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Impact of high-protein enteral nutrition on muscle preservation in mechanically ventilated patients with severe pneumonia: a randomized controlled trial

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Abstract

Background This study aimed to assess the effects of enteral nutrition with different protein concentrations on muscle mass in severe pneumonia patients, providing insights for enteral nutrition practice in intensive care units (ICUs).

Methods A total of 120 severe pneumonia patients admitted to Dazhou Central Hospital's ICU between June 1, 2022, and February 1, 2023, meeting inclusion criteria, were randomly assigned to either a high-protein group ($n=60$, 1.8 g/kg/d) or a standard-protein group ($n=60$, 1.2 g/kg/d). Changes in relevant indicators were monitored on days 1, 5, and 10 of ICU admission, including quadriceps and diaphragm thickness, nutritional status (prealbumin and albumin), and adverse events such as diarrhea and constipation.

Results Autoregressive of order 1 model (AR(1)) analysis revealed a decrease in both quadriceps and diaphragm thickness over time in both groups. A significant group × time interaction was observed in quadriceps thickness. By day 10, compared to baseline, quadriceps thickness decreased in the high-protein (-0.315 cm [95% CI, -0.340 to -0.289]) and standard-protein (-0.429 cm [95% CI, -0.455 to -0.404]) groups. The high-protein group exhibited a lower quadriceps atrophy rate (13.97 ± 2.43%) compared to the standard-protein group (18.96 ± 2.61%), showing a significant difference ($P<0.001$). No significant differences were found in diaphragmatic thickness between groups and over time. By day 10, both groups exhibited decreased diaphragmatic muscle thickness compared to baseline. The high-protein group (33.76 ± 5.09%) had a slightly lower phrenic atrophy rate compared to the standard-protein group (33.41 ± 4.53%). Both groups experienced enteral nutritional intolerance manifested as diarrhea, constipation, and other adverse events.

Conclusion High-protein enteral nutrition significantly improved quadriceps thickness and demonstrated good safety in severe pneumonia patients, suggesting its suitability for widespread clinical application.

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Keywords Severe pneumonia, Enteral nutrition, Quadriceps muscle layer thickness, Diaphragmatic thickness, Muscle wasting

Introduction

Severe pneumonia poses a significant threat to patients in intensive care units (ICUs) [1] due to its high mortality rate, numerous complications, and poor prognosis, imposing a substantial global economic and social burden [2]. Patients afflicted with this disease often necessitate mechanical ventilation, bed rest and other treatments during hospitalization, all of which increase the risk of malnutrition, which can lead to the loss of skeletal muscle throughout the body [3–5]. Failure to address these conditions can result in challenges with weaning off mechanical ventilation, prolonged extubation duration and increased failure rates, heightened incidence of ICU-acquired weakness, and prolonged hospital stays [6]. Some observational studies have indicated that higher protein intake may yield better patient outcomes than higher total energy delivery [7, 8], underscoring the critical importance of protein provision in intensive care settings.

However, findings from randomized controlled trials investigating protein-based nutritional support have yielded conflicting results. Although several randomized controlled trials have investigated protein-supported therapies at different concentrations, only a few have reported positive outcomes with high protein regimens [9–12]. One reason for this inconsistency is the simultaneous elevation of total energy intake alongside increased protein provision in many studies. Additionally, the outcomes of nutritional therapy may hinge on its precise implementation.

Recently, muscle thickness has been seen as an important indicator of the efficacy of nutritional interventions [13]. Muscles serve as sensitive markers of protein synthesis and breakdown in response to nutrition. Moreover, post-intensive care physical dysfunction, known as Post-Intensive Care Syndrome or ICU-acquired weakness, underscores the significance of assessing skeletal muscle status [14]. Direct measurements of skeletal muscle provide accurate insights into the efficacy of nutritional support. While computed tomography (CT) scans offer precise muscle measurements [15], their real-time application in clinical decision-making may be impractical. Conversely, bedside ultrasound, owing to its portability, non-invasiveness, and ease of use, has gained prominence for assessing skeletal muscle in clinical settings.

Therefore, this study aimed to investigate the impact of enteral nutrition with different protein concentrations on peripheral skeletal muscle thickness and related nutritional parameters in severe pneumonia patients. By assessing its effects on the preservation of muscle mass in critically ill patients, this research seeks to provide valuable insights into nutritional support strategies for severe pneumonia patients.

Materials and methods

Study design

This single-center, randomized, controlled, double-blind, prospective clinical study was conducted in accordance with the Declaration of Helsinki and has received approval from the Ethics Committee of Dazhou Central Hospital (Ethical Application Ref: 2019021). Researchers have explained the study protocol to all patients or their legal representatives and have obtained written informed consent. Strict confidentiality is maintained for clinical information such as the names and home addresses of the research subjects. Screening all patients with severe pneumonia admitted to the Intensive Care Unit of Dazhou Central Hospital from June 1, 2022, to February 1, 2023.

Participants

One hundred and twenty patients with severe pneumonia were ultimately recruited for this study. The inclusion criteria for this study required patients to be 18 years or older, meet the diagnostic criteria for severe pneumonia according to the "Chinese Adult Community-Acquired Pneumonia Diagnosis and Treatment Guidelines (2016 Edition)," require mechanical ventilation and enteral nutrition, have an expected ICU stay of more than 10 days, and have complete clinical data. The exclusion criteria ruled out patients whose family members refused participation, those with a history of neurological or neuromuscular diseases, those with lower limb amputations, external fixators, or limb fractures, patients with severe liver or kidney impairment, pregnant patients, those who recently received nutritional support, patients with gastrointestinal diseases, obese patients (BMI>45 kg/m^2), and those with concurrent malignant tumors. The elimination criteria included subjects who requested to withdraw, patients who received enteral nutrition support for less than 10 days or required parenteral nutrition during the study period, and patients with incomplete clinical data. Reasons for withdrawal or discontinuation of enteral nutrition were recorded.

