Original Article

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Internal Medicine Section

Nutritional Adequacy, Body Composition, and Functional Recovery in ICU Survivors: A Prospective Observational Study from Mumbai, India

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ABSTRACT

Introduction: Critical illness is associated with rapid skeletal muscle wasting and impaired functional recovery. Adequate nutritional intake during critical illness and the post-Intensive Care Unit (ICU) recovery period may influence preservation of lean body mass and restoration of muscle strength. Evidence from Indian ICU cohorts remains limited, particularly for studies combining serial body composition, hand grip strength, and nutrition-delivery assessment.

Aim: To evaluate longitudinal changes in body composition and muscle strength among ICU survivors and to estimate minimum nutritional adequacy in an Indian ICU cohort receiving standardised nutrition therapy.

Materials and Methods: This prospective observational study included 150 adult ICU survivors treated at a tertiary care hospital in Mumbai, India. Participants were assessed at ICU admission, ICU discharge, and three months after hospital discharge using Bioelectrical Impedance Analysis (BIA) and hand grip dynamometry. All patients received a standardised nutrition prescription of 25 kcal/kg/day with oral nutritional supplementation. Minimum energy adequacy was estimated using a conservative intake model. Statistical analysis included descriptive statistics, longitudinal comparison of repeated measurements using repeated-measures Analysis of Variance (ANOVA) and multivariable linear regression for predictors of grip-strength recovery.

Results: A total of 150 ICU patients were included. Mean age was 63.6±15.2 years and 85 (56.7%) were male. Skeletal Muscle Mass (SMM) declined from 23.04±5.66 kg at ICU admission to 21.99±5.12 kg at ICU discharge and remained reduced at 22.00±4.74 kg at three-month follow-up. Mean right-hand grip strength improved from 8.79±8.01 kg at admission to 12.43±6.15 kg at three months. Estimated minimum nutrition adequacy during hospitalisation was 60.5% of the prescribed energy target. Multivariable regression analysis demonstrated that duration of ICU stay (β=-0.94, p-value<0.001), baseline right-hand grip strength (β=-0.63, p-value<0.001), and admission phase angle (β=0.81, p-value=0.013) were independently associated with grip-strength recovery. Age, sex, and estimated nutrition adequacy were not significant predictors.

Conclusion: ICU survivors demonstrated persistent skeletal muscle loss despite progressive improvement in muscle strength during recovery. Estimated minimum nutrition adequacy was approximately 60% of the prescribed target, highlighting the challenges of achieving optimal nutrition delivery in critically-ill patients.

Keywords: Critical illness, Hand grip strength, Intensive care units

INTRODUCTION

Critical illness results in profound metabolic and physiological changes that lead to rapid skeletal muscle wasting and functional impairment [1]. Muscle loss during ICU stay occurs due to systemic inflammation, immobilisation, neuromuscular dysfunction, and increased catabolic activity [1,2]. Persistent muscle weakness following critical illness contributes substantially to long-term morbidity among ICU survivors [2,3].

Adequate nutritional support during critical illness is an important strategy for attenuating lean tissue loss, but prescribed nutritional targets are often difficult to achieve because of feeding intolerance, clinical instability, procedures, and interruptions in enteral feeding [4,5]. Current critical-care nutrition guidance emphasises progressive, individualised nutritional therapy, preferably informed by measured or estimated energy requirements, while recognising the practical difficulty of avoiding both underfeeding and overfeeding during different phases of critical illness [5,6].

Rehabilitation is another central determinant of post-ICU recovery. ICU-acquired weakness and poor physical recovery may persist for months to years after discharge and are associated with prolonged ventilation, longer ICU stay, reduced mobility, impaired quality of life, and increased mortality [7]. Hand grip dynamometry offers a simple bedside method for quantifying muscle strength and may complement body-composition assessment in monitoring recovery [8].

Most previous studies [1-3,7] evaluating muscle wasting and functional impairment after critical illness have been conducted in non-Indian cohorts, and many have focused either on imaging-based muscle mass or functional outcomes rather than the combined assessment of body composition, nutrition adequacy, and serial hand grip strength. Indian ICU data are limited, despite important differences in baseline nutritional status, dietary patterns, body composition, and post-discharge rehabilitation access. This gap supports the need for a prospective Indian cohort evaluating nutritional adequacy, body composition, and functional recovery together.

