.828–0.983), with a sensitivity of 0.844 and specificity of 0.884. Similarly, combining grip strength < 9.1 kg and DE < 2.23cm resulted in an AUC of 0.896 (95% CI: 0.817–0.975), a sensitivity of 0.875, and a specificity of 0.814. These

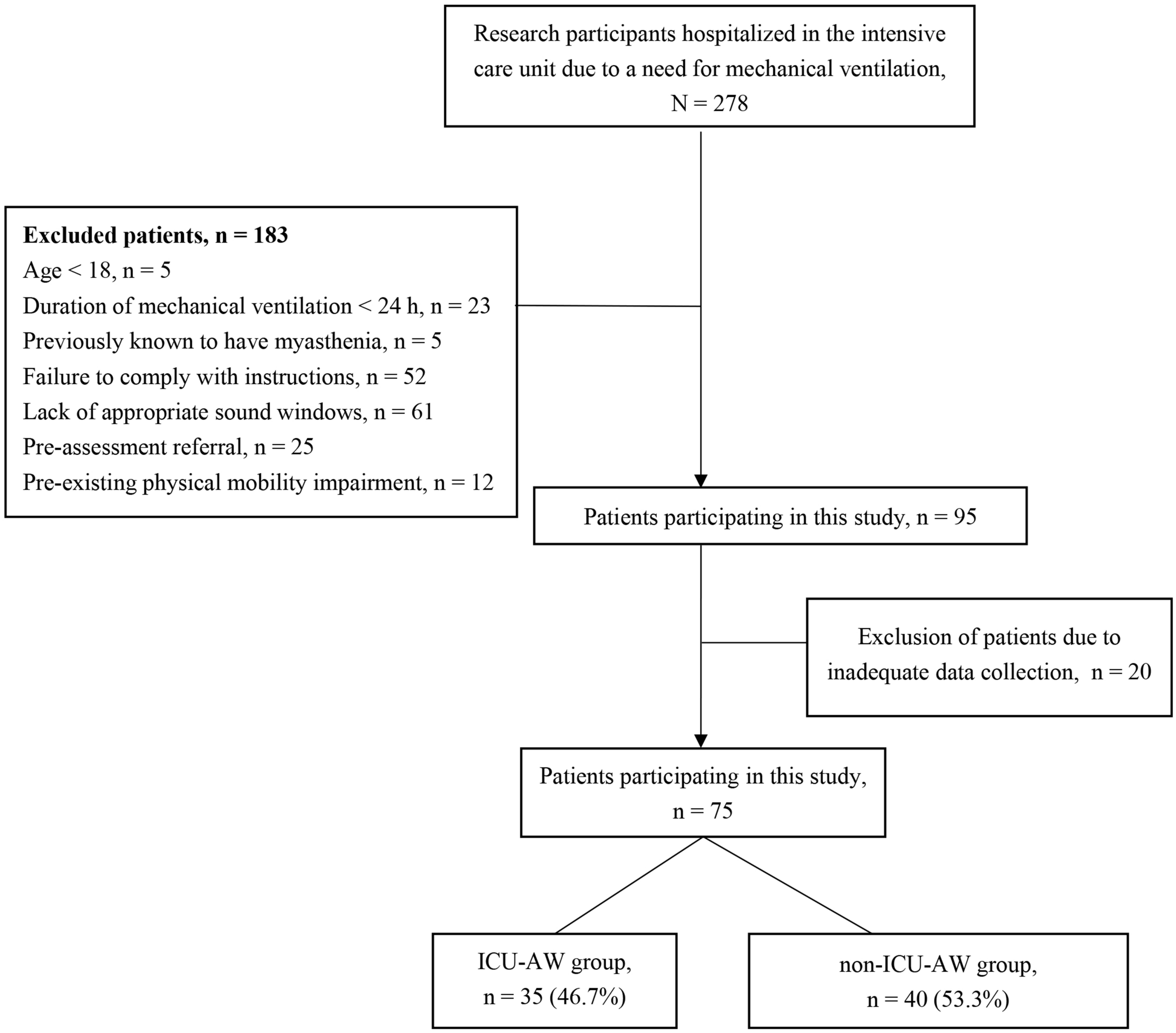

Figure 3 Flowchart of study selection.

findings underscored the significantly enhanced diagnostic value achieved through the combination of handgrip dynamometry with diaphragm ultrasound (refer to Table 3).