Sample size

In the population of patients with severe pneumonia, there have been no similar studies in the past. The sample size and power calculations are based on our preliminary pre-experiment results ($n=30$). We observed that on the

10th day of ICU stay, the ultrasound-measured quadriceps muscle layer thickness (QMLT) in the intervention group decreased by 0.32±0.11 cm, while it decreased by 0.43±0.19 cm in the control group. Setting a two-sided $\alpha=0.05$ and a test power (1-β) of 80%, and considering a 20% loss to follow-up, we used PASS 15 software (Power Analysis and Sample Size) to calculate a total sample size of $N=84$ for both groups. Referencing recently published literature [10, 16], we expanded the sample size, and the study ultimately included 120 patients.

Randomization and masking

According to the random number table method, the enrolled patients were divided into 2 groups by simple randomization, namely the high protein group, and were given enteral nutrition with the target protein of 1.8 g/kg/d. Standard protein group, administered enteral nutrition with a target protein of 1.2 g/kg/d. Sequentially numbered, light-tight sealed envelopes will be kept by the research assistant after randomization and held by the research assistant who is not involved in the study, and if the patient drops out during the study, the envelope will be returned to the replacement sequence until the sample size of each group (60 patients per group) is completed.

The study was conducted in a double-blind trial (neither the investigator nor the subjects were aware of the nutritional regimen). On the day of admission to the ICU, the research assistant delivered the envelope to the researcher, the researcher first collected the patient's corresponding clinical data, and then calculated the protein, fat and carbohydrate needed by the patient, and informed the nutrition department to distribute the corresponding nutritional preparations.

Intervention

The energy and protein supply for all severe pneumonia patients were calculated based on Ideal Body Weight (IBW). For the first 10 days of ICU admission, the energy supply was set at 25 kcal/kg/d. The high-protein group received enteral nutrition with a target protein supply of 1.8 g/kg/d, while the standard-protein group received a target protein supply of 1.2 g/kg/d. Both groups of patients underwent standard ICU treatment, which included the management of primary diseases, correction of fluid and electrolyte imbalances, and mechanical ventilation. The treatment principles were in accordance with the "Chinese Expert Consensus on Clinical Practice for Emergency Severe Pneumonia," and patient care was conducted following the recommendations of this consensus. Apart from differing protein dosages, both groups received medical, nursing, and rehabilitative exercise interventions.

Endpoints

The primary endpoint of this study is quadriceps thickness. The secondary endpoints of this study is diaphragm thickness and nutritional indexes.

Ultrasound measurement method for (quadriceps muscle layer thickness) QMLT

The QMLT measurements were conducted using the high-frequency linear probe (8 MHz) in B-mode ultrasound examination with the Mindray M9 system. A fixed measuring point was selected at the lower one-third between the right anterior superior iliac spine (ASIS) and the upper pole of the patella. This point was marked on the skin to ensure consistent probe placement during each measurement. Subjects were positioned in supine, with full exposure of the thigh, knee extended, and toes pointing towards the ceiling. The probe was placed perpendicularly on the marked point on the anterior thigh. For each measurement, the probe was oriented perpendicularly to the long axis of the limb and applied with minimal skin indentation. A static image was captured using the "Freeze" button, followed by distance measurement of quadriceps muscle thickness using planimetric techniques: specifically, the linear horizontal distance from the fat-muscle interface to the bone surface.

Ultrasound measurement method for diaphragm thickness

The diaphragm thickness was also measured using the high-frequency linear probe (8 MHz) in B-mode ultrasound examination with the Mindray M9 system. Subjects were positioned in supine, and the measuring point was selected at the right mid-axillary line between the 7th and 8th ribs. The probe marker was oriented towards the patient's head, and the point was marked on the skin to ensure consistent probe placement. In 2D mode, the diaphragm was located, and a static image was captured using the "Freeze" button. The diaphragm thickness was then measured using planimetric techniques: specifically, the distance between the pleura and the peritoneum. All ultrasound measurements were performed by the same experienced operator. Each measurement was repeated three times, and the mean value was used as the final value.

Data collection

The study records general clinical data such as the patient's gender, age, height, weight, APACHE II score, SOFA score, and underlying diseases. Measurements of the quadriceps femoris muscle and diaphragm thickness are taken on the day of ICU admission, the 5th day, and the 10th day. Nutritional status indicators, as well as the incidence of gastrointestinal intolerance conditions like diarrhea and constipation, are also recorded on the day of ICU admission, the 5th day, and the 10th day. The

thickness of the quadriceps femoris and the diaphragm will be obtained from ultrasound images and data.