Therefore, the present study aimed to evaluate longitudinal changes in body composition and muscle strength, estimate minimum nutritional adequacy, and identify predictors of functional recovery among ICU survivors.

MATERIALS AND METHODS

This prospective observational study was conducted in the ICU of S.L. Raheja Hospital — A Fortis Associate, Mumbai, Maharashtra, India, from April 2024 year to October 2024. The study protocol was approved by the Institutional Ethics Committee of the hospital (IEC approval number: ECR/70/inst/MH/2013/RR-19), and the study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants or their legally authorised representatives before inclusion in the study.

Inclusion criteria: Adult ICU patients aged ≥18 years who survived to ICU discharge and were available and consented for serial assessment at ICU admission, ICU discharge, and three months after hospital discharge were included in the study.

Exclusion criteria: Patients with pre-existing neuromuscular disease, upper-limb deformity or injury preventing hand grip testing, implanted electrical devices or other contraindications to BIA, pregnancy, major limb amputation, inability to obtain consent, or incomplete follow-up data were excluded from the study.

Sample size: The sample size was calculated for detecting a clinically meaningful longitudinal change in SMM using the formula for comparison of paired means: $n=\{(Z\alpha/2+Z\beta)^2 \times SDd^2\}/d^2$, where SDd is the standard deviation of the paired difference and d is the expected mean change. This method is recommended for sample size estimation in paired continuous outcomes [9]. Based on institutional pilot observations, an expected mean change of 0.75 kg in SMM and an estimated standard deviation of paired differences of 3.0 kg were used. Considering a two-sided α of 0.05 and 80% power, the minimum required sample size was 126 patients. After accounting for an anticipated attrition rate of 10%, the required sample size was 140 patients. Hence, inclusion of 150 patients was considered adequate.

Study Procedure

Participants were assessed at three predefined time points: ICU admission, ICU discharge, and three months following hospital discharge. Baseline demographic and clinical variables recorded for the present analysis included age, sex, height, weight, and duration of ICU stay. Illness-severity scores such as APACHE II or SOFA, primary diagnostic category, mechanical ventilation status, and co-morbidity profiles were not systematically available in the study dataset and were therefore not included in the analysis

Body composition was evaluated using BIA using the Inbody 970 analyser. Measurements were obtained according to the manufacturer's protocol, preferably in the supine position after removal of metallic objects and after standardisation for hydration status as clinically feasible. The parameters recorded include SMM, Skeletal Muscle Index (SMI), and phase angle. SMI was calculated as SMM divided by height squared (kg/m^2) [10]. Muscle strength was assessed using a calibrated hand grip dynamometer, measurements were obtained for both hands at ICU admission, ICU discharge, and three-month follow-up. Patients were positioned consistently, and the best of three attempts of the dominant hand was recorded according to the study protocol.

During hospitalisation, all patients received a standardised nutrition prescription with an energy target of 25 kcal/kg/day, consistent with European Society for Clinical Nutrition and Metabolism (ESPEN) recommendations for weight-based estimation of energy requirements in critically-ill patients when indirect calorimetry is not routinely available [5]. Nutritional support consisted of the hospital kitchen diet along with a daily oral nutritional supplement (Pentasure; three scoops dissolved in 150 mL of water; approximately 165 kcal/day). Throughout the hospital stay, patients consumed at least 50% of the prescribed hospital diet based on dietitian documentation. At ICU discharge, patients were provided individualised home dietary recommendations by a dietitian. They were also advised to continue appropriate physiotherapy and strengthening exercises prescribed by a physiotherapist. Adherence to dietary advice, and physiotherapy was monitored telephonically every two weeks by the dietitian.