Considering the potential influence of gender on grip strength, a subgroup analysis based on gender was conducted using ROC curves (refer to Figure 4).[19] In male patients, grip strength, DE, grip strength combined with DE, and grip strength combined with DTF demonstrated diagnostic significance for the occurrence of ICU-AW in patients who were critically ill ($P < 0.05$). Setting the cutoff value at grip strength < 13.2 kg and DTF < 24%, the AUC was 0.879 (95% CI: 0.756–0.988), with a sensitivity of 0.842 and specificity of 0.883. In female patients, grip strength, DTF, grip strength combined with DE, and grip strength combined with DTF also exhibited diagnostic values for ICU-AW in patients who were critically ill ($P < 0.05$). Using the cutoff values grip strength < 9.5 kg and DTF < 28%, the AUC reached 0.964 (95% CI: 0.903–1.000), achieving a sensitivity of 1.000 and a specificity of 0.846, which were notably superior to other diagnostic tools (refer to Table 3).

Analysis on Risk Factors for Complication of ICU-AW in Patients Who are in the ICU

In the univariate analysis, indexes with a significance level of $P < 0.05$ in the comparison between the two groups were incorporated into the logistic regression analysis. The cut-off values selected were 7 days for the length of stay in the

Table 2 Comparison of General Data Between Mechanically Ventilated ICU-AW Group and Non-ICU-AW Group

Index	Total (n = 75)	ICU-AW (n=35)	Non-ICU-AW (n=40)	P value
Age, years, median (IQR)	64 (49, 73)	64 (49, 69)	65 (53, 73)	0.338
Male, cases (%)	49 (65.3%)	22 (62.8%)	30 (67.5%)	0.350
BMI, kg/m² ($\bar{x} \pm s$)	24.15±2.1	22.13±4.1	25.20±2.5	0.231
Complication				
Sepsis, cases (%)	34 (45.3%)	27 (84.3%)	7 (16.2%)	<0.01
Respiratory failure, cases (%)	39 (52%)	23 (65%)	16 (40%)	0.066
Acute kidney injury, cases (%)	15 (20%)	7 (20%)	8 (20%)	0.237
Operation history, cases (%)	45 (60%)	20 (62.5%)	24 (55.8%)	0.561
Past medical history				
Hypertension, cases (%)	16 (21.3%)	7 (21.8%)	9 (20.9%)	0.961
Diabetes, cases (%)	14 (18.4%)	7 (21.8%)	7 (16.3%)	0.538
Tumor history, cases (%)	42 (56%)	17 (53.1%)	25 (58.1%)	0.665
Drug use				
Muscle relaxant, cases (%)	5 (7%)	2 (6.2%)	3 (6.9%)	0.901
Hormone, cases (%)	13 (17.3%)	8 (25%)	5 (11.6%)	0.130
Parenteral nutrition, days, median (IQR)	4 (1, 6)	5 (1.25, 13.5)	2 (0, 4)	0.050
Enteral nutrition, days, median (IQR)	1 (0, 6)	17 (12, 23)	1 (0, 4)	0.824
Laboratory results				
Procalcitonin, mmol/L, median (IQR)	2.34 (0.27, 8.40)	2.48 (0.60, 8.40)	0.85 (0.16, 8.40)	0.445
Lactic acid, mmol/L, median (IQR)	1.6 (1.1, 2.3)	1.8 (1.4, 2.3)	1.5 (1.0, 2.3)	0.030
PH value, mmol/L, median (IQR)	7.39 (7.32, 7.44)	7.40 (7.36, 7.44)	7.39 (7.32, 7.42)	0.120
Indicators of disease severity				
APACHEII Score, points, median (IQR)	15 (10, 20)	17 (10, 23)	13 (9, 18)	0.070
SOFA Score, points, median (IQR)	9 (7, 10)	10 (8, 12)	7 (5, 10)	0.187
Prognostic indicators				
Mechanical ventilation days, days, median (IQR)	3 (2, 6)	6 (2, 10)	2 (2, 4)	<0.01
Successful extubation, cases (%)	66 (88%)	27 (77.1%)	39 (97.5%)	0.579
Length of ICU stay, days, median (IQR)	7 (5, 12)	11 (6, 23)	6 (4, 9)	<0.01
Improved, cases (%)	64 (85.3%)	27 (77%)	40 (100%)	0.840

Abbreviations: APACHEII, Acute Physiology and Chronic Health Evaluation; SOFA, Sequential Organ Failure Assessment.