Statistical analysis

All data were analyzed using SPSS 22.0 statistical software. For data that followed a normal distribution, the mean±standard deviation ($\bar{x} \pm s$) was used to describe the data distribution. Intra-group and inter-group comparisons were analyzed using a linear mixed effects model: the fixed effects included group, time, and group × time interactions. Gender, age, height, weight admitted to ICU, baseline Nutric score, baseline APACHE2 total score and baseline SOFA score were covariates. Autoregressive of order 1 model (AR(1)) to deal with the correlation of participants' measured results at different points in time [17]. For non-normally distributed data or data with unequal variances, the median (M) and interquartile range (IQR) were used, and the Wilcoxon rank-sum test was applied. Diaphragm thickness and QMLT at different time points was assessed using a 2×3 (group × time) repeated-measures ANOVA with the same factors. Alpha significance was set a priori at $p<0.05$. Count data were represented as percentages (%), and the chi-square test was used. The significance level α was set at 0.05, and $P<0.05$ was considered statistically significant.

Results

Comparison of baseline characteristics in both groups

From June 2022 to February 2023, a total of 426 patients were screened, with 83 not meeting the inclusion criteria and 211 being excluded (Fig. 1). Consequently, 132 patients were recruited. During the analysis, 2 patients were excluded due to partial data loss and 10 died within 72 h of ICU admission, leaving 120 patients for baseline ultrasound analysis.

Statistical analysis was conducted on the remaining 120 patients, comprising 60 in the high-protein group and 60 in the standard-protein group. The cohort included 80 males and 40 females, with an average age of 61.4±12.01 years. The history of comorbidities included 37 patients with diabetes, 11 with a history of stroke, and 7 with chronic obstructive pulmonary disease (COPD). Baseline characteristics such as gender, age, height, actual weight, BMI, APACHE II score, SOFA score, and comorbidities were balanced between the two groups, showing no statistically significant differences ($P>0.05$), as presented in Table 1.

Upon ICU admission, mNUTRIC scores were calculated for both groups. On Day 1 (D1), 62 patients (51.7%) had baseline mNUTRIC scores<5, indicating low nutritional risk, while 58 patients (48.3%) had scores>5, indicating high nutritional risk, with a relatively higher proportion in the standard-protein group. The baseline nutritional risk assessment revealed a high prevalence of nutritional risk in both groups, accounting for nearly 50%, as shown in Table 1.

Comparison of QMLT between the two groups

Compared with the standard protein group, the high protein group can significantly slow down the rate of decrease in quadriceps thickness (Table 2). On Day 5, the QMLT of both groups had decreased compared to the baseline, but the difference was not statistically significant ($P=0.745$). On Day 10, the QMLT of both groups had further decreased, and the decline was slower in the high-protein group compared to the standard protein group, with the difference being statistically significant ($P=0.025$), as shown in Fig. 2A. We also observed the trend changes in QMLT and found a more significant decline in the standard-protein group between Day 5 and Day 10. The QMLT atrophy ratio was calculated and compared between the groups. During Day 1-Day 5, QMLT decreased by approximately 11% in both groups. Specifically, the standard-protein group saw a decrease of 0.267±0.735 cm (11.83±2.95%), and the high-protein group saw a decrease of 0.246±0.693 cm (10.89±2.96%). The absolute numbers in the high-protein group were noticeably lower compared to the standard protein group, but the difference was not statistically significant ($P=0.093$). During Day 5-Day 10, the QMLT of both groups continued to decline, but the decline in the high-protein group was significantly slower.

The results of AR(1) showed that the group factor itself had no significant effect ($P=0.440$). However, time had a significant effect on the atrophy of quadriceps muscle thickness ($F=158.108$, $P<0.001$). The interaction between group and time was significant, indicating that the different protein doses significantly influenced QMLT over time ($F=34.972$, $P<0.001$). The differences in QMLT from baseline at Day 10 were −0.315 cm (95%CI, -0.340 to -0.289) in the high protein group and −0.429 cm (95%CI, -0.455 to -0.404) in the standard protein group. This corresponded to 13.97±2.43% and 18.96±2.61% of the mean baseline values, respectively, as shown in Fig. 2B. The trend chart revealed that QMLT decreased over time, with the decline significantly slowing between Day 5 and Day 10 in the high-protein group (Fig. 2A). AR(1) autocorrelation coefficient was 0.291785, with no significant statistical significance ($P=0.068>0.05$).

Comparison of diaphragm thickness between the two groups

The effect of high-protein intake on diaphragm thickness was not statistically significant compared to the standard-protein group (Table 3). On Day 5, the diaphragm thickness of both groups had decreased compared to the baseline, but the difference was not statistically significant ($P=0.800$). On Day 10, diaphragm thickness had