Nutrition adequacy was estimated using a study-specific conservative estimation model developed because individual daily dietary intake records were not available for all participants. Minimum delivered energy intake was conservatively estimated as 50% of the prescribed energy target plus the caloric contribution from the prescribed oral nutritional supplement, where applicable. Energy adequacy (%) was calculated as:

(Estimated minimum delivered energy/Prescribed energy target) × 100. This approach was used to provide a conservative estimate of minimum likely energy intake rather than a direct measurement of actual intake.

This model was used because direct individual dietary-intake records were not available for all participants; therefore, the estimate represents minimum likely energy delivery rather than measured intake. The primary outcome was change in SMM from ICU admission to ICU discharge and three-month follow-up. Secondary outcomes included changes in SMI, phase angle, right-hand and left-hand grip strength, estimated minimum energy adequacy, and predictors of three-month right-hand grip-strength recovery.

STATISTICAL ANALYSIS

Statistical analysis was performed using IBM Statistical Package for the Social Sciences (SPSS) Statistics for Windows, version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean±standard deviation or median (interquartile range), depending on distribution. Categorical variables were summarised as frequencies and percentages. Normality was assessed using the Shapiro-Wilk test and visual inspection of histograms and normal Q-Q plots. Longitudinal changes in SMM, SMI, phase angle, and hand grip strength across the three time points were analysed using repeated-measures ANOVA for normally distributed data or the Friedman test for non-normally distributed data, followed by post-hoc pairwise comparisons with appropriate correction for multiple testing.

Multivariable linear regression analysis was performed to identify factors associated with recovery of right-hand grip strength at three months. Independent variables entered into the model included age, sex, duration of ICU stay, baseline right-hand grip strength, estimated nutrition adequacy, and admission phase angle. Admission phase angle was selected as the representative body composition parameter for the final multivariable model because SMM and SMI are closely related measures of muscle quantity and their simultaneous inclusion could introduce multicollinearity. Regression coefficients (β), 95% confidence intervals, and p-values were reported. A p-value <0.05 was considered statistically significant.

RESULTS

A total of 150 patients admitted to the ICU were included in the study. The mean age was 63.6±15.2 years, with 85 (56.7%) males and 65 (43.3%) females. The median ICU stay was 5 days (interquartile range: 4-6 days). Baseline characteristics are summarised in [Table/Fig-1].

Variable	Value
Age, years	63.6±15.2
Male sex, n (%)	85 (56.7)
Female sex, n (%)	65 (43.3)
ICU stay, days	5 (4-6)
Height, cm	166.2±9.8
Weight, kg	65.96±14.92

[Table/Fig-1]: Baseline demographic and clinical characteristics (n=150).

Body composition analysis demonstrated a decline in SMM during ICU stay. Mean SMM decreased from 23.04±5.66 kg at ICU admission to 21.99±5.12 kg at ICU discharge and remained relatively unchanged at 22.00±4.74 kg at the three-month follow-up. Similarly, SMI declined from 6.38±1.40 kg/m^2 at admission to 5.80±1.20 kg/m^2 at discharge and remained at 5.79±1.15 kg/m^2 during follow-up. Phase angle decreased with slight recovery at three months [Table/Fig-2].

Parameters	ICU admission	ICU discharge	Three-month follow-up	Overall p-value
Skeletal Muscle Mass (SMM), kg	23.04±5.66	21.99±5.12	22.00±4.74	<0.001
Skeletal Muscle Index (SMI), kg/m^2	6.38±1.40	5.80±1.20	5.79±1.15	<0.001
Phase angle, degrees	4.09±1.31	3.73±1.21	3.79±1.30	<0.001

[Table/Fig-2]: Longitudinal changes in body composition parameters.
Values are mean±SD

Hand grip strength improved progressively during the recovery period [Table/Fig-3]. Mean right-hand grip strength increased from 8.79±8.01 kg at ICU admission to 10.52±7.14 kg at discharge and further to 12.43±6.15 kg at three-month follow-up. Mean left-hand grip strength increased from 7.50±7.02 kg at admission to 9.41±6.44 kg at discharge and 11.74±6.22 kg at three months.