ICU, 5 days for the duration of mechanical ventilation, and > 2 mmol/L for lactic acid. From the results, we discovered that a duration of mechanical ventilation exceeding 5 days emerged as a significant risk factor for the occurrence of ICU-AW in patients who were mechanically ventilated (P = 0.017) (refer to Table 4).

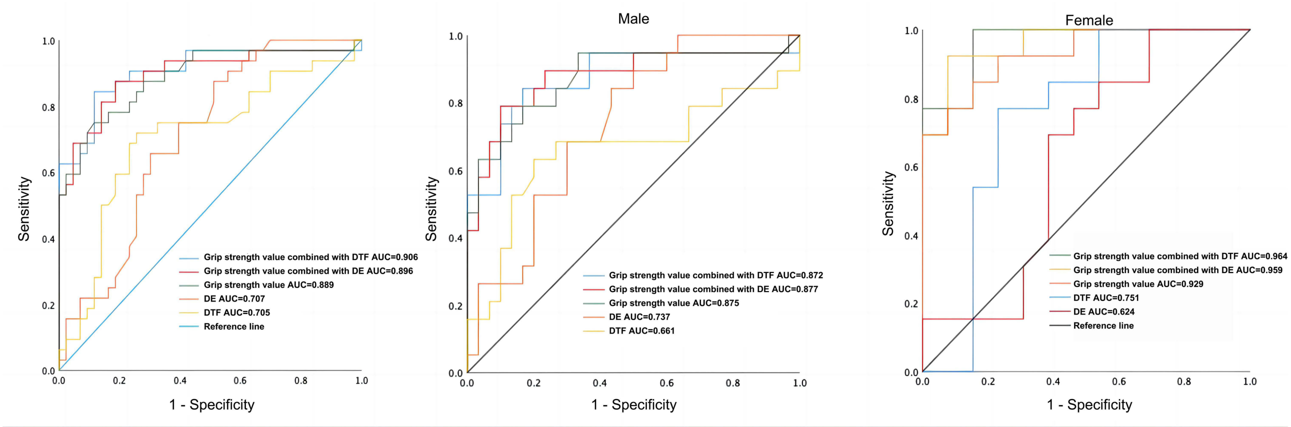

Figure 4 Comparison of diaphragm ultrasonography and handgrip dynamometer ROC curves for the identification of ICU-AW in patients who are mechanically ventilated.
Abbreviations: ICU-AW, ICU Acquired Weakness; DE, Diaphragmatic excursion; DTF, Diaphragm thickening fraction.

Discussion

Based on the results of this study, compared to patients in the non-ICU-AW group, those in the ICU-AW group exhibited diminished grip strength, reduced DE, and weakened diaphragm contraction function. Grip strength, DTF, DE, and the combination of grip strength with diaphragm ultrasound demonstrated diagnostic significance for the occurrence of ICU-AW in patients who were critically ill. Notably, the integration of grip strength with diaphragm ultrasound further enhanced the

Table 3 The Gender Analysis-Based Diagnostic Utility of Diaphragm Ultrasound and Handgrip Dynamometer in ICU-AW

Group	Index	AUC	95% CI	*P* value	Sensitivity	Specificity	Optimal Cut-Off Value
	Grip strength value (kg)	0.889	0.808–0.969	<0.01	0.742	0.907	9.1
	DE (cm)	0.706	0.589–0.822	<0.01	0.871	0.488	2.23
	DTF (%)	0.700	0.574–0.827	<0.01	0.710	0.744	28%
	Grip strength value combined with DTF	0.950	0.828–0.983	<0.01	0.844	0.884	
	Grip strength value combined with DE	0.896	0.817–0.975	<0.01	0.875	0.814	
Male	Grip strength value (kg)	0.875	0.762–0.987	<0.05	0.789	0.833	13.2
	DE (cm)	0.737	0.599–0.874	<0.05	0.842	0.567	2.22
	DTF (%)	0.661	0.485–0.368	>0.05	0.632	0.800	24%
	Grip strength value combined with DTF	0.879	0.756–0.988	<0.05	0.842	0.883	
	Grip strength value combined with DE	0.877	0.763–0.991	<0.05	0.789	0.900	
Female	Grip strength value (kg)	0.929	0.834–1.000	<0.05	0.920	0.769	9.5
	DE (cm)	0.624	0.398–0.850	>0.05	1.000	0.308	2.66
	DTF (%)	0.751	0.546–0.957	<0.05	0.769	0.769	28%
	Grip strength value combined with DTF	0.964	0.903–1.000	<0.05	1.000	0.846	
	Grip strength value combined with DE	0.959	0.890–1.000	<0.05	0.923	0.923	

Abbreviations: ICU-AW, ICU Acquired Weakness; OR, odds ratio; 95% CI, 95% confidence interval.