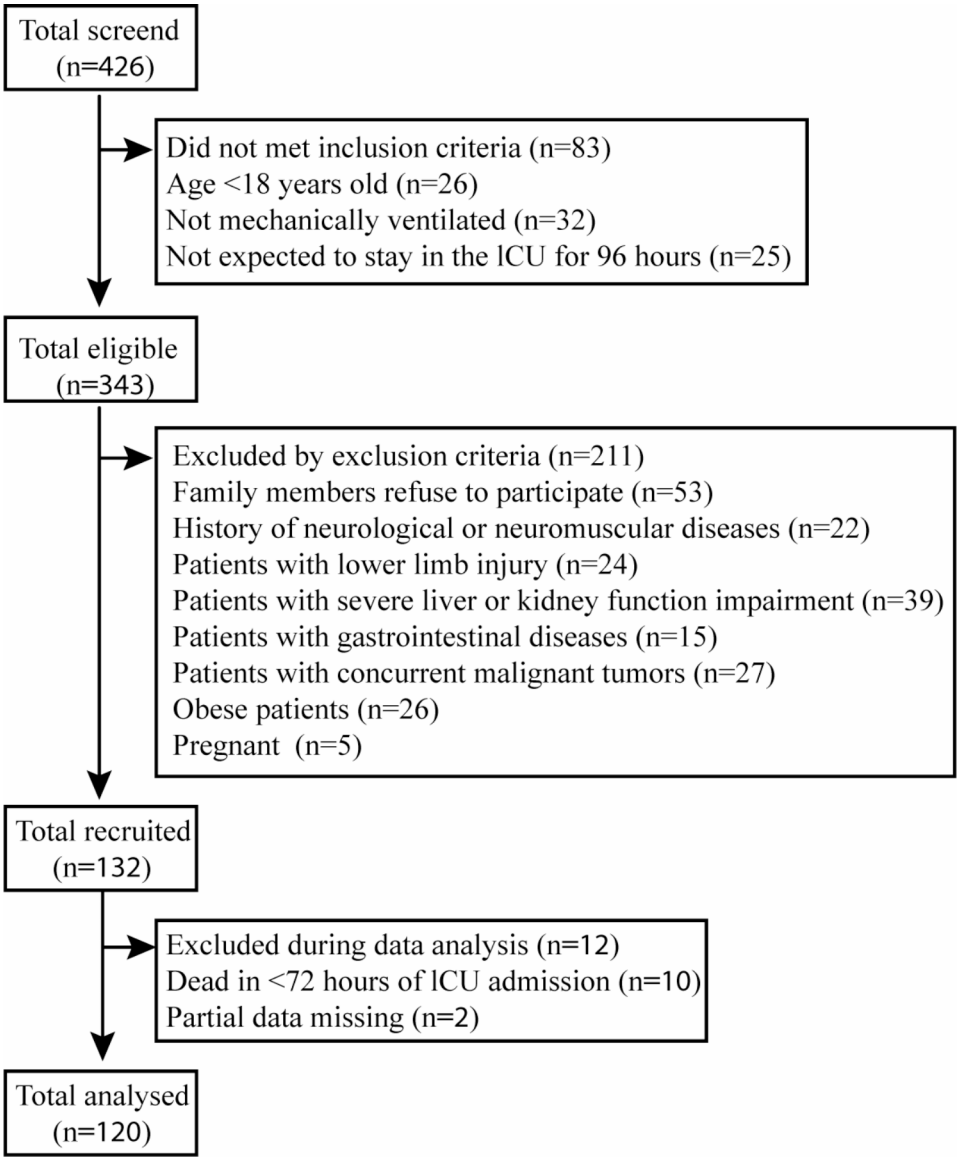

Fig. 1 Inclusion and exclusion of the recruited patients. A total of 426 patients were screened, with 83 not meeting the inclusion criteria and 211 being excluded. Consequently, 132 patients were recruited. During the analysis, 2 patients were excluded due to partial data loss and 10 died within 72 h of ICU admission, leaving 120 patients for baseline ultrasound analysis

further atrophied in both groups, with a slower decline compared to earlier measurements. The high-protein group showed relatively less atrophy compared to the standard protein group, but the difference was not statistically significant (P=0.873), as detailed in Fig. 3A. The decline in diaphragm thickness was more pronounced between Day 1 and Day 5. Despite the absolute values in the high-protein group being lower than those in the standard-protein group at each time point, the differences were not statistically significant. Therefore, we calculated the diaphragm atrophy ratio and compared it between the groups. On Day 5, the diaphragm thickness of both groups had significantly atrophied compared to the baseline, with the high-protein group at 26.57±2.97% vs. the standard protein group at 26.14±3.41%, but the difference was not statistically significant (P=0.465). On Day 10, further atrophy was observed in both groups compared to baseline and Day 5, but the degree of atrophy was less severe, with the high-protein group at 33.76±5.09% and the standard-protein group at 33.41±4.53%, and again, the difference between the two groups was not statistically significant (P=0.694), as detailed in Fig. 3B.

Comparison of nutritional indexes between two groups

Compared with the standard protein group, the high protein group showed a more significant improvement in nutritional indexes. On Day 5, albumin levels in both

Table 1 Baseline characteristics of patients

	Standard protein group (*n* = 60)	high protein group (*n* = 60)	t/x^2 value	*P* value
Age (year,±s)	61.70 ± 12.17	61.15 ± 11.95	0.25	0.80
Gender				
Male [n (%)]	41 (68.3)	39 (65)	0.15	0.70
Female [n (%)]	19 (31.7)	21 (35)		
Height (cm,±s)	167.25 ± 7.57	167.30 ± 7.05	-0.04	0.97
Weight (kg,±s)	63.81 ± 10.62	64.19 ± 10.61	-0.19	0.85
IBW (kg,±s)	60.03 ± 3.9	60.23 ± 3.65	-0.28	0.78
BMI (kg/m^2, ±s)	22.75 ± 3.02	22.85 ± 2.86	-0.19	0.85
APACHE II [score, ±s]	20.67 ± 5.92	19.17 ± 5.47	1.4	0.15
SOFA [score,±s]	6.93 ± 3.16	6.43 ± 2.41	0.97	0.33
Comorbidity				
Diabetes [n (%)]	18 (30)	19 (31.6)	0.039	0.84
Stroke [n (%)]	5 (8.3)	6 (10)	0.100	0.75
COPD [n (%)]	3 (5)	4 (6.7)	0.000	1.0
mNUTRIC score				
<5	29 (48.3)	33 (55)	0.23	0.62
≥ 5	31 (51.7)	27 (45)	0.17	0.67