Parameters	ICU admission	ICU discharge	Three-month follow-up	Overall p-value
Right-hand grip strength, kg	8.79±8.01	10.52±7.14	12.43±6.15	<0.001
Left-hand grip strength, kg	7.50±7.02	9.41±6.44	11.74±6.22	<0.001

[Table/Fig-3]: Longitudinal changes in hand grip strength.
Values are mean±SD.

Based on the standardised nutrition protocol, the mean prescribed energy target was 1649.08±373.04 kcal/day. Assuming a minimum intake of 50% of the prescribed hospital diet together with oral nutritional supplementation, the estimated minimum delivered energy intake was 989.54±186.52 kcal/day. The corresponding estimated energy adequacy was 60.50±2.28% of the prescribed energy target [Table/Fig-4].

Nutrition variable	Mean±SD
Body weight (kg)	65.96±14.92
Prescribed energy target (kcal/day)	1649.08±373.04
Estimated minimum delivered energy (kcal/day)	989.54±186.52
Estimated energy adequacy (%)	60.50±2.28

[Table/Fig-4]: Conservative estimation of minimum energy adequacy during hospitalisation.

Predictors of Grip-strength Recovery

Multivariable regression analysis demonstrated that duration of ICU stay (β=-0.94, p-value<0.001), baseline grip strength (β=-0.63, p-value<0.001), and admission phase angle (β=0.81, p-value=0.013) were independently associated with recovery of grip strength at three months. Age, gender, and estimated nutrition adequacy were not independently associated with the outcome [Table/Fig-5].

Variables	Beta coefficient	95% CI	p-value
Age	-0.03	-0.07 to 0.01	0.097
Male gender	0.58	-0.56 to 1.72	0.318
Duration of ICU stay	-0.94	-1.49 to -0.39	<0.001
Baseline right-hand grip strength	-0.63	-0.97 to -0.29	<0.001
Admission phase angle	0.81	0.18 to 1.44	0.013
Estimated nutrition adequacy	-0.11	-0.41 to 0.20	0.472

[Table/Fig-5]: Multivariable linear regression analysis for predictors of grip strength recovery at three months.

In the expanded multivariable regression model, estimated nutrition adequacy was included as an independent variable but was not significantly associated with grip-strength recovery at three months (β=-0.11, 95% CI: -0.41 to 0.20, p-value=0.472). This finding supports the interpretation that the present estimated nutrition adequacy measure was not an independent predictor of functional recovery in this cohort.

Overall, the findings demonstrate that ICU survivors experienced reductions in SMM during ICU stay, while functional muscle strength improved progressively during recovery. SMM remained persistently reduced at three months, suggesting that functional improvement may occur despite incomplete restoration of muscle mass.

DISCUSSION

This prospective observational study from an Indian ICU cohort showed three main findings. First, SMM, SMI, and phase angle declined during ICU stay and remained incompletely recovered at three months. Second, hand grip strength improved progressively from ICU admission to three-month follow-up. Third, conservative estimation suggested that patients achieved only 60.5% of prescribed energy targets. In multivariable analysis, duration of ICU stay, baseline grip strength, and admission phase angle were independently associated with grip-strength recovery, whereas age, sex, and estimated nutrition adequacy were not significant predictors.

The observed reduction in SMM was consistent with previous work demonstrating rapid muscle wasting during critical illness. Puthucheary ZA et al., reported early and substantial skeletal muscle loss in critically-ill patients, particularly during the first week of ICU admission [1]. The persistence of reduced SMM at three months in the present study was also consistent with literature on post-intensive care syndrome and prolonged physical recovery, in which muscle weakness and impaired exercise capacity may persist for months or years after hospital discharge [3,7].