Table 4 Multivariate Logistic Regression Analysis of ICU-AW in Mechanically Ventilated Patients

Index	OR	95% CI	*P* value
Sepsis	1.004	0.340–2.969	0.994
Length of stay	1.516	0.448–5.135	0.503
Duration of mechanical ventilation	4.576	1.313–15.948	0.017
Lactic acid	2.024	0.672–6.095	0.210

Abbreviations: ICU-AW, ICU Acquired Weakness; OR, odds ratio; 95% CI, 95% confidence interval.

diagnostic value for the occurrence of ICU-AW in patients who were critically ill. Furthermore, a duration of mechanical ventilation exceeding 5 days served as a risk factor for the development of ICU-AW in patients who were critically ill.

Previous reports have indicated that a decline in muscle and nerve excitability could be observed in patients in the ICU-AW ward as early as 2 days following admission.[20] In this study, the incidence of ICU-AW was found to be 46.7%, and it was observed that the duration of mechanical ventilation and length of stay in the ICU were significantly prolonged in patients with ICU-AW. Hence, timely and accurate diagnosis was deemed crucial, emphasizing the potential utility of early mobilization strategies in the treatment of ICU-AW.[21] Traditionally, ICU-AW diagnosis has relied heavily on the MRC score; however, for patients who were critically ill, the MRC score presents limitations, including the necessity for professional knowledge training for the examiner and the prolonged duration of assessment. Consequently, the objective of this study was to explore a simplified and user-friendly diagnostic method as an alternative to the MRC score.

It was determined that the handgrip dynamometer exhibited high concordance with the MRC score in diagnosing ICU-AW, thereby indicating its potential as a substitute for the MRC score in clinical settings.[10] Specifically, a diagnosis of ICU-AW could be established when grip strength fell < 11 kg for males and < 7 kg for females.[7] However, the results from this study as per the ROC curve, indicated optimal cutoff values for grip strength of < 13.2 kg for males and < 9.5 kg for females in diagnosing ICU-AW. Notably, the relatively higher cutoff values in this study, attributed to a higher proportion of postoperative patients, shorter ICU stays, and the ability to engage in early activities, highlighted the potential influence of patient characteristics on diagnostic parameters. In an effort to enhance ICU-AW diagnosis, a dual diagnostic method proposed by Parry et al was explored. This method involved initial assessment of muscle strength using a handgrip dynamometer, followed by subsequent assessment with the MRC score. If grip strength was below the designated cutoff values and no discrepancies were observed in handgrip dynamometer results, the MRC score assessment might be omitted. The handgrip dynamometer method was identified as a more convenient alternative to the MRC method, providing practical implications in clinical practice.[22] Clinical observations have indicated that ICU-AW not only affects the extremities but also impacts respiratory muscles, particularly the diaphragm. The diaphragm, responsible for 60–80% of ventilation, plays a pivotal role in respiratory function. Dysfunction in the diaphragm, leading to delayed evacuation, can prolong the duration of mechanical ventilation.[23] The reduction in diaphragmatic contractility, as observed in the pathophysiology of diaphragmatic dysfunction, is attributed to a decline in contractile proteins and dysfunction of these proteins. The current gold standard for assessing diaphragmatic contractility in patients who are mechanically ventilated involves measuring changes in endotracheal pressure induced by magnetic stimulation of the phrenic nerve during airway occlusion (Ptr, magn). An advantage of this method is its ability to be performed at the bedside without requiring patient cooperation. A study reported that Ptr, magn was measured for 85 patients who were critically ill within 24 hours of mechanical ventilation, revealing that Ptr, magn in 54 patients (64%) was < 11 cm H_2O, indicating a diagnosis of diaphragmatic dysfunction. However, due to its invasive nature and technical challenges, phrenic nerve stimulation has not been routinely used in clinical practice.[24] Bedside ultrasound has been investigated as an alternative method for continuous monitoring of diaphragmatic function in mechanically ventilated patients, providing early prediction and diagnosis of diaphragmatic dysfunction. Specifically, a diaphragmatic excursion (DE) of < 1.4 cm (right) and < 1.2cm (left) has been indicated to indicate diaphragmatic dysfunction.[25] In this study, only the right diaphragm was assessed, yielding an AUC for DE of 0.706 (95% CI: 0.589–0.822). With a cutoff value of DE < 2.23 cm, the sensitivity was 0.871, and the specificity was 0.488. Gender-based analysis indicated that DE had diagnostic value for the occurrence of ICU-AW in male but not female patients. The higher optimal cutoff value in this study was influenced by the characteristics of the included patients, predominantly postoperative with generally normal respiratory function, as well as the small sample size, emphasizing the need for validation with a larger sample. Recent studies have identified DTF as an ideal indicator for diagnosing diaphragmatic dysfunction, with DTF < 30% indicating dysfunction.[14] In this study, results indicated that for all included patients, a DTF < 28% could lead to a diagnosis of ICU-AW, consistent with findings from most studies.[26] Further gender-based analysis revealed that DTF had diagnostic value in female patients (P < 0.05), while in male patients, DTF revealed no diagnostic value in ICU-AW. These results highlight the importance of recognizing gender-based differences in diagnostic indicators during clinical practice. The above results indicate a low consistency between DE /DTF and the MRC score, with this relationship being influenced by gender. Consequently, in clinical practice, it is imperative to be cognizant of the variations in the indicators of interest among different genders.