Table 2 Comparison of QMLT between the standard-protein and high-protein groups

QMLT (cm, ±s)	Standard protein group (*n* = 60)	high protein group (*n* = 60)	t/x^2 value	*P* value
Day1	2.25 ± 0.33	2.25 ± 0.3	0.08	0.93
Day5	2.047 ± 0.26	1.95 ± 0.31	1.8	0.07
Day10	1.92 ± 0.24	1.84 ± 0.3	1.6	0.12

groups declined, but the decrease was less pronounced in the high-protein group (31.83 ± 5.26 g/L) compared to the standard-protein group (29.50 ± 5.83 g/L), with the difference being statistically significant (P = 0.023),

Table 3 Comparison of diaphragm thickness between the two groups

Diaphragm thickness (cm, ±s)	Standard protein group (*n* = 60)	high protein group (*n* = 60)	t/x^2 value	*P* value
Day1	2.38 ± 0.25	2.41 ± 0.23	0.66	0.51
Day5	1.76 ± 0.23	1.77 ± 0.22	0.25	0.8
Day10	1.6 ± 0.27	1.64 ± 0.24	0.16	0.87

as shown in Fig. 4A. In terms of prealbumin levels, the standard-protein group showed a significant decreasing trend, while the decline in the high-protein group was not significant. The difference was statistically significant (P < 0.001). On Day 10, both albumin and prealbumin levels had improved in both groups compared to Day 5, as shown in Fig. 4B.

Discussion

Our main findings in the study are: (1) The high-protein group significantly slowed the rate of decrease in quadriceps thickness compared to the standard-protein group. (2) Compared with the standard protein group, the effect of high protein group on diaphragm thickness was not statistically significant. (3) The high-protein group showed more significant improvements in nutritional indexes compared to the standard-protein group.

Current data indicate that the average protein intake for critically ill patients is around 0.6 g/kg/d [18–20]. This data drives us to conduct prospective randomized controlled clinical trials on high-protein enteral nutrition to explore the best nutritional support strategy for critically ill patients. In this study, we used AR(1) to analyze the effects of time and intake of two different protein doses on the thickness of the quadriceps muscle. AIC= -516.425 and BIC= -504.817 indicate that the model fits

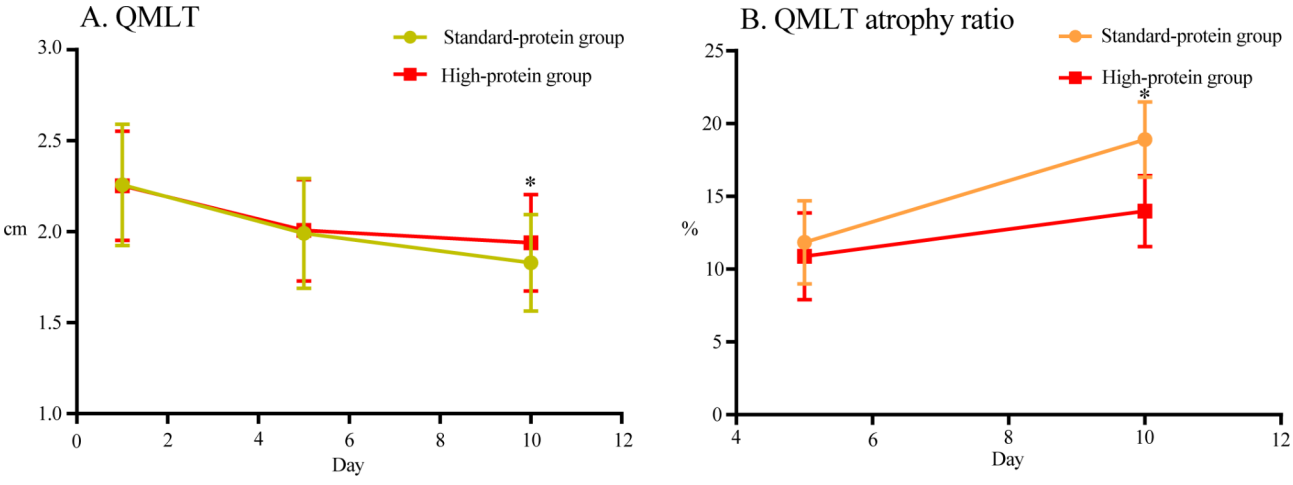

Fig. 2 Comparison of QMLT Between the standard-protein Group and High-protein group. (**A**) The QMLT data of two groups on day 1, 5, and 10. (**B**) The QMLT atrophy ratio on day 5 and day 10, as comparing to the QMLT on day 1. Data are presented as mean ± SD. "Asterisk" indicates a significant difference between the two groups (p < 0.05)