The improvement in hand grip strength despite incomplete restoration of SMM is clinically important. Similar dissociation between structural and functional recovery has been described in post-ICU rehabilitation literature, where neuromuscular adaptation, improved coordination, mobilisation, and rehabilitation may contribute to functional gains even before complete restoration of lean tissue [7,11]. Therefore, serial grip-strength assessment may be useful as a pragmatic functional marker in ICU survivors, particularly in resource-limited settings where imaging-based muscle assessment is not routinely feasible. An additional finding of the present study was the independent association between admission phase angle and subsequent recovery of grip strength. Phase angle, derived from BIA, is considered a marker of cellular integrity, membrane function, and overall nutritional and physiological status [12,13]. Patients with higher admission phase angle values demonstrated better recovery of muscle strength during follow-up, even after adjustment for age, sex, duration of ICU stay, baseline grip strength, and estimated nutrition adequacy. This observation was consistent with previous studies showing that phase angle is associated with nutritional status, functional status, and clinical outcomes in hospitalised and rehabilitation populations [12,14,15]. The findings suggest that phase angle may serve as a useful prognostic marker of functional recovery in ICU survivors and may provide additional information beyond conventional measures of muscle quantity such as SMM or SMI.

The estimated energy adequacy of approximately 60% highlights the challenge of meeting nutrition targets in routine ICU practice. International guidelines and expert reviews emphasise the need for phase-specific, individualised nutrition therapy, with careful progression of energy and protein delivery and attention to feeding intolerance and interruptions [5,6,16]. However, the absence of an independent association between estimated nutrition adequacy and grip recovery in this study should not be interpreted as evidence that nutrition is unimportant. Rather, it may reflect the limitations of using a conservative estimated intake model, the narrow range of estimated adequacy, residual confounding, and the influence of rehabilitation, illness severity, inflammation, and baseline functional reserve.

The findings of the present study are consistent with earlier studies evaluating nutritional delivery and functional recovery after critical illness. Weijs PJ et al., reported that adequate protein and energy intake was associated with lower mortality in mechanically ventilated critically-ill patients [17]. Bear DE et al., highlighted the potential role of nutritional support in physical and functional recovery after critical illness [18]. Wischmeyer PE et al., emphasised the need for personalised nutrition therapy across the ICU and post-ICU recovery phases [16]. Later reviews have also suggested that the relationship between nutrient dose and recovery outcomes is complex and may vary according to illness phase and patient phenotype [6,16].

Hand grip dynamometry has been used as a feasible bedside measure of peripheral muscle strength in critically-ill patients and ICU survivors. Previous studies have shown that reduced grip strength is associated with ICU-acquired weakness, difficult weaning, impaired functional recovery, and poorer clinical outcomes [8,11,19]. In this context, the present study adds Indian cohort data showing persistent reduction in body composition parameters despite functional improvement.

This study has practical implications. ICU survivorship care should not rely only on weight or discharge status, because SMM may remain reduced even when strength improves. Integrated follow-up including nutrition counselling, oral nutritional supplementation where indicated, progressive resistance and functional rehabilitation, and serial assessment using simple tools such as BIA and hand grip dynamometry may help identify patients at risk of incomplete recovery. Future studies should incorporate direct dietary-intake measurement, protein adequacy, inflammatory markers, severity-of-illness scores, and objectively monitored rehabilitation adherence.

Limitation(s)

The study has limitations. The study did not systematically capture illness-severity scores such as APACHE II or SOFA, primary ICU diagnostic categories, mechanical ventilation status, or detailed co-morbidity profiles. Therefore, residual confounding related to baseline illness severity and clinical heterogeneity could not be fully addressed. Nutrition adequacy was estimated using a conservative intake model rather than direct weighed dietary-intake measurement, and protein adequacy was not separately quantified. Post-discharge adherence to dietary advice and physiotherapy was assessed through telephonic follow-up, which may introduce reporting bias. Finally, the single-centre design may limit generalisability to other ICU settings.

CONCLUSION(S)

The ICU survivors in this prospective Indian cohort demonstrated a decline in SMM, SMI, and phase angle during ICU stay. SMM remained persistently reduced at three months, despite progressive improvement in grip strength. Duration of ICU stay, and baseline grip strength were significant predictors of grip-strength recovery, whereas estimated nutrition adequacy was not independently associated with recovery in the adjusted model. These findings suggest that post-ICU recovery requires coordinated nutrition optimisation, structured rehabilitation, and serial functional assessment rather than nutrition prescription alone. The key take-home message is that ICU survivorship programmes should monitor both body composition and muscle function to identify incomplete recovery and guide targeted rehabilitation.

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