For patients who are critically ill, the presence of limb weakness is often correlated with diaphragmatic dysfunction. In light of this, a hypothesis was formulated that combining grip strength with diaphragm ultrasound might enhance the diagnostic accuracy of ICU-AW. The results aligned with this hypothesis, indicating that the combination of grip strength and diaphragm ultrasound yielded a high diagnostic value for ICU-AW in patients who are mechanically ventilated. Subgroup analysis based on gender further demonstrated that this combined approach maintained a high diagnostic value for both male and female patients. Currently, aside from the MRC score, there are no other straightforward and precise methods for diagnosing ICU-AW. The results of this study indicate that the integration of handgrip dynamometry with diaphragm ultrasound could serve as an initial diagnostic step for ICU-AW in clinical practice. If the measurement falls outside the designated cutoff values, subsequent MRC assessment could be pursued; otherwise, only the initial step would be necessary. It is essential to note that the findings of this study should undergo further validation with a larger sample size to enhance the robustness of the results.

A meta-analysis revealed a significant association between APACHE II, neuroleptic agents, and aminoglycosides, with other identified risk factors encompassing age, gender, multi-organ failure, systemic inflammatory response syndrome, sepsis, electrolyte disorders, hyperosmosis, elevated lactate levels, duration of mechanical ventilation, parenteral nutrition, and the use of noradrenaline.[8] Along with these findings, the present study demonstrated statistically significant differences in sepsis, duration of mechanical ventilation, length of stay in the ICU, and lactate levels between the ICU-AW group and non-ICU-AW group ($P < 0.05$), while differences in other indicators were not statistically significant. Multifactorial regression analysis identified the duration of mechanical ventilation exceeding 5 days as the primary risk factor for the occurrence of ICU-AW. The manifestation of ICU-AW extended the duration of mechanical ventilation and hospital stay, impacting the long-term quality of life for patients. Therefore, the early diagnosis and prevention of ICU-AW are deemed crucial.

This study is subject to certain limitations: 1) Difficulty in differentiating conditions: The assessment of muscle strength using the MRC scale encountered challenges in differentiating between conditions corresponding to 4 points and 5 points, introducing potential ambiguity. 2) Subjective impressions in diaphragm ultrasound: The measurement of diaphragm ultrasound was susceptible to subjective impressions from physicians, introducing a potential source of bias. 3) Small sample size: The sample size of this study was relatively small, and as such, the results may benefit from validation through further investigations with larger sample sizes to enhance statistical robustness and generalizability. These limitations underscore the importance of interpreting the study findings with caution and highlight areas for improvement and refinement in future research endeavors.

Conclusion

Grip strength, DE, DTF, and the combination of handgrip dynamometer with diaphragm ultrasound demonstrated diagnostic value in identifying ICU-AW. However, notably, the combination of grip strength with diaphragm ultrasound exhibited a superior diagnostic performance in patients who are critically ill with ICU-AW compared to individual assessments.

Data Sharing Statement

The relevant supporting data are available from the author upon request.

Ethics Approval and Consent to Participate

The study was conducted in accordance with the Declaration of Helsinki. The study was approved by Ethics Committee of the Fourth Hospital of Hebei Medical University (No.2019150). Written informed consent was obtained from all participants.

Acknowledgments

We are particularly grateful to all the people who have given us help with our article.

Disclosure

The authors declare that they have no competing interests in this work.

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