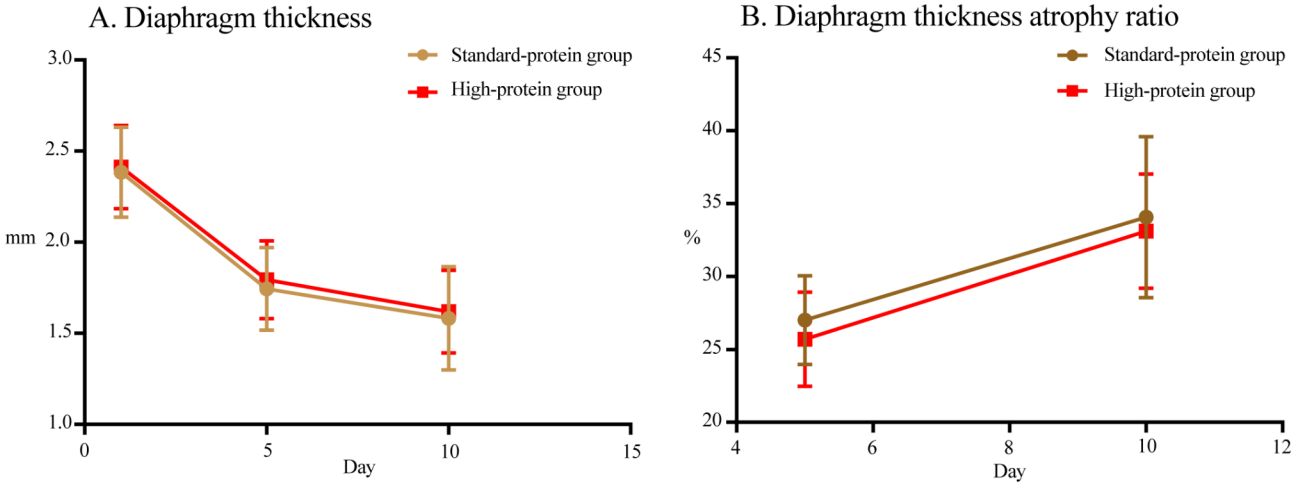

Fig. 3 Comparison of diaphragm thickness between the standard-protein Group and High-protein group. (**A**) The diaphragm thicknesses of two groups on day 1, 5, and 10. (**B**) The diaphragm atrophy ratio on day 5 and day 10, as comparing to the diaphragm thickness on day 1. Data are presented as mean ± SD. "Asterisk" indicates a significant difference between the two groups ($p < 0.05$)

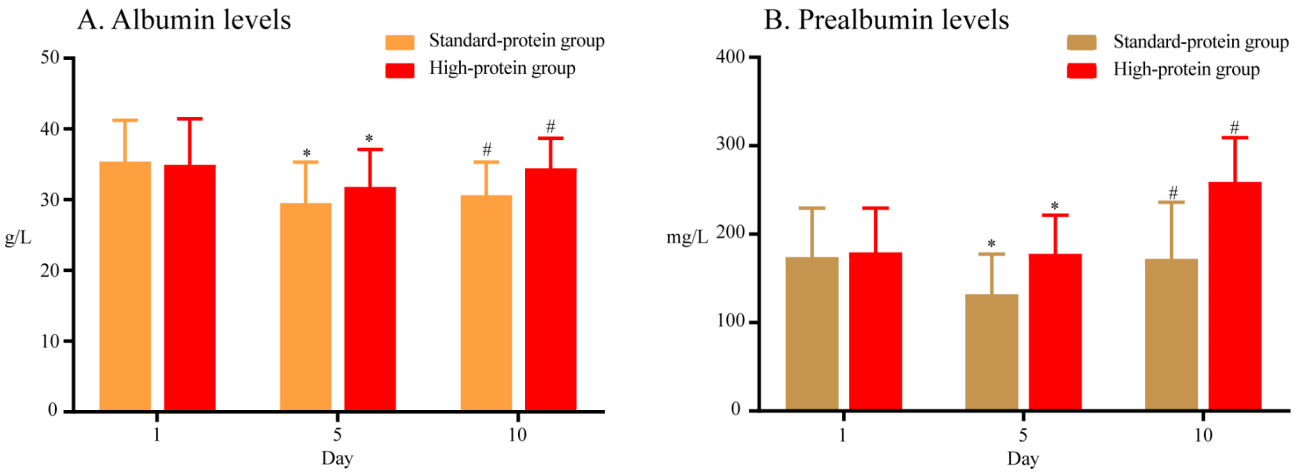

Fig. 4 Comparison of nutritional indexes between the standard-protein Group and High-protein group. (**A**) The albumin levels in two groups on day 1, 5, and 10. (**B**) The albumin levels in two groups on day 1, 5, and 10. Data are presented as mean ± SD. "Asterisk" indicates that, comparing to day 1, the decline of the measured parameters of two groups on day 5 was significantly different ($P < 0.001$); "Well" indicates that, comparing to day 5, the increase of the measured parameters of two groups on day 10 was significantly different ($P < 0.001$)

the data well. The results showed that QMLT decreased over time in both groups, with time being an important factor, which may be related to the duration of treatment or different stages of the disease process. Nakamura et al. evaluated the effects of high protein (1.8 g/kg/d) and medium protein supply (0.9 g/kg/d) on QMLT in a randomized controlled trial, and their results showed that high protein supply was associated with a lower decrease in QMLT (12.9±8.5%) [16]. Our results also showed that high-protein EN can reduce quadriceps atrophy in patients with severe pneumonia and preserve more quadriceps in the acute phase of critically ill patients, but it takes some time to produce a significant effect. However, the group factor itself did not have a significant effect, but the interaction between the group and time was significant, indicating that the high-protein group could slow down the atrophy of the quadriceps muscle over time and retain more quadriceps muscle in the acute phase of critically ill patients, but it took some time to produce a significant effect. The AR(1) coefficient of the model was 0.291785 (P=0.068), indicating that the correlation between the measurement time points was poor, so we speculated that different albumin nutritional treatment strategies might yield different effects at different time points. Dresen et al [21]. conducted a randomized controlled trial to evaluate the impact of enteral and/or parenteral nutrition with target proteins of 1.8 g/kg/d and 0.9 g/kg/d on QMLT under equal energy intake. The actual protein supply did not meet the target; They also observed a decrease in QMLT over time (P<0.001) in

both groups of patients, but the estimated average daily changes in QMLT were −0.15±0.08 mm for the intervention group and −0.28±0.08 mm for the standard group, respectively, with no significant difference between the groups. This contrary conclusion, which supports differences in the timing of protein nutrition strategy initiation on peripheral skeletal muscle, may guide us to conduct a more detailed analysis of the effects of different nutritional treatment strategies at different time points. In addition, the data from our study showed no improvement in diaphragmatic atrophy in either group. This trend is consistent with the findings of Schepens et al., who conducted a longitudinal cohort study assessing diaphragm atrophy in mechanically ventilated patients through ultrasound and concluded that the most significant atrophy occurred within one week [22]. A prospective observational study by Grassi et al. confirmed the impact of mechanical ventilation modes on diaphragm thickness, showing a significant reduction during controlled ventilation and partial recovery during assisted ventilation [23]. Therefore, diaphragm atrophy may be associated with longer durations of controlled ventilation and higher levels of Positive End-Expiratory Pressure (PEEP).

Prealbumin, with a half-life of only 2.5 days, is a sensitive indicator of nutritional status and the dynamic changes in nutritional metabolism after nutrient intake [24]. When protein intake is sufficient, prealbumin levels can rise rapidly. The results of this study show that there was no statistical significance in albumin levels between the two groups on Day 5, but there was statistical significance on Day 10. The prealbumin levels in both groups were statistically significant on both Day 5 and Day 10. These data indicate that the nutritional status of patients in both groups improved significantly. Neither group of patients experienced any severe adverse events. This aligns with the findings of Chapple et al., who conducted a randomized cohort study using 1.5 g/kg/d of high-protein enteral nutrition and reported no severe adverse events [25]. Similarly, Rugeles et al. safely administered 1.7 g/kg/d of high-protein, low-calorie enteral nutrition without any severe adverse events, consistent with our study conclusions [26].

However, this study has certain limitations. Firstly, it is a single-center clinical study with a small sample size, which inherently limits its generalizability. Secondly, the observation period was short, and no follow-up on long-term prognostic indicators was conducted. The protein EN doses in both groups were 1.2 g/kg/day and 1.8 g/kg/day. Further research is needed to verify whether higher protein intake would be more beneficial for patients with severe pneumonia, and whether the same conclusions apply to critically ill patients admitted to the ICU within the first 10 days with high-protein EN. Prospective, multi-center, large-sample randomized controlled clinical studies are needed to assess the relationship between early protein supply and peripheral muscle in critically ill patients to develop the best nutritional treatment plan. In addition, Future studies should consider evaluating treatment intervals and duration in more detail and how they affect the biomechanical properties of the quadriceps muscle.

Conclusion

High-protein enteral nutrition can significantly slow the atrophy of the quadriceps in patients with severe pneumonia and improve related nutritional indicators. This intervention is an important measure for preventing or improving muscle atrophy in critically ill patients, thereby promoting the late recovery and improving clinical outcomes. Future research will explore the correlation between high-protein enteral nutrition and mortality in critically ill patients.

Author contributions

guarantor of integrity of the entire study: Xiangde Zhengstudy concepts: Xiangde Zhengstudy design: Cheng Liu and Li Hedefinition of intellectual content: Cheng Liu and Li Heliterature research: Cheng Liu and Li Heclinical studies: Cheng Liu and Li Heexperimental studies: Cheng Liu and Li Hedata acquisition: Jin Hui Zhang, JiangShan He and Lin Tiandata analysis: Jin Hui Zhang, JiangShan He and Lin Tianstatistical analysis: Jin Hui Zhang, JiangShan He and Lin Tianmanuscript preparation: Cheng Liu and Li Hemanuscript editing: Xiangde Zhengmanuscript review: Xiangde Zheng.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

All procedures performed in studies involving human participants were in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study is approved by the Ethics Committee of The Central Hospital of Dazhou. Written informed consent was obtained.

Consent for publication

Informed consent was obtained from all individual participants included in the study.

Competing interests

The authors declare no competing interests.

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References

1. Niederman MS, Torres A. Severe community-acquired pneumonia. Eur Respir Rev. 2022;31(166):220123.

2. Martin-Loeches I, Torres A. New guidelines for severe community-acquired pneumonia. Curr Opin Pulm Med. 2021;27(3):210–5.
3. Wandrag L, Brett SJ, Frost GS, Bountziouka V, Hickson M. Exploration of muscle loss and metabolic state during prolonged critical illness: implications for intervention. PLoS ONE. 2019;14(11):e0224565.
4. van Gassel R, Baggerman MR, van de Poll M. Metabolic aspects of muscle wasting during critical illness. Curr Opin Clin Nutr Metab Care. 2020;23(2):96–101.
5. Lee ZY, Ong SP, Ng CC, et al. Association between ultrasound quadriceps muscle status with premorbid functional status and 60-day mortality in mechanically ventilated critically ill patient: a single-center prospective observational study. Clin Nutr. 2021;40(3):1338–47.
6. Brook MS, Wilkinson DJ, Atherton PJ. An update on nutrient modulation in the management of disease-induced muscle wasting: evidence from human studies. Curr Opin Clin Nutr Metab Care. 2020;23(3):174–80.
7. Allingstrup MJ, Esmailzadeh N, Wilkens Knudsen A, et al. Provision of protein and energy in relation to measured requirements in intensive care patients. Clin Nutr. 2012;31(4):462–8.
8. Nicolo M, Heyland DK, Chittams J, Sammarco T, Compher C. Clinical outcomes related to protein delivery in a critically Ill Population: a multicenter, multinational Observation Study. JPEN J Parenter Enter Nutr. 2016;40(1):45–51.
9. Ferrie S, Allman-Farinelli M, Daley M, Smith K. Protein requirements in the critically ill: a Randomized Controlled Trial using Parenteral Nutrition. JPEN J Parenter Enter Nutr. 2016;40(6):795–805.
10. Fetterplace K, Deane AM, Tierney A, et al. Targeted full energy and protein delivery in critically ill patients: a pilot randomized controlled trial (FEED trial). JPEN J Parenter Enter Nutr. 2018;42(8):1252–62.
11. van Zanten A, Petit L, De Waele J, et al. Very high intact-protein formula successfully provides protein intake according to nutritional recommendations in overweight critically ill patients: a double-blind randomized trial. Crit Care. 2018;22(1):156.
12. Yeh DD, Ortiz LA, Lee JM, et al. PEP uP (enhanced protein-energy provision via the Enteral Route Feeding Protocol) in Surgical Patients-A Multicenter Pilot Randomized Controlled Trial. JPEN J Parenter Enter Nutr. 2020;44(2):197–204.
13. Landi F, Camprubi-Robles M, Bear DE, et al. Muscle loss: the new malnutrition challenge in clinical practice. Clin Nutr. 2019;38(5):2113–20.
14. Kortebein P, Ferrando A, Lombeida J, Wolfe R, Evans WJ. Effect of 10 days of bed rest on skeletal muscle in healthy older adults. JAMA. 2007;297(16):1772–4.
15. Paris M, Mourtzakis M. Assessment of skeletal muscle mass in critically ill patients: considerations for the utility of computed tomography imaging and ultrasonography. Curr Opin Clin Nutr Metab Care. 2016;19(2):125–30.
16. Nakamura K, Nakano H, Naraba H, Mochizuki M, Takahashi Y, Sonoo T, Hashimoto H, Morimura N. High protein versus medium protein delivery under equal total energy delivery in critical care: a randomized controlled trial. Clin Nutr. 2021;40(3):796–803. https://doi.org/10.1016/j.clnu.2020.07.036.
17. Coffman CJ, Edelman D, Woolson RF. To condition or not condition? Analysing 'change' in longitudinal randomised controlled trials. BMJ Open. 2016;6(12):e013096.
18. Alberda C, Gramlich L, Jones N, Jeejeebhoy K, Day AG, Dhaliwal R, Heyland DK. The relationship between nutritional intake and clinical outcomes in critically ill patients: results of an international multicenter observational study. Intensive Care Med. 2009;35(10):1728–37. https://doi.org/10.1007/s00134-009-1567-4.
19. Mitchell A, Clemente R, Downer C, Greer F, Allan K, Collinson A, Taylor S. Protein provision in critically ill adults requiring Enteral Nutrition: are guidelines being Met. Nutr Clin Practice: Official Publication Am Soc Parenter Enter Nutr. 2019;34(1):123–30. https://doi.org/10.1002/ncp.10209.
20. Weijs P, Mogensen KM, Rawn JD, Christopher KB. Protein intake, Nutritional Status and outcomes in ICU survivors: a single Center Cohort Study. J Clin Med. 2019;8(1):43. https://doi.org/10.3390/jcm8010043.
21. Dresen E, Weißbrich C, Fimmers R, Putensen C, Stehle P. Medical high-protein nutrition therapy and loss of muscle mass in adult ICU patients: a randomized controlled trial. Clin Nutr. 2021;40:1562–70.
22. Schepens T, Verbrugghe W, Dams K, Corthouts B, Parizel PM, Jorens PG. The course of diaphragm atrophy in ventilated patients assessed with ultrasound: a longitudinal cohort study. Crit Care. 2015;19:422.
23. Grassi A, Ferlicca D, Lupieri E, Calcinati S, Francesconi S, Sala V, et al. Assisted mechanical ventilation promotes recovery of diaphragmatic thickness in critically ill patients: a prospective observational study. Crit Care. 2020;24:85.
24. Fanali G, di Masi A, Trezza V, Marino M, Fasano M, Ascenzi P. Human serum albumin: from bench to bedside. Mol Aspects Med. 2012;33(3):209–90. https://doi.org/10.1016/j.mam.2011.12.002.
25. Chapple LS, Summers MJ, Bellomo R, Chapman MJ, Davies AR, Ferrie S, Finnis ME, Hurford S, Lange K, Little L, O'Connor SN, Peake SL, Ridley EJ, Young PJ, Williams PJ, Deane AM. Use of a high-protein Enteral Nutrition Formula to increase protein delivery to critically ill patients: a Randomized, Blinded, Parallel-Group, feasibility trial. JPEN J Parenter Enteral Nutr. 2021;45(4):699–709. https://doi.org/10.1002/jpen.2059.
26. Rugeles SJ, Rueda JD, Díaz CE, Rosselli D. Hyperproteic hypocaloric enteral nutrition in the critically ill patient: a randomized controlled clinical trial. Indian J Crit care Medicine: peer-reviewed Official Publication Indian Soc Crit Care Med. 2013;17(6):343–9. https://doi.org/10.4103/0972-5229.123438.